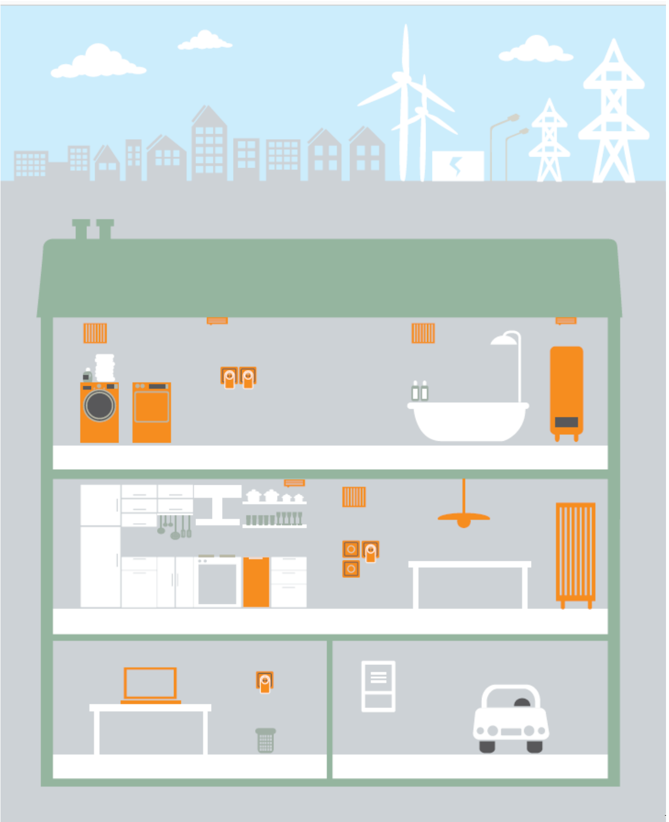
Ecodesign Preparatory study on Smart Appliances (Lot 33)

MEErP Tasks 1-6



FINAL REPORT

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AC	Air Conditioning
ADSL	Asymmetric Digital Subscriber Line
AMI	Advanced Metering Infrastructure
BACS	Building Automation and Control System
BAT	Best Available Technology
BAU	Business As Usual
BEMS	Building Energy Management System
BRP	Balancing Responsible Parties
CBA	Cost-Benefit Analysis
CEM	Customer Energy Manager
CEMS	Customer Energy Management System
CF	Commercial refrigeration products
CFL	compact fluorescent light
CHP	Combined Heat and Power
CSWH	hot water buffers; continuous water heaters
DHW	Domestic Hot Water
DOCSIS	Data Over Cable Service Interface Specification
DR	Demand response
DRES	Distributed Renewable Energy Sources
DSF	Demand side flexibility
DSO	Distribution System Operators
EC	European Commission
ECHR	European Convention for the Protection of Human Rights and Fundamental Freedoms
EEA	European Economic Area
EED	Energy Efficiency Directive
EMS	Energy Management System
EPBD	Energy Performance of Buildings Directive
ESCO	Energy Service Company
ETS	Emission Trading System
ETSI	European Telecommunications Standards Institute
EV	Electric vehicle
FRC	Frequency Containment Reserves (or currently called primary reserves)
FRRa	automated Frequency Restoration Reserves (or currently called secondary reserves). FRRa is activated automatically
FRRm	manual Frequency Restoration Reserves (or currently called secondary reserves). FRRm is activated manually
GLS	general lighting service 'incandescent'
GPP	Green Public Procurement
GSM	Global System for Mobile Communications
GW	gigawatt
HEG	Home Energy Gateway
HEMS	Home Energy Management System
HEMS	Home Energy Management System
HID	high intensity discharge lamp
HVAC	Heating, Ventilation and Air Conditioning
IoT	Internet of Things
K	Temperature expressed in Kelvin
KPI	Key Performance Indicator

LED	light emitting diode
LFL	linear fluorescent lamp
LLCC	Least Life Cycle Cost
LTE	3GPP Long Term Evolution (4G)
M2M	Machine to Machine
MEErP	Methodology for Energy related products
NEEAP	National Energy Efficiency Action Plan
NRVU	Non-Residential Ventilation Units
NSWH	Night storage water heaters
PLC	power line communication
PV	Photovoltaic
RES	Renewable Energy Sources
RTE	Transmission network - Réseau de transport d'électricité
RVU	Residential Ventilation Units
SAREF	Smart Appliances REFerence ontology
SOC	State Of Charge
TD	Tumble dryer
TEU	Treaty on European Union
TSO	Transmission System Operators
TWh	TeraWatt hour
UMTS	Universal Mobile Telecommunications System
UPS	Uninterruptible power supply
VDSL	Very-high-bitrate Digital Subscriber Line
VRES	Variable Renewable Energy Sources
VRF	variable refrigerant flow

EXECUTIVE SUMMARY

The Ecodesign Preparatory Study on Smart Appliances (Lot 33) analyses the technical, economic, market and societal aspects with a view to a broad introduction of smart appliances and to develop adequate policy approaches supporting such uptake. The study started in September 2014 and should deal with Task 1 to 7 of the MEErP methodology as follows:

- Scope, standards and legislation (Task 1, Chapter 1);
- Market analysis (Task 2, Chapter 2);
- User analysis (Task 3, Chapter 3);
- Technical analysis (Task 4, Chapter 4);
- Definition of Base Cases (Task 5, Chapter 5);
- Design options (Task 6, Chapter 6);
- Policy and Scenario analysis (Task 7). ***The work on Task 7 is still in progress and therefore is not yet integrated in this study. The refinement of policy options will be the subject of an ongoing second phase of this Preparatory Study.***

Three stakeholder meetings have taken place:

- The first stakeholder meeting on 10 March 2015 focused on determining the scope of the study, the state of play regarding standardization and a discussion of interoperability issues.
- The second stakeholder meeting on 19 November 2015 discussed the review of the Task 1 report according to the comments received from stakeholders and presented the Task 2, 3 and 4 report as well as the model approach for Task 5.
- The third stakeholder meeting on 30 May 2016 discussed the review of the Task 2, 3 and 4 reports according to the comments received from stakeholders and presented Task 5 as well as the preliminary results of Task 6. Stakeholders were invited to comment on the potential policy options of Task 7, in writing as well as by means of bilateral meetings that were organised afterwards.

Scope of this Preparatory Study

For the purpose of this preparatory study, a **smart appliance is defined as an appliance that supports Demand Side Flexibility (DSF)**:

- It is an appliance that is able to automatically respond to external stimuli e.g. price information, direct control signals, and/or local measurements (mainly voltage and frequency);
- The response is a change of the appliance's electricity consumption pattern. These changes to the consumption pattern are what we call the 'flexibility' of the smart appliance;

Whereby:

- The specific technical smart capabilities do not need to be activated when the product is placed on the market; the activation can be done at a later point in time by the consumer or a service provider.
- A distinction might be made later in the process between appliances able to communicate and process external signals and (non-communicating) appliances automatically reacting to local power quality measurements.

The following clarifications can be added to this definition:

- Manual start time delay is not considered smart control, because it is not automated.
- Automatic actions to safeguard the technical safety of the appliance are not considered smart control.

Based on a preliminary analysis, the appliances in scope of the study were sorted in 3 categories according to their flexibility potential:

- **High flexibility potential with few comfort and/or performance impacts**: dishwashers, washing machines, washer dryers, buffered water heaters, radiators, boilers, heat pumps, circulators, residential and non-residential air conditioners and battery storage systems;
- **Smaller flexibility potential and/or larger comfort/health impacts**: tumble dryers, refrigerators, freezers, extraction fans, heat recovery ventilation and air handlings units and chargers (low power);
- **Only emergency flexibility potential**: electrical hobs, ovens, hoods, vacuum cleaners and lighting.

A general guideline was followed that the higher the potential in providing DSF, the more in-depth and quantitative the analysis of the appliance has been.

Important to note is that the focus of this study is on the smart appliances and the potential flexibility they generate, independent of how this flexibility is used in a specific energy market structure (for the value of the flexibility will depend on the flexibility use in a specific market setting). Moreover, the end-user i.e. residential consumer is taken as the main reference point, because the challenges of uptake are considered most relevant for this user group. Additionally, commercial refrigeration and HVAC in the tertiary sector have been included in the scope of the study. Smart meters are included specifically and only with respect to their energy consumption as part of the overall communication infrastructure.

Environmental and economic impacts on the energy system

Almost all individual products in the scope of this Lot 33 Preparatory Study are subject to vertical (product-specific) Ecodesign measures; however this Preparatory Study specifically addresses the implications underlying the connectivity and DSF functionality aspect of these products. The environmental and economic implications therefore need to be considered on different levels:

- On the one hand, the DSF functionality will have implications on the level of the **individual product** and the network connections through which the product functions;
- On the other hand, the aggregated DSF that potentially can be provided by a whole group of smart appliances gives rise to environmental and economic impacts which go beyond the product level and exist at the level of the **entire energy system**. Smart appliances can provide services in day-ahead and real-time for system operators and commercial parties by shifting operation (i.e. shifting energy consumption for better alignment between production and consumption). This will allow limiting the use of polluting and expensive peak generation to cover excess demand and it will also result in a decrease of Renewable Energy Sources (RES) curtailment in case of insufficient demand. In addition, a shift in energy consumption can also support solving congestion issues in the distribution grid. This leads to both monetary savings as a result of lower consumption of fuel, as well as reduced CO_2 emissions.

A generic optimisation model was developed to quantify the economic and environmental benefits of smart appliances from an energy system perspective by means of the following Key Performance Indicators (KPIs):

- CO_2 emission savings;
- Impact on the utilized generation mix in terms of efficiency, which indirectly shows the primary energy savings and how many more Renewable Energy Sources (RES) can be integrated in the system;
- Impact on the total energy system costs and marginal energy prices.

To quantify the KPIs, the model was run over a time horizon of one year for each of the three chosen benchmark years: 2014, 2020, and 2030. Specifically for the use cases defined in Task 2, **day-ahead use case and imbalance use case**[1], the resulting KPIs are compared for a situation without uptake of smart appliances (base case scenario) and a situation in which a certain share of the appliances provides flexibility to the energy system according to a Business as usual (BAU) scenario, based on expert judgement, and a 100% uptake scenario. The latter maximum scenario was introduced because of the uncertainties involved in an attempt to estimate how much uptake of smart appliances would be realized in response to a specific policy package. Such uptake depends on numerous factors, such as e.g. the specific type of appliance, the expected technological innovations and the degree to which the policy package would pull or push the market to develop business cases that would increase consumer confidence and install financial remuneration mechanisms, which then would attract a potential amount of end-users to step in and provide flexibility.

Smart appliances can provide energy system services, both in day-ahead and in real-time (imbalance use case) by shifting operation and as a result, adapting their energy consumption. In day-ahead, this leads to a reduced cost and CO_2 emissions, because a shift in load would avoid the need for additional generation by conventional power plants. In addition, smart appliances can also avoid the curtailment of RES during the night in case of moments of low consumption. The following Table shows that the more flexibility is provided by smart appliances, the higher the economic and environmental benefits are. As a general tendency, the 2020 benefits are a tenfold of the situation in 2014 (BAU scenario). The 100% uptake scenario can be considered as a maximum of the total added value.

[1] In **day-ahead**, the schedule of electricity production and consumption is determined. In order to match supply and demand, balance responsible parties can adapt their production volume by optimizing own generation units or by participating to the various European Power Exchanges that enable them to trade volumes in the short term (day-ahead). The prices on the power exchange are determined on an hourly basis and reflect the marginal cost of the last unit that is needed to produce these volumes. In **real-time** however, deviations in the expected production of wind and solar and deviations in the forecasted consumption are observed between supply and demand of energy which need to be mitigated (**imbalance** use case).

Environmental and economic benefits of flexibility provided by smart appliances for the energy system (BAU and 100% uptake scenario, day-ahead use case)

Day-ahead use case	Savings in total system costs [M€]		Savings in CO_2 emissions [kt]		Primary energy savings [%]	
Scenario	BAU	100%	BAU	100%	BAU	100%
2014	12	898	14	639	0,002	0,34
2020	138	1336	127	1170	0,021	0,48
2030	2343	3873	58	**-346**[2]	0,114	0,60

Derived from the total economic benefits from this Table, the following Table shows the theoretical monetary benefits per appliance per year, as a result of the optimal flexible demand shifting, taking into account the number of hours that a certain category of appliances can shift its consumption and the marginal energy price during the part of the day it is typically used. The longer the average shifting time is, the more value per group of appliance will be generated. The Table shows that the highest benefits can be attributed to home batteries (combined with solar panels), heat pump based heating and cooling and most of the periodical appliances. As can be seen from the Table, a saturation effect is observed for the majority of appliances, meaning that the total value per appliance decreases in the 100% scenario compared to the BAU scenario. Nevertheless, the total benefits for the system are still higher in the 100% scenario compared to the BAU scenario, as can be seen from the table above.

[2] The reason for this negative figure lies in the load shedding that occurred in the base case for 2030, whereas there was no load shedding in 2020. In the flexible case for 2030, there is still load shedding, but less compared to the base case. Therefore, more energy is produced to satisfy the load in the flexible case for 2030 compared to the base case for 2030. This explains a lower increase in CO_2 emissions savings compared to 2020 where there was no load shedding and the same amount of electrical load was served in both reference and flexible case. A decrease in load shedding might increase the amount of energy produced but will have substantial benefits from a societal point of view, as the ‘social cost’ of involuntary load shedding is considered as high, or more specifically, much higher compared to the cost of CO_2 emissions.

Theoretical monetary benefits from providing flexibility per smart appliance per year (BAU and 100% scenario)
(given in [€/year/appliance] or [€/year/m^2] for tertiary cooling)

		2014		2020		2030	
Group	**DSF capable appliance**	**BAU**	**100%**	**BAU**	**100%**	**BAU**	**100%**
Periodical appliances	Dishwashers	0,0	1,6	4,1	2,4	14	6,4
	Washing machines	0,0	1,0	2,4	1,4	7,6	3,6
	Tumble dryers, no heat pump	0,0	1,9	4,8	2,7	16	7,0
	Tumble dryers, heat pump based	0,0	1,5	3,8	2,1	13	5,6
Energy storing appliances	Refrigerators and freezers (residential)	0,0	0,2	0,5	0,3	1,6	0,8
	Electric storage water heaters (continuously heating storage)	0,0	1,3	2,3	1,8	9,4	4,7
	Electric storage water heaters (night storage)	0,0	0,5	1,4	0,8	2,2	2,7
	Tertiary cooling - compressor	0,0	0,4	0,1	0,6	1,4	1,9
	Tertiary cooling - defrost	0,0	0,4	0,1	0,6	1,5	1,8
Residential cooling and heating (heat pump based)	HVAC cooling, no storage	0,6	0,3	0,9	0,3	1,0	1,1
	HVAC cooling, with thermal storage	4,2	1,9	6,8	2,1	6,8	7,1
	HVAC heating, no storage	9,2	3,8	12,5	5,1	105	14
	HVAC heating, with thermal storage	64	25	92,3	36,3	528	87
Tertiary cooling and heating (heat pump based)	HVAC cooling, no storage	6,9	5,6	11,1	4,9	11	11
	HVAC cooling, with thermal storage	74	50	122	45	118	96
	HVAC heating, no storage	1,0	0,7	2,3	0,9	14	2,2
	HVAC heating, with thermal storage	8,5	5,0	17,0	6,4	82	15
Joule based tertiary and residential cooling and heating	Electric radiators, no inertia	0,0	0,3	1,2	0,5	9,6	1,3
	Electric radiators, with inertia	0,0	0,5	2,0	0,8	15	2,0
	Boilers	0,0	2,7	9,9	4,1	76	10
Residential energy storage systems	Home batteries	28	49	71,6	79	1031	136

As with the day-ahead use case, the flexibility from smart appliances can also play an important role in the **imbalance use case**, by mitigating differences between supply and demand of energy in real-time. Similar benefits can be observed in case a shift in demand by smart appliances avoids additional production by conventional generation units. In addition, the use of smart appliances leads to a reduction in curtailment of RES in case there is too much intermittent energy production compared to energy demand. Modelling results show that benefits for day-ahead and imbalance use cases are in the same order of magnitude (note that both use case values are mutually exclusive and benefits cannot be added up).

In addition to the day-ahead and imbalance use case, additional use cases exist where the flexibility of smart appliances can have significant value. One of the most interesting use cases is the **congestion use case**: flexibility is used by distribution system operators (DSOs) to solve local grid constraints (congestion management and voltage control) in specific areas of the distribution grid. The value is highly dependent on the local grid conditions like the amount of RES connected, energy demand, availability of flexibility and grid reinforcement investments or operational costs that DSOs could postpone or avoid thanks to the use of flexibility. Several projects tried to estimate the value flexibility has for the DSOs (between 0€ and 200€/kW/year), but these results are mostly based on small-scale research and innovation projects, and they are highly location dependent. Due to the complexity of the modelling of the distribution grid and the lack of public data, detailed calculations have not been possible of overall EU28 benefits from smart appliances' flexibility for the congestion use case.

In conclusion, the **use of flexibility from smart appliances can support the energy system in many ways**:

- It can optimize the planning in day-ahead by replacing expensive gas and coal units during moments of peak consumption. This optimization results in a decrease of system costs and a reduction in CO_2 emissions.
- It can support the system in real-time (imbalance use case) when energy production is not sufficient to cover the demand. Similar to the day-ahead use case, flexibility from smart appliances can be used to avoid the activation of gas or coal power plants by energy producers or network operators on the one hand, or the possibility of load shedding on the other hand. This again results in a decrease in system costs and a potential reduction in CO_2.
- It can support the system in real-time in case there is too much production (e.g. in case a lot of wind and solar energy are produced) or alternatively, in case demand is much lower compared to the initial forecast. The use of flexibility from smart appliances can in this case prevent the curtailment of wind and solar energy in the system. As a result, the use of smart appliances allows an increase in hosting capacity of RES.

In the BAU scenario, **yearly economic benefits** are estimated in the order of magnitude of **138M€ and 2.3 billion € savings in total system costs** for respectively 2020 and 2030. As a maximum boundary, in the 100% uptake scenario these yearly savings amount to 1.3 and 3.9 billion € respectively for 2020 and 2030. **Yearly environmental benefits** in terms of **CO_2 emission savings amount to 127 and 58 kilotons in respectively 2020 and 2030** for the BAU scenario. Additional environmental benefits come from **primary energy savings**, amounting to **about 0.02 and 0.1% in respectively 2020 and 2030** for the BAU scenario and about 0.5 and 0.6% in respectively 2020 and 2030 for the 100% uptake scenario.

Specifically in the case of **home battery systems**, in combination with solar panels, the use of smart appliances will also increase the share of self-consumption. This creates additional benefits such as a **potential reduction in grid tariffs**, as there is less need to increase the capacity of the distribution grid.

Environmental and economic impacts on the end-user

The modelling results in the following Table show that the **theoretical potential monetary benefit of DSF per end-consumer appliance** varies strongly between appliances. When committed in the day-ahead or real-time electricity markets and according to the BAU scenario, the value is estimated to be **up to 120€/year/m² in 2020** (for tertiary cooling with thermal storage) and up to **530 €/year in 2030** (for residential heating with thermal storage). For residential energy storage systems the values are even higher. Depending on the combination of appliances used, this can add up to a considerable financial benefit.

Note that this calculated value is the result of a theoretical exercise, as in reality the financial benefits will depend on factors such as the market business models, the degree to which the benefits are transferred through the value chain to the end-user, the availability of other flexibility types (e.g. industrial Demand Response, Demand Response from electric vehicles), etc. The net financial benefit for the end-user will depend on the potential higher purchasing price of appliances and/or remuneration for available flexibility. In case DSF is used for e.g. grid congestion management or other ancillary reserves, the value could be higher for specific regions or districts.

Theoretical monetary benefits from providing flexibility per enabled smart appliance per year (given in [€/year/appliance] or [€/year/m2] for tertiary cooling)

		2014	2020	2030
Group	**Smart appliance**			
Periodical appliances	Dishwashers	0,00	4,07	14,01
	Washing machines	0,00	2,37	7,63
	Tumble dryers, no heat pump	0,00	4,77	16,28
	Tumble dryers, heat pump based	0,00	3,84	13,14
Energy storing appliances	Refrigerators and freezers (residential)	0,00	0,48	1,63
	Electric storage water heaters (continuously heating storage)	0,00	2,31	9,44
	Electric storage water heaters (night storage)	0,00	1,35	2,20
	Tertiary cooling - compressor	0,00	0,09	1,40
	Tertiary cooling - defrost	0,00	0,10	1,51
Residential cooling and heating (heat pump based)	HVAC cooling, no storage	0,58	0,94	0,96
	HVAC cooling, with thermal storage	4,22	6,75	6,76
	HVAC heating, no storage	9,16	12,51	104,64
	HVAC heating, with thermal storage	64,24	92,29	528,17
Tertiary cooling and heating (heat pump based)	HVAC cooling, no storage	6,87	11,09	11,08
	HVAC cooling, with thermal storage	74,07	121,54	118,13
	HVAC heating, no storage	0,96	2,25	13,73
	HVAC heating, with thermal storage	8,45	17,04	81,51
Joule based tertiary and residential cooling and heating	Electric radiators, no inertia	0,00	1,24	9,55
	Electric radiators, with inertia	0,00	1,99	15,28
	Boilers	0,00	9,93	76,41
Residential energy storage systems	Home batteries	27,74	71,62	1030,8

Cost elements that need to be considered from an end-user perspective are the initial investment costs for the appliance on the one hand and the recurrent operational costs on the other hand which can be specifically attributed to the DSF functionality of the appliance. Analysis of publicly available information and contacts with industry have made it clear that it is very difficult to derive generalised estimations of the **additional investment costs** that can only be attributed to the DSF feature. Generally, this additional investment cost amounts to ranges of **5-10€/appliance (non-recurrent) if the appliance is already network enabled and 15-20€/appliance (non-recurrent) in case of a non-network enabled appliance**. Input from industry indicated that adding a Demand Response (DR) interface to a heating device using a vapour-compression cycle would raise the retail price approximately with 100€-200€ including software adaptation and development, installation costs, intervention etc. According to the authors of this report, this should rather be considered as the high end of the range of additional costs, including research & development costs and costs associated with the first appliances being produced in small series in a short term perspective.

The operational cost consists of the operating cost of the communication infrastructure and the costs related to increases in energy consumption. The **operating costs related to in-house communication infrastructure** is mostly shared with other devices and applications, so the cost that can be attributed to the smart appliance is assumed to be very low or negligible.

Concerning the **impact on energy consumption** at the end-user level, the use of the DSF may result in operating points that deviate from the most energy efficient operation point, e.g. by cooling deeper or heating higher. However, the assumptions underlying the estimates of the value of flexibility in the modelling were chosen in such a way that this surplus consumption is considered to be negligible. Additional electricity consumption for operation of DSF-specific electronics is small to negligible. On the other hand, the functionality required for DSF offers opportunities for improved energy efficiency, as smart appliances allow a detailed view of the energy consumption of those appliances. Studies assessing the effectiveness of energy use feedback indicate energy savings which usually range between 5 and 12%. Moreover, the measurement and control functionality that is required for DSF functionality can also be used to analyse and optimize the operation of the smart appliance from an energy efficiency point of view. Smart appliances also allow a more user-friendly operation (e.g. through use of apps as opposed to manuals) which leads the end-user to the optimal operational setting under the given circumstances. Even though quantitative evidence is currently available, the operational mode which is advised by the smart setting is expected to be more energy efficient compared to the setting the end-user would choose manually. The degree of increased energy efficiency will depend on various factors, such as the specific smart appliance (e.g. more potential for a dishwasher compared to a washing machine), risk aversion from the end-user (e.g. preference for washing at higher temperature), potential rebound effects (e.g. end-user is more confident to use the appliances), etc.

Generally, one of the key arguments convincing consumers towards home automation and communication-enabled appliances is the increased **comfort and ease of use**. The functionality and infrastructure required for the support of DSF, and shared with Internet of things (IoT) applications in general also offers opportunities in this area. The additional impact of supporting demand response flexibility on the comfort of the end-consumer is strongly device dependent; potential negative impacts are overcome by existing standards, by means of the comfort settings defined by the end-user or by broadening the current innovations that are already on the market.

Environmental and economic impacts on industry

In the majority of the cases, the appliances will only need very limited additions of electronic circuitry and other components. This is partly because in many cases the DR enabled appliances will already be network connected for communication with a smart phone or other devices and partly because major changes of the product and addition of hardware would be too expensive compared to the economic benefits of the DR enabling. Therefore, the impact of the add-ons to the products to provide connectivity and DSF functionality on resources and energy used for the production, distribution and end-of-life phase is assumed to be marginal and is not further assessed in the context of this study.

Based on the limited available data on additional costs, it has not been possible to make an analysis of the impacts on industry regarding required investment levels and the derived impacts on the sectors‘ profitability, competitiveness and employment. The market trends/forecasts clearly show that digital communication functionality will be a common (commodity) function in most appliances sold from 2020 onwards. Manufacturers will most likely include digital communication functionality in all or (at least) in special product series for all product categories in the scope of this Preparatory Study, leading to ‘connected’ (communication-enabled) and ‘app-enabled’ appliances. However, this tendency does not imply that these appliances will be interoperable or will provide DSF functionality, given the fact that in 2015 most of the communication-enabled appliances are not yet part of a DR program - except maybe for smart thermostats and energy management systems.

It is clear that the trend towards connected devices will have a significant impact on the business models, the roles, the sales channels and service channels in this market. Instead of a one-time contact (sales) with the customer, the manufacturer/vendor/service provider will in the IoT scenario have a permanent link with the customer for the entire lifetime of the product. Adding the DSF functionality will bring more opportunities for improving existing services and/or extending to new services valorising the benefits to the energy system.

CHAPTER 1 SCOPE, STANDARDS AND LEGISLATION

1.1. CONTEXT

1.1.1. POLICY CONTEXT

Since the 1990s the EU has been pursuing climate change mitigation targets. Following the international commitment to the legally binding greenhouse gas reduction under the Kyoto Protocol, the 2020 policy package consists of a set of binding legislation to ensure that the EU meets its climate and energy targets for the year 2020. The package sets three key targets: 20% reduction in greenhouse gas emissions (from 1990 levels), 20% of EU energy from renewables (as well as a 10% target for renewable fuels) and 20% improvement in energy efficiency. The targets were set by EU leaders in 2007 and enacted in legislation in 2009[3]. They are also headline targets of the Europe 2020 strategy for smart, sustainable and inclusive growth.

In 2009, the European Council agreed the long-term objective of reducing EU greenhouse gas emissions by at least 80-95% by 2050, compared to 1990 levels[4]. To outline the path towards such a low carbon future, the EC presented roadmaps for a competitive low-carbon economy[5], resource efficiency, energy and transport. In October 2014, the 2030 policy framework for climate and energy[6] was adopted in which the EU committed to **reduce greenhouse gas emissions with 40% compared to 1990 levels by 2030 and at least 27% renewable energy without country specific targets and 27% energy saving compared to 2007**[7].

1.1.1.1. Specific policy context - Energy efficiency of products

Ecodesign "contributes to sustainable development by **increasing energy efficiency and the level of protection of the environment, while at the same time increasing the security of the energy supply**"[8].

The **Ecodesign Directive** sets the framework defining the “rules” for setting mandatory requirements to improve the environmental impact of products. The requirements are established in implementing measures (regulations) or, alternatively, voluntary agreements. While most of the implementing measures are product-specific, there are also measures that address horizontally modes or functions (standby, networked standby).

[3] http://ec.europa.eu/clima/policies/strategies/2020/index_en.htm
[4] Council of the European Union. 1 December 2009, http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/110889.pdf
[5] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - A Roadmap for moving to a competitive low carbon economy in 2050, Brussels, 8 March 2011, http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52011DC0112
[6] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - A policy framework for climate and energy in the period from 2020 to 2030, Brussels, 22 January 2014, COM(2014) 15 final http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2014%3A15%3AFIN
[7] On the basis of the Energy Efficiency Directive, the European Council has endorsed an indicative energy savings target of 27% by 2030 (this target was not included in the Communication COM(2014) 15). This target will be reviewed in 2020 having in mind a 30% target.
[8] Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products, Article 1.

An energy-related product is defined within the framework of the amended Energy-Related Product Directive[9] as *"any good that has an impact on energy consumption during use which is placed on the market and/or put into service, and includes parts intended to be incorporated into energy-related products covered by this Directive which are placed on the market and/or put into service as individual parts for end-users and of which the environmental performance can be assessed independently"*.

The **Energy Labelling Directive**[10] helps consumers identify products with high environmental performance. It gives the framework defining the "rules" for setting product-specific requirements/ legislation on standard information regarding the consumption of energy and other environmental resources.

While the Ecodesign Directive addresses the supply side, the Energy Labelling Directive addresses the demand side - it is the combined effect of both measures which ensures a dynamic improvement of the market.

In the Ecodesign Commission's work plan for 2012-2014, smart appliances/meters had been identified as one of the priority product groups to be assessed in the frame of preparatory studies and to potentially be subject to an implementing measure (Lot 33).[11].

1.1.1.2. The wider policy context

For smart appliances that do not only focus on energy efficiency, but also bring about benefits for the integration of renewable energies and thus for the efficiency and sustainability of the energy system as a whole, there is a broad range of policies that are relevant for their design and deployment:

With its **Framework Strategy for the Energy Union**, the European Commission (EC) sets the vision for the future and integrates a series of policy areas into one cohesive strategy. The EC's Communication considering 'A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy' (COM(2015) 80 final)[12] states that energy markets and grids have to be fit for renewables to integrate renewable production progressively and efficiently into a market that promotes competitive renewables and drives innovation. Smart technologies will help consumers and energy service companies working for them to reap the opportunities available on the energy market by taking control of their energy consumption and possible self-production. Existing legislation and new market rules need to be fully implemented, enabling the roll-out of new technologies, smart grids and Demand Response.

The Staff Working document (SWD) on Demand Response[13] back in 2013 already called for actions aimed at the development of demand response in the EU to form an integral part of its energy

[9] Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products

[10] Directive 2010/30/EU of the European Parliament and of the Council of 19 May 2010 on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products

[11] Commission staff working document. Establishment of the working plan 2012-2014 under the Ecodesign Directive. SWD(2012) 434 final. 7/12/2012

[12] Energy Union Package - Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions and the European Investment Bank, 'A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy', Brussels, 25 February 2015, COM(2015) 80 final http://eur-lex.europa.eu/resource.html?uri=cellar:1bd46c90-bdd4-11e4-bbe1-01aa75ed71a1.0001.03/DOC_1&format=PDF

[13] Commission Staff Working Document "Incorporating demand side flexibility, in particular demand response, in electricity markets" [SWD(2013) 442] accompanying the document COMMUNICATION FROM THE COMMISSION Delivering the internal electricity market

policy and of its forthcoming actions on the retail aspects of the internal energy market. *"Actions by other policymakers, regulators and energy companies are equally needed to trigger more demand response participation in the short term. Together, they should ensure that both price-based and incentive-based demand response programmes are available to different types and sizes of consumers while demand side participation in the market should be given a fair treatment and clear, practical set of technical rules. They should also ensure that demand response is able to play the role it deserves in contributing to system efficiency and reliability."*

The Commission will prepare an ambitious redesign of the electricity market, followed by legislation in 2016. It will push back on the renationalisation of energy policy through for example capacity mechanisms and propose new incentives for smart grids and rewards for flexibility[14]. *"The Commission will continue to push for standardisation and to support the national roll-out of smart meters and to promote the further development of smart appliances and smart grids, so that flexible energy use is rewarded." (…) "However, this will only work if market prices send the right signals."*

In July 2015 the European Commission proposed a 'Summer Package'[15] as a step towards implementing its Energy Union strategy. The package proposes a 'new deal' for energy consumers, a redesign of the electricity market and a revision of the energy label for more clarity (see Commission Report on Review of the energy labelling Directive[16]). In the Communication from the Commission considering 'Delivering a New Deal for Energy Consumers' (COM(2015) 339 final)[17] the following three key points have been identified as core: consumer empowerment, smart homes and networks and finally data management and protection. One of the steps to achieve this, is to make sure that smart home appliances and components are fully interoperable and easy to use and that smart metering systems fit for purpose with the recommended functionalities, in order to maximise their benefit to consumers.

Reviews of existing legislation (the Energy Efficiency Directive, the Energy Performance of Buildings Directive, and the Renewable Energy Directive) are planned to identify where action is required at EU level in order to deliver this new deal.

The **Energy Efficiency Directive** (EED)[18] establishes a common framework of measures for the promotion of energy efficiency within the Union in order to ensure the achievement of the Union's 2020 20% headline target on energy efficiency and to pave the way for further energy efficiency improvements beyond that date and includes the following elements to be highlighted:

- When Member States roll out smart meters they should ensure that the metering systems provide to final customers information on actual time of use and ensure the data security and privacy of final customers and that, if final consumers request it, metering data on their electricity input and off-take is made available to them or to a third party acting on their behalf.

and making the most of public intervention, https://ec.europa.eu/energy/sites/ener/files/documents/com_2013_public_intervention_swd07_en.pdf

[14] Energy Post, 'Highlights from the Energy Union package – and responses', February 26, 2015, http://www.energypost.eu/highlights-energy-union-package-responses

[15] https://ec.europa.eu/energy/en/news/new-electricity-market-consumers

[16] http://ec.europa.eu/energy/sites/ener/files/documents/1_EN_ACT_part1_v5.pdf

[17] COM(2015) 339 final, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committeee and the Committee of the Regions, 'Delivering a New Deal for Energy Consumers', Brussels, 15 July 2015, https://ec.europa.eu/energy/sites/ener/files/documents/1_EN_ACT_part1_v8.pdf

[18] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC

- Member States shall ensure the removal of those incentives in network tariffs that are detrimental to energy efficiency and that might hamper DR.
- Member States shall ensure that national energy regulatory authorities encourage demand side resources, such as DR, to participate alongside supply in wholesale and retail markets.
- Member States shall ensure that network operators treat DR providers in a non-discriminatory manner and that technical modalities for the participation in balancing, reserve and other system markets are defined on the basis of the technical requirements and capabilities of DR; they should be defined in close cooperation with DR services providers and shall include the participation of aggregators.
- Member States shall ensure that tariffs allow suppliers to improve consumer participation in DR, depending on national circumstances.

The **Internal Market-legislation**[19] on common rules for the internal electricity market holds the following elements relevant in the context of this study:

- Member States (or the regulatory authority) shall strongly recommend that electricity undertakings optimise the use of electricity for example by introducing intelligent metering systems or smart grids.
- Member States shall ensure that customers are entitled to receive all relevant consumption data.
- 80% of the consumers shall be equipped with intelligent metering systems by 2020 (where roll-out assessed positively).

Also related to metering, the Commission has issued on 9 March 2012 a recommendation on preparations for the **roll-out of smart metering systems** (2012/148/EU). It describes the minimum functional requirements for the smart metering system including:

- Provide readings directly to the customer and any third party designated by the consumer by provision of standardised interfaces for energy management solutions in 'real time' for DR services etc.
- Update the readings frequently enough (every 15 minutes) as a general rule.
- Smart metering systems should include advanced tariff structures, time-of-use registers etc. to achieve energy efficiencies and reduce the peaks in energy demand.

The **Network Code on Demand Connection** (adoption of Commission Regulation planned for 2015) is foreseen to lay down the requirements for grid connections of demand facilities and distribution systems and to establish a common framework for connection agreements between the demand facility owner or the distribution system operator vis-à-vis the transmission system operators. Inter alia it will set out procedures and overall technical requirements for the equipment intended to provide DR services. It will address active power control, reactive power control, transmission constraint management, system frequency control and very fast active control. It will not apply for DR services other than those delivered to the transmission system operators.
One of the objectives of the ENTSO-E Network Code on Electricity Balancing (Version 3.0, 6 August 2014) is to facilitate participation of Demand Side Response including aggregation facilities and energy storage supporting the achievement of the EU's targets for penetration of renewable generation.

An evaluation is ongoing of the **Energy Performance of Buildings Directive** 2010/31/EU (EPBD) replacing Directive 2002/91/EC setting a more ambitious framework to improve the energy efficiency of EU buildings in the light of the experience gained and progress made during its

[19] Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC

application. Some of the elements investigated in the public consultation (due by the end of 2016[20]) and relevant in the context of this study is whether DR is being stimulated at the individual building level and if so, how this is done. The consultation also aims to have a better understanding of the impact of the EPBD framework on the self-consumption of electricity in buildings.[21]

The **Renewable Energy Sources (RES) Directive** 2009/28/EC requires Member States, in their building regulations and codes, to use minimum levels of energy from renewable sources in new buildings and in existing buildings that are subject to major renovation. These provisions are complementary to the Near Zero-Energy Building (NZEB) requirements in the EPBD, which recommend that the nearly-zero or very low amount of energy needed should be covered to a very significant extent by energy from renewable sources.

1.1.2. TECHNICAL AND ECONOMIC CONTEXT

1.1.2.1. The energy transition

The European electricity system is quickly evolving. Although there a large national differences, there is a tendency of decreasing classical centralised power plants with controllable production power and increasing intermittent electricity production from Renewable Energy Sources (RES), combined with growing electrification of heating and transport. As the share of controllable production lowers, maintaining the balance between production and consumption becomes more difficult, leading to both energy shortages and energy excesses. Additionally, the grid capacities have not been designed to include the increased local electricity consumption and production, which leads to more grid congestion.

Demand response (DR) is one of the concepts to overcome this and to achieve a better balancing of energy supply and energy demand while accommodating more renewable energy and increasing the energy efficiency of the energy conversion, transmission and distribution, thereby avoiding electricity grid congestion. DR refers to intentional modifications to consumption patterns of electricity of end-use customers that are intended to alter the timing, level of instantaneous demand, or the total electricity consumption[22]. Or, according to the Smart Grid Coordination Group:

Demand response (DR)[23]: '*A concept describing an incentivizing of customers by costs, ecological information or others in order to initiate a change in their consumption or feed-in pattern ("bottom-up approach" = Customer decides)'.*

Demand Side Management (DSM)[24]: '*Measures taken by market roles (e.g. utilities, aggregator/flexibility operator) controlling electricity demand as measure for operating the grid ("Top-down approach")'.*

Technically, this can take many forms: peak demand reduction reserves, frequency containment reserves, frequency restoration reserves, emergency reserves, day-ahead or intra-day BRP

[20] https://ec.europa.eu/energy/en/consultations/public-consultation-evaluation-energy-performance-buildings-directive
[21] https://ec.europa.eu/eusurvey/runner/EnergyPerformanceBuildingsDirectiveConsultation1
[22] Albadi, M. H.; E. F. El-Saadany (2007). "DR in Electricity Markets: An Overview". IEEE
[23] Overview of the main concepts of flexibility management, CEN-CENELEC-ETSI Smart Grid Coordination Group, version 3.0, 11/2014.
[24] Overview of the main concepts of flexibility management, CEN-CENELEC-ETSI Smart Grid Coordination Group, version 3.0, 11/2014.

(Balancing Responsible Party) portfolio balancing, etc. Demand response can be implemented at industrial, commercial and residential level.

1.1.2.2. The role of smart appliances in the energy transition

Smart appliances are probably the main option to achieve flexibility of the energy demand in the residential and commercial sector. The energy consumption load patterns of smart appliances can be remotely shifted or otherwise altered with acceptable user impact.

In providing flexibility, smart appliances potentially have a positive impact on the environmental performance of the energy system:

- by helping accommodating renewable energy and limiting the required installed capacity of (peak) fossil fuel generation,
- by increasing the energy efficiency over the whole system (energy conversion, transmission and distribution),

Thus they can help save primary energy and CO2. Moreover, they can contribute to security of supply.

To achieve larger uptake of smart appliances, consumer agreement and/or consumer enabling of the electricity consumption altering functionality is needed, which requires that incentives – typically financial through tariffs or a capacity payment – should be offered to the consumers.

DR and DSM are well-developing in the industrial sector, where the large energy consumption of a single installation justifies a customised approach and technical solutions. Industrial and possibly commercial consumers are generally more aware of demand response-functionalities and solutions, not at least because they have better access to time-differentiated pricing and other reward schemes. On the other hand, residential DR and DSM are only developing slowly. The cause is what can be described as a “Chicken and Egg Problem”:

- On the one hand, limited/no residential DR products are developed, as there is insufficient capacity available due to a low installed base of appliances enabling demand side flexibility. Without consumers equipped to participate in DR, there is less (or no) incentive to offer time-differentiated supply contracts.
- On the other hand, development of appliances with demand side flexibility features is low, as there are insufficient DR products that can offer sufficient return for the user stimulating him/her to invest in this extra functionality. Without price signals, capacity fees and/or other rewards, there is no incentive for consumers to buy smart appliances and to participate in DR.

Nevertheless, there are many developments that support the introduction of DR and uptake of smart appliances:

- Rollout of smart meters with electricity consumption measured in intervals of typically 15-60 minutes and in some cases with a possibility of reporting live power data;
- Rollout of internet connections to a large proportion of end-users all over EU;
- An introduction of networked appliances, which can be controlled over the internet or other networks through smart phones, tablets, computers etc. and which can go into a networked standby and be woken up via a network trigger signal. There is beginning interest from consumers to acquire these appliances.

1.2. OBJECTIVE OF THE PREPARATORY STUDY ON SMART APPLIANCES (LOT 33) AND OF TASK 1

The objective of this Ecodesign Preparatory Study on Smart Appliances (Lot 33) is to analyse the technical, economic, market and societal aspects with a view to a broad introduction of smart appliances and to develop adequate policy approaches.

The study will follow the MEErP (Methodology for Energy related products), although it should be acknowledged that this methodology has been designed for mainly specific and rather homogenous product groups. The work on Task 7 of the MEErP (Policy and Scenario analysis) is still in progress and therefore is not yet integrated in this study. The refinement of policy options will be the subject of an ongoing second phase of this Preparatory Study.

The lot 33 "Smart appliances" differs from this in two important aspects:

- Smart appliances can be very different products that just have one functionality in common. The approach of the study (not necessarily the policy measures) will thus be horizontal. This means that the definitions, analyses and policy measures related to this study should be generally applicable to all existing and future appliances, which are "smart" in the sense of the study. Consequently, even though we base much of the study on analyses of selected appliances, it is important that the terminology and concepts for smart appliances can be applied to all other relevant appliances, also those not in scope of this study.
- Secondly, positive environmental impacts are mainly generated at the level of the overall energy system, not at the product itself. Hence, the MEErP approach and the calculation tools will fit well for some aspects, less for others.

The aim of Task 1 is to clearly delineate and define the scope of the Preparatory Study. It consists of 4 parts:

- Section 1.3 defines what is meant by ‘smart’ appliances in the context of this Lot 33 study.
- In section 1.4, information regarding today’s status of the Demand Response (DR) readiness of the various appliances is investigated;
- In section 4.5, information regarding today’s status of the interoperability of the various appliances is given;
- Last, the conclusions from the previous parts are summarised and formalised which determine the scope of this Preparatory Study on Smart Appliances.

1.3. SMART APPLIANCES WITHIN LOT 33

Only energy related products within the scope of the Ecodesign and Energy Labelling Framework Directives are in the scope of this study, as these Directives form the legal background for the study and policy measures potentially to be implemented after the study. As such, means of transport for persons or goods including electric vehicles (EVs) are not in scope of the Ecodesign Framework Directive and consequently are not in scope of the present study. However, certain aspects in the on-going process (like interoperability, measurement standard for demand responsiveness) could prove to be relevant for EVs as well.

The focus of this study is on ‘**end devices**’, meaning the appliances that are being controlled and that alter their electricity consumption, as opposed to those devices that control other appliances or end devices. There will be no specification of who or what should activate the DR functionality. All control architectures should be supported.

Building automated control systems (BACS) on the other hand are one of the product groups that might be included in the Ecodesign Working plan 2015-2017 and which would then probably be addressed by a separate preparatory study[25]. However, certain aspects in the on-going process (like interoperability, measurement standard for demand responsiveness) could prove to be relevant for BACs as well.

The following categories and types of appliance will be subject to further study:

- Household appliances:
  - Periodical appliances: Dishwashers, washing machines, tumble dryers and washer dryers;
  - Energy storing appliances: Refrigerators, freezers, commercial refrigeration products and storage water heaters;
  - Behavioural appliances: Electrical hobs, ovens, hoods, vacuum cleaners and instantaneous water heaters;
- Heating, ventilation and air conditioning (HVAC):
  - Electric heating: Electric radiators, electric boilers, electric and hybrid heat pumps and boiler circulators;
  - Ventilation: Local and central extraction fans and local and central heat recovery ventilation units and central extractors and air handling units;
  - Air conditioning: Residential, non-residential air conditioners;
- Battery operated rechargeable appliances: Multimedia devices, power tools etc.;
- Residential energy storage systems: Backup systems like UPS (uninterruptible power supply systems) and home battery storage systems;
- Lighting systems: Lighting in residential and commercial indoor areas and street lighting.

[25] The adoption of the Ecodesign Working Plan was originally foreseen for December 2015.

1.3.2. DEFINITION

Smart appliances - in its broadest sense, and not only limited to smart grid functionality – are mostly understood as appliances that are communication enabled. This communication platform can be used to offer multiple classes of functionality (see Figure 1):

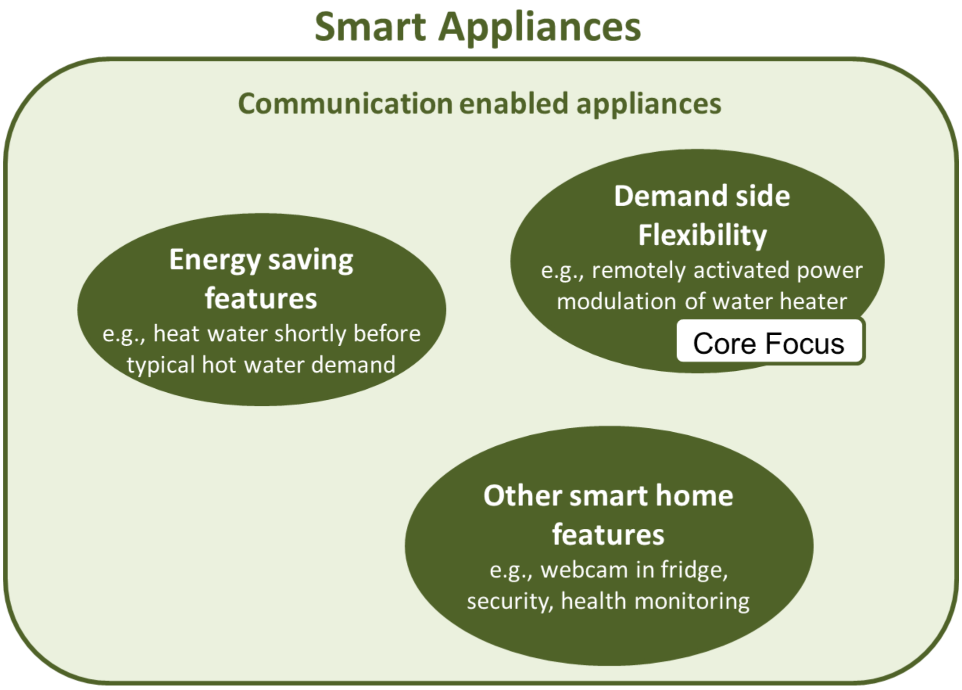

Figure 1 The functionality classes associated with smart appliances, with the focus functionality class of this study highlighted, i.e., demand side flexibility.

As a result of reflections and discussions with stakeholders and under the perception that the study needed to be refocused to produce tangible results for a potential regulatory process, the present study will focus on appliances with demand response-enabling functionalities.

It will not address functionalities that make appliances "energy-aware", i.e. functionalities that enable an appliance to measure, calculate and visualise energy consumption and potential energy efficiency losses over time. This is despite the fact that energy awareness as such might trigger substantial energy savings, mainly through changing consumer behaviour, as existing programmes and projects suggest[26].

Likewise, appliances that provide other features that help save energy (e.g. through better maintenance and direct communication with the retailer/installer or through intelligent sensors) will not be addressed here. Instead, energy awareness and other features with potentially positive impact on energy consumption could be tackled in other horizontal or product-specific lots.

[26] See for example http://www.ict-nobel.eu. A further, rough estimation of the saving potential through energy awareness will be provided in the Task 7 report although energy awareness is not subject to any policy options to be assessed under this study.

Hence, for the purpose of this preparatory study, a smart appliance is an appliance that **supports Demand Side Flexibility**:

- » is an appliance that is able to **automatically** respond to external stimuli e.g. price information, direct control signals, and/or local measurements (mainly voltage and frequency);
- » The response is a **change** of the appliance's **electricity consumption pattern**. These changes to the consumption pattern is what we call the 'flexibility' of the smart appliance;

Whereby:

- » The specific technical smart capabilities do not need to be activated when the product is placed on the market; the activation can be done at a later point of time by the consumer or a service provider;
- » A distinction might be made later in the process between appliances able to communicate and process external signals and (non-communicating) appliances automatically reacting to local power quality measurements.

Note that manual start time delay is not considered smart control because it is not automated. The action of the user would be smart, but the smartness is not part of the appliance.

Automatic actions to safeguard the technical safety of the appliance are not considered smart control. Examples of this are a washing machine that is switched off because of a tripped fuse or the activation of its overvoltage protection.

Behavioural and electricity consumption data from appliances that cannot adapt their electricity consumption may still be relevant information for the DR/DSM control systems. However, the focus of the study is on those appliances that can offer a large flexibility potential with limited or no comfort impact.

In order to enable the modelling of economic and environmental impacts, a definition of flexibility potential is required. The **flexibility potential** of a group of appliances is defined by two parameters:

1. A **shifting potential** = amount of energy that can be shifted, expressed in [MWh/h].
2. **Average maximal shifting period** = average maximum number of hours [h] that appliance can be shifted (i.e., to consume later/earlier in time than initially planned)

1.3.3. USE CASE EXAMPLES

We present a set of use cases examples, serving the purpose of an overall understanding of the scope and of the functionalities that appliances may support and to illustrate the connection between the supply side system and the demand side i.e. the appliances.

The use cases are intended to be representative rather than exhaustive. Variations of the examples given may emerge, both regarding variety and complexity of control objectives, as regarding variety or number of appliances. However the aim is to illustrate the typical modes of operation from the point of view of the smart appliance.

1.3.2.1. Use case example 1: Load shifting of heat pump supplied houses

The use case is based on the assumption that an agreement exists between the consumer and an aggregator or similar intermediate organisation.

Suppose that a peak load is foreseen the next day at 18h, which would have required starting up power generating units at higher costs and/or higher environmental impacts. Instead, the BRP sends a signal to the aggregator requesting a reduction of 50 MW during 1 hour from 18h onwards. The aggregator sends signals to the heat pumps and/or the Home Energy Gateways in 50,000 houses requesting these are not switched on during the mentioned period, resulting in an average 1 kW load per house reduced.

The local heat pump or Home Energy Gateway secures that there is sufficient heat stored in the building components and the warm water tank to limit the impact on the user. The heat pump owner may be remunerated for his/her flexibility, e.g. by means of a yearly capacity fee.

1.3.2.2. Use case example 2: Self-consumption of on-site produced RES energy

Several possibilities for in-house power generation are available on the market. These comprise mostly PV systems, but also smaller wind turbines and gas fired micro-CHP (small combined heat and power systems). Often, such prosumers receive no remuneration for the energy injected in the grid, or a remuneration lower than the electricity purchase price. The prosumer has thus an incentive to use its own production locally as much as possible.

In this case, the prosumer has a Home Energy Controller, which may take the form of a separate energy gateway device, or which may be integrated, e.g., in the PV inverter controller. This controller measures the local RES production, the local (non-controllable) consumption and dispatches smart appliances to minimise the injection of RES energy in the grid.
For instance, if the user owns a PV installation and a battery system, then the controller will charge the battery when the PV production exceedes the non-controllable consumption of the household, which will typically occur at noon, and will order the discharge of the battery when consumption exceeds the PV production.

1.3.2.3. Use Case Example 3: Variable pricing support by a washing machine

In this use case, the user has an electricity contract based on variable prices, e.g., prices based on the day-ahead energy market,
Those prices are directly downloaded to the washing machine, which has a communication interface that supports the used pricing scheme and which is equipped with dynamic pricing scheduling logic.

When the user configures the machine, he/she sets a deadline when the laundry should be finished the latest, and the washing machine then automatically starts the washing programme such, that the total energy price for the programme is cheapest, while the laundry is still finished in time. The washing machine may also give indications via its user interface to the user on when the cheapest and/or highest prices occur, such that the user can take this into account during configuration.

1.3.2.4. Use Case example 4: Appliance-based System Frequency Control of freezers

Suppose that an emergency situation occurs in the power system, resulting in a reduction in voltage and frequency at the consumers' level in a local area. Suppose that 1,000 households with system frequency control freezers switch off, resulting in a total load reduction of 100 kW, sufficient to stabilise the grid.

The freezers dispose of built-in control, securing a maximum of half a degree raise of temperature during maximum 1 hour. The household owners could be remunerated for the flexibility.
This type of DR is based on internal measurements and control: The appliance is equipped with power measurements (e.g., frequency and voltage) and it switches or modulates its electricity consumption in function of those measurements. This type of control requires no communication to or from the appliance.

1.3.2.5. Use case example 5: distribution grid congestion management by buffered water heaters

Suppose a very high installed base of photovoltaic panels within a single low voltage distribution grid segment, in which the injection of energy would cause frequent overvoltages if no countermeasures are taken. In this use case example, the distribution system operation (DSO) has chosen to use DR. The DSO has an agreement with the local owners of buffered water heaters, e.g., in the form of an annual capacity fee. At noon, when the local solar production is high, the water heaters are automatically switched on. The increased consumption drops the voltage levels, the amount of injected energy is reduced, and overvoltages are avoided. The heat generated is stored in the thermal buffers and remains there until the heater owner requires it. The DSO has avoided grid reinforcements and the associated investment cost.

1.3.2.6. Use case example 5: Frequency restoration reserves based on commercial refrigeration

Suppose a supermarket chain with a large number of cooling assets distributed across its sites. These refrigerators and freezers are all connected to a central energy management system, allowing the supermarket chain to offer ancillary services to the Transmission System Operator (TSO), more specifically emergency frequency restoration reserves. In case of a production shortage, the TSO sends a signal to the energy management system of the supermarket chain, which automatically powers down all operational compressors of refrigerators and/or freezers with a temperature below a maximum allowed temperature. In case of a production surplus, the TSO can remotely switch on the compressors of all refrigerators and/or freezers with a temperature above the lowest allowed temperature. The supermarket chain receives a capacity reservation fee based on the guaranteed minimum power it can switch on/off, supplemented with an activation fee every time the TSO calls on the reserve.

1.3.2.7. Use case example 6: Peak shaving combined with energy efficiency by appliances controlled by a building automation and control system

Suppose a building automation control system that centrally monitors and controls all smart appliances within a large building, e.g., heating, HVAC, ventilation, etc. The owner of the building has a contract with an aggregator to supply emergency peak shaving reserves. Besides a fixed capacity fee per year, the owner of the building receives an activation fee, each time a peak shaving signal is sent to the building automation system. The number of peak shaving signals per day is contractually limited to, e.g., one single signal per day. When such a signal is received, the building automation system decreases the total electricity consumption of the building below the contractually agreed levels for a predefined fixed period of time, e.g., 3 hours. Outside of the peak shaving periods, the building automation system controls the smart appliances as to optimise the energy efficiency of the building as a whole.

1.3.4. System Frequency Control

In certain cases smart appliances locally measure a grid parameter and autonomously respond to this, with system frequency control by thermal appliances as the best known example. The operating principles of the latter are:

- the appliance temperature set points remain user controlled,
- the appliance measures the frequency in a given interval and with a certain accuracy,
- the appliance operates normally within a defined deadband around the nominal frequency (50.00 Hz),
- if the frequency drops below the deadband, the hysteresis offset point is lowered for heating systems and raised for cooling systems; the inverse is executed when the frequency raises above the deadband.

If this control is realised without changes to the temperature setpoint and if the hysteresis range settings are not exceeded nor altered, then there is no noticeable impact on consumer comfort.

This type of DR differentiates itself, as – from a purely technical standpoint - no communication is required from the smart appliance to the outside world. The grid frequency reflects the electricity system balance and 'communicates' what proper actions to take for the smart appliance. Note that the same principle can be used for other grid parameters, e.g., line voltage, three-phase voltage or current imbalance, etc. With exception of the system frequency, these are typically grid parameters that reflect the state of the local distribution grid.

System frequency control based on smart appliances with local measurements has a number of advantages and disadvantages. The strongest advantage is that extra communication links are redundant. Costs are avoided, no privacy issues emerge and uptake is not hindered for people who lack affinity with networked technology. On the other hand, the appliance must be equipped with extra measurements. They also cannot participate to other DR schemes, unless extra communications are established, which forfeits a lot of the advantages.

A distinct difficulty due to the lack of a communication channel, is that the DR contribution of the appliance cannot be easily measured, nor verified. As such, simple and transparent compensation mechanisms are hard to establish[27]. Nevertheless, because of the many advantages of frequency control based on local measurements, system frequency control remains a viable DR option.

System frequency control is also one of the DR mechanisms that is addressed in the Network Code on Demand Connection (adoption foreseen in 2015). A mandatory deployment of frequency control-enabled temperature-controlled appliances, as initially proposed by ENTSO-e, is no longer envisaged.

[27] Probably the most practical remuneration scheme for system frequency control is a simple capacity fee in the form of single time bonus when the appliance is purchased, or a fixed annual reduction to the energy bill. Biggest drawback of such schemes is that the fee has no relation to the effective capacity made available to the frequency reserves.

The Demand Connection Code[28] establishes, *inter alia*, technical rules for equipment that is contracted to provide DR reserves. As technical specifications (deadband width, nominal frequency/voltage/…, etc.) depend for the moment on the specific needs of the local TSO, these need to be programmed in the appliance. Harmonisation across Europe of the minimum ranges within which the technical specifications are being defined would reduce costs for the manufacturers and hence the end-user. Further harmonisation of the technical requirements would be necessary in the longer run. The findings of this study and the Ecodesign Smart Appliances process might be able to support this process.

1.4. Demand Response Readiness Status

An important point of attention of this preparatory study, is the functionality required for smart appliances to support and offer demand side flexibility and the resulting flexibility potential per appliance type, which varies per appliance type. This section discusses these aspects and classifies the appliance types in scope of the preparatory study based on flexibility potential and the associated impact on the user's comfort. We further discuss the possible control architectures and the impact of those on this study. Also the impact on the study of the energy market organisation and of the possible DR business cases is discussed.

There are today a limited number of appliances with built-in smartness and it is necessary to redesign the appliances in minor or larger degree, depending on the level of smartness to build in and the type of appliances.

The redesigns should include:

- A communication module to communicate with the system, e.g., using wireless, wired and/or power line communication (PLC) technology.
- A control module for switching on, off, load modulation etc. of the relevant components of the appliance.
- Components separating the ones applicable for the load shifting from the ones not applicable. E.g. in the case of a fridge, the light should be always on when the door is open, even though the compressor has received a pause signal. Also the internal control unit needs to adapted to handle this separation.
- Additional logic to safeguard the comfort should be added.

The redesigns will have a different nature depending on the type of appliance. For some appliances a redesign of the compete design platform is needed, while other appliances only need smaller redesigns.

<u>Demand Response Readiness gap</u>

The main gap is that similar appliances of different manufacturers should provide the same demand side flexibility functionality, or a subset of a commonly agreed upon set of functionalities, such that the demand control system does not need to differentiate between appliances of different brands. This also maximises the guarantee for the end-consumers that the available DR systems support the appliance of choice.

Appliance gaps are taken into account by TC 59.

[28] See the site of ENTSO-e for more information: www.entsoe.eu

1.4.1. FLEXIBILITY POTENTIAL OF APPLIANCES

Each main category of appliances within the scope of this study, as listed in Section 1.3, is described in detail in Annex 1 of this report regarding:

- Installed base
- Electricity consumption
- Identification and description of the energy shifting and/or power modulating possibilities - the nature of it, size, in which periods (working days, weekends, seasons etc.).
- Estimation of the flexibility potential per appliance
- Estimation of total flexibility potential for the category based on an estimate of the total amount of appliances in EU and the potential per appliance
- Identification and description of any comfort and user impact
- Identification and description of any gaps and/or pre-conditions for the flexibility potential (technical maturity, redesign needed, availability, other)

Note that in the following Task reports, more details will be integrated on these characteristics.

In relation to comfort and user impact, it is important to emphasize that this will have an important impact on the flexibility potential. It is however not possible to look at it in an isolated way because it also depends on the economic benefit and/or other benefits related to accepting that the appliances will be DR enabled. We have therefore tried to estimate a balance between possible comfort losses and user benefits when estimating the potential.

We consider as a pre-condition that the smart appliances are being designed for the demand side flexibility functionality and that there would be no negative impact on the lifetime and repair costs. The technical analyses are described in Task 4 report.

No negative impacts on privacy protection is also a pre-condition. This is further detailed in Task 3.

It is necessary to look into the single appliances, because eventually a possible regulation would cover individual appliances.

Below, we summarise the results of the detailed analyses and references as described in Annex 1 and conclude with a ranking of the appliance types, according to flexibility potential and user comfort impact.

1.4.1.1. Periodical household appliances: Dishwashers, washing machines, tumble dryers and washer dryers

Periodical appliances are appliances that periodically execute a user initiated cycle. There is no interaction with the user while running and often the user does not require the programme to be finished as soon as possible.

There are three different possibilities to shift energy or modulate power:

1. Start time delay controlled by the user: This is a common function in dishwashers and washing machines, 30-40 % of the appliances have the functions. This function is not considered "smart" in the sense of the study.
2. Remote activation: the user selected programme is remotely activated before the user deadline is reached.

3. Altered electricity consumption pattern: while the appliance is activated, the consumption patterns changed through pausing the operation, changing the temperatures, etc.

The complexity of technical adjustments and redesign needed increases from the first to the third level.

Appliances in this category offer a high energy shifting capacity and a limited power modulation capacity. Pilot studies in the framework of the Linear project indicate that around 30% of the configurations of washing machines and tumble dryers can be with remote activation. For dishwashers this is 56%. Depending on the study, the average length of the time window for remote activation varies from 3 to 8h.

Flexibility is typically situated in the afternoon and especially in the evening. The evening flexibility peak is most pronounced for the dishwashers. There is more flexibility in the weekends than in during weekdays. For dishwashers and washing machines, there are almost no seasonal effects. However, tumble dryers are predominately used in winter season.

In the framework of the Smart-A project, it was estimated that about 20 % of dishwashers, 10 % of washing machines and 30 % of tumble dryers may be operated in altered consumption pattern mode.

Consumer's acceptance for remote activation is expected to be rather high, especially so for dishwashers and washing machines. However, there can be concerns regarding an external steering of appliances as well as regarding safety (especially in periods of absence) and noise (during the night). Altered consumption mode operation may have an impact on the quality of the appliance's operation (e.g. changes in cleaning performance or colour fading due to pausing and prolonging the operation) and on its energy consumption. If a process, for example, is interrupted during a critical heating phase, the process temperature will decrease due to heat losses and additional energy is needed after the pause to compensate for this lost heat.

The total energy consumption of dishwashers, washing machines, washer dryers and tumble dryers is relatively small in comparison to other household appliances (e.g. refrigerators or water heaters), as the operation time and number of operation cycles is limited. However, the higher power during operation, the larger delay windows (higher flexibility) and the high market penetration in Europe, especially in the case of washing machines and dishwashers, results in a significant DR potential.

By taking into account all households in Europe, an energy shifting potential of washing machines of about 5 GWh was calculated. For tumble dryers, it is between 3 and 10 GWh and for dishwashers, it amounts to 8 GWh.

1.4.1.2. Energy storing household appliances: Refrigerators, freezers and storage water heaters

Energy storing appliances are appliances that provide a capacity to store energy in a form ready to be delivered to the user without any further transformation. These appliances require no interaction with the user after initial set up, although user actions can impact the appliance's operation.

There are two different possibilities to shift energy or modulate power:

1. Remote activation: the cooling or heating is remotely activated or delayed.

2. Altered electricity consumption pattern: changes in the operational parameters of the appliance (motor speed, temperature settings, etc.) allow modification of the consumption pattern.

The complexity of technical adjustments and redesign needed is higher for the second option.

For appliances in this category, flexibility depends on the thermal storage capacity. In first instance, it may be considered as evenly distributed throughout the day and throughout the week. For refrigerators and freezers, seasonal effects are only weak. Water heater loads are highly seasonal with highest potential occurring in winter. This can be explained by the fact that both, differences in water temperature and hot water consumption are higher in winter season.
Appliances in this category offer a high flexibility in energy shifting operation. Consumer's acceptance is assumed to be rather high if food safety and quality is not compromised and if there is no loss of comfort. Short-term interruptions of heating or heating processes or power modulation (e.g. changes in temperature setting or reduction in motor speed) can be realised for all appliances in this category. In this way, power demand curve can be changed instead of merely shifted.

Assuming a potential for short term interruptions of 5 Wh per household in Europe, an energy shifting potential of 1.56 GWh for refrigerators and freezers in 2025 was calculated.

1.4.1.3. Behavioural household appliances: Electrical hobs, ovens, hoods vacuum cleaners and instantaneous water heaters

Behavioural appliances are appliances where the operation is linked to its functionality and whose operation require the active involvement of consumers[29].

There are three different possibilities to shift energy or modulate power:
1. Manual intervention by the user. This option is not considered "smart" in the sense of the study
2. Altered electricity consumption pattern: pause between heating cycles, interrupt the heating phase, etc.

The complexity of technical adjustments and redesign needed increases from the first to the third level.

An estimate on the shifting potential is hard to state, since not much research has been done on this in view of appliances in this category.

Concerning hobs and ovens, it has to be examined whether short term interruptions of heating phases or prolongation of the interval between two heating phases by seconds or minutes compromise the cooking process and consequently the performance**.** However, the consumer's acceptance is supposed to be low.

In view of range hoods and vacuum cleaners, a reduction of power will result in a lower air change rate or a loss of suction power, respectively, leading to a lower effectiveness and a highly variable background noise.

[29] Robot vacuum cleaners can be regarded as an exception to this. However, as the flexibility of robot vacuum cleaners is in the charging of the battery, the assessment is part of the analysis of chargers.

For instantaneous water heaters, the aforementioned scenarios are improbable. Short term interruptions in power supply would cause losses in comfort, which will not be accepted by consumers.

1.4.1.4. Heating (electric and hybrid) (permanent appliances): Radiators, boilers, heat pumps and circulators

This category comprises direct effect electric radiators (with or without built-in heat storage capability), electric and hybrid (gas or fuel + electric) heat pumps and boiler circulators.

There are three different types of flexibility involved for heating :

- Inertia of the building (this includes all types of electric heating without storage and boiler circulation pump),
- Inertia built in the heating system (electric storage radiators and electric boilers)
- Energy source shift (gas or fuel) for hybrid electric heat pumps during peak hours; this potential is extremely high - the electricity consumption can be lowered at any time, but the market for hybrid heat pumps is just at its beginning (still negligible in 2014).
- Power to heat aims to absorb power supply peaks, which can be achieved for example by electrical heaters inside storage tanks of hydraulic heating systems. Switching to electrical heating has no restrictions for the user.

All electric heating appliances include some sort of controls, mainly thermostatic. Newer installations of electric heaters and heat pumps have more advanced control systems though typically not enabled for exchanging signals with third parties.. Recently, smart thermostats have been proposed to customers of energy suppliers, allowing to control electric radiators and boilers, but only in the mode ON/OFF. HVAC manufacturers typically offer central controllers with more sophisticated controls for their own units (integration of other variables as variable speed of the compressor drive), which may communicate with a building controller or a network for some of them.
The smart control might (or not) be integrated directly into the unit, the ensemble “control+unit” is considered the smart appliance as a whole, thus encompassing 1 or 2 energy related products. Therefore, smart thermostats are considered as smart energy related products.

Potential is estimated at:

- Peak power: Up to about 95 GW (2010)
- Energy consumption: About 280 TWh/year
- Potential energy to be shifted: About 30 TWh/year and about 100 GWh/day in the coldest winter months

The flexibility potential is divided at about 50/50 between built-in system inertia (storage radiators, electric boilers) and building thermal mass (inertia). This means about 40 % (40 GWh/day) can be used to store renewable heat in excess during coldest winter days (wind or solar photovoltaic electricity which can be used to heat electric storage, instead of using grid electricity). Regarding the use of building thermal mass, several smart grid and DR experiments are on-going in France. They will help characterise the user acceptance regarding the comfort variations due to heating power modulation and the need for two way communication in order to satisfy comfort and then ensure the durability of any DR programme based upon electric heating.

Comfort is the limiting factor as temperature will drop in the house when the heating system is stopped. Strategies can be adapted (heat pre-charging of the building structure, ventilation can be stopped) but this requires two way communication. Another limiting factor is the speed of air temperature variation in the house, if it is too drastic, occupants' comfort might be jeopardised. This may be mitigated by modulating the orders (not full stop but only 50% of the capacity supplied over a longer period).

1.4.1.5. Ventilation (permanent appliances): extraction fans, heat recovery ventilation units and air handling units

This category comprises local and central extraction fans and local and central heat recovery ventilation units in the residential sector and central extractors and air handling units in the tertiary sector.

In the residential sector, ventilation is mainly constituted of one or several local exhaust fans (mainly in wet rooms) or of a central extractor. Balanced ventilation units with heat recovery are growing in numbers, but still represent a very limited share of market and stock.

All these systems operate continuously and may be controlled by the end-user. Some central extraction units are equipped with two speeds with manual control - either by wired control or radio frequency control. Best available technologies (here with the meaning of Ecodesign Best Available Technologies, see DG ENER lot 10[30] & ENTR lot 6[31] studies for these products) include demand controlled ventilation based on CO_2 or other presence sensors, balanced heat recovery ventilation and motors having the capacity to adapt the motor frequency to adjust the flow but they have very low sales share.

In the non-residential sector, ventilation works on the same principle with larger and more sophisticated units.
Air handling units encompass more air treatment functions, which require more sensors for control. Local sensor can communicate with the products through radiofrequency and it is now common to see manufacturers proposing web interface for their products, for maintenance and energy consumption and performance measurement. The share of end-user buying these options is not known.

As a conclusion, some degree of smartness already penetrated the non-residential sector, but probably a small part only, while the residential sector is probably fully without smartness.

The power consumption can be shifted directly, i.e. by stopping or modulating the fan electric power. For ventilations systems which also transport heating and/or cooling this will have an impact on the heating and cooling consumption. In this section, only ventilation shifting potential is included.

The limit for the stopping or reducing the ventilation is the CO_2 concentration, but there still could be a shifting potential if associated with-periods with higher than necessary ventilation levels. However, with air volume change per hour of 0.8, this probably leads to potentials of a few minutes only.

[30] http://www.eceee.org/ecodesign/products/airco_ventilation
[31] http://www.eceee.org/ecodesign/products/standby

Maturity and potential probably exclude residential ventilation, because unitary power per unit is very low.

Flexibility potential :

- The peak power of non-residential ventilation is relatively low, about 10 GW.
- 59 TWh in 2010 for non-residential ventilation. Energy consumption of non-residential ventilation is relatively important because units operate all year long during working hours.
- Units may probably shift about 10 GWh/day during working hours in the week.

The main risk regards health because of increased CO_2 concentration levels.

1.4.1.6. Air conditioning (permanent appliances): Residential and non-residential air conditioners

This category comprises all cooling systems for comfort cooling:

- Residential air conditioners, mainly split and multi-split systems, but also portable air conditioners
- Non-residential air conditioning systems, i.e. chillers, large split, multi-split and VRF (variable refrigerant flow) systems, rooftop air conditioners and cooling systems of air handling units

Air conditioning units are equipped with sophisticated controllers and except small split units using a remote control, a central controller is generally installed with the unit. To get smarter, air conditioners may require slight adaptation however, they can be equipped with DR capability by adding a network adaptor as an interface to a listed protocol or a centralised controller. Australia has for instance adopted a standard (AS 4755, 2008) for air conditioners to be equipped with specific DR signals (stopped, working at 50% or 75% of their demand) in order to ease the interaction with a standardised DR enabling device which can be operated by external agents.

As for heating, electric cooling shifting potential mainly relies on the building capacity to maintain indoor air temperature within acceptable limits when the cooling power is reduced or cut. All new equipment sold from 2012 onwards are equipped with multi-stage compression circuit or variable speed drive to control the cooling capacity output.

It is believed some electric cooling appliances are equipped with the communication and control functionality to support DR, due to the fact that they are already capable of exchanging signals with a domestic control server or remote activation via wifi for example. Although smart thermostats are offered in Europe mainly for heating, they could also provide communication and control functionality for cooling appliances.
Potential reduction in user comfort is the main limiting factor of the shifting potential in the residential sector. For tertiary purposes, many restrictions according to the industry might be limiting factors (e.g. temperature controls in pharmaceutical laboratories).

Another important issue regarding flexibility potential for air conditioners are restrictions related to ensure secured spaces during heat waves in Europe. In France for example, after the heat wave of 2003 where more than 15000 elder died, dictated that at least one conditioned space must exist in a retirement home. Specific restrictions regarding electricity supply also exist. In addition to local regulations, flexibility potential will be modulated by the acceptance of DR mechanism by the end-users.

Flexibility potential:
- Peak power: Up to about 160 GW (2010)
- Energy consumption: About 80 TWh in 2010
- Potential energy to be shifted: About 65 GWh/d in the summer and about 8 TWh/a in total

1.4.1.7. Battery operated rechargeable appliances

This category comprises charging of battery equipped (low power) appliances. These include all kind of multimedia devices (phones, tablets, video cameras etc.), power tools and other household appliances with rechargeable batteries (clocks, electric shaving, toothbrushes, etc.) on a low power level.

Currently little of these appliances are ready for smart charging. However, a distinction needs to be made between the devices with a rather large processing power capability (most multimedia appliances) and network communication support and those without. Smart charging functionality could be added as a software application without the need to further adaptations. The latter need extra (physical) adaptations, which in the light of the 'low' selling prices of these appliances, could be relative expensive. An alternative could be the usage of general purpose smart power adapters, but then the control logic is part of the adapter and not the end device.

There is a certain potential, however its capacity will depend on controlling large numbers. Peak powers and average consumption is rather low for these appliances. Numbers are very high (millions).

Limited research has been done on the potential of smart charging in the low power appliances, but similar techniques already were investigated for electric vehicles, which could also be applied for this.

The comfort impact may be small, if the shifting periods are limited and take place during a no-use period such as during the night.

1.4.1.8. Residential energy storage systems

This category comprises larger battery storage systems:
- Backup systems like uninterruptible power supply systems (UPS)
- Battery energy storage systems, which are mainly meant for load levelling and peak power shaving. E.g. minimising the PV power injection into the grid.

UPS systems already have a high technical maturity and already were subject of an ecodesign preparatory study. The battery energy storage systems for residential use are rather new. For load shifting a redesign might be needed.

Both described battery storage systems are from a technical point of view similar to each other but differ in their usage. The backup systems, by the nature of their usage, do not allow a large amount of flexibility.

The battery energy storage systems are meant exactly to provide flexibility for different usages, but at the moment their installed base is limited, so also the total capacity. However, when in future these systems will find their way to the market, they could represent a larger potential.

These units could be controlled through a control logic that optimises along a given strategy (“kWh, €, CO2…).
Because transport is not part of the Ecodesign and Energy Labelling Framework Directives, battery charging systems for electric vehicles cannot be included in implementing measures as easily as the other appliances under investigation. However it should be noted that the expansion of electric transport will entail a modification of the load curve, especially in the night period.

1.4.1.9. Lighting (behavioural appliances)

This category comprises lighting in residential and commercial indoor areas and street lighting using the following lighting technologies: LFL (linear fluorescent lamp), CFL (compact fluorescent light), Tungsten, GLS (general lighting service 'incandescent'), HID (high intensity discharge lamp) and LED (light emitting diode).

There are the following possibilities to shift or modulate capacities:

- For advanced LED light bulbs: There are already LED light bulbs on the market, which can be controlled by a smart phone over Wi-Fi – in some cases combined with a special hub for the bulbs. This can be further developed into a system controlled by signals from the power supply system. For LED systems there will be no technical problems in dimming and switching off the light.
- For CFLs: It is also possible to build in DR enabling, but in a less extent dimming compared to LEDs.
- Generally, for all light bulbs (LED, CFL, Tungsten, GLS) it is technical possible to mount an extra DR module for switching on and off the bulbs.
- For luminaries and lighting systems in commercial areas (mainly LFL): There are already advanced systems on the market, which can be controlled by local conditions in the lighted area through presence sensors and solar radiation sensors combined with the time of day. This can be further developed into a system controlled by signals from the power supply system.
- Street lighting: Street lighting are already highly controlled from outside and it is possible to combine this with a DR module.

Many light technologies can be dimmed (tungsten, halogen, fluorescent, LED etc.) resulting in reduction in power load and energy consumption.
Lighting including street lighting is naturally mostly switched on in periods with no solar radiation apart from indoor areas with no or few windows such as basements, commercial centres etc. meaning that the energy consumption is higher in evenings and during nights, though also depending on time of year and geographical location within EU. For offices and some other commercial area, the energy consumption is reduced during weekends.

The energy consumption is higher during these periods, which would be a basis for the flexibility potential.

There are not many technological gaps, because the technology exists. There may be technological gaps regarding some lighting technologies, which are not suitable for dimming and/or often switching on/or, else the gaps are few and technology are already used for lighting systems on the market.

Due to already effective energy labelling and ecodesign measures, there is a high focus on energy efficient lighting, both regarding efficient lighting devices and regarding efficient control (presence sensors, automatic dimming according to actual needs, etc.). When lighting is an energy service, which needs to be produced simultaneous as the needs occur, all lighting load shifting will have serious user impacts, which may include safety issues.

Therefore, even though the technical potential is large, the flexibility is low, especially for homes and commercial areas, and the real potential will mainly exist for short periods of emergency load shifting.

There is very little data on shifting potential for lighting. Based on available data and assumptions on stock, lumen, efficiencies, comfort impact etc. we have estimated a total shifting potential at about 28 GW corresponding to about 4 GWh/day. Of this street lighting is estimated at about 5 GW corresponding to about 2,5 GWh/day.

1.4.1.10. Conclusion

We have divided the appliances into 3 categories of potentials:

- High flexibility potential with few comfort and/or performance impacts: Dishwashers, washing machines, washer dryers, buffered water heaters, radiators, boilers, heat pumps, circulators, residential and non-residential air conditioners and battery storage systems;

- Smaller flexibility potential and/or larger comfort/health impacts: Tumble dryers, refrigerators, freezers, extraction fans, heat recovery ventilation and air handlings units and chargers (low power);

- Only emergency flexibility potential: Electrical hobs, ovens, hoods, vacuum cleaners and lighting.

Further product development including the products' control system may move more products to the high flexibility potential category. E.g. refrigerators and freezers may have more cooling capacity built in and may store more cool before the planned shifting period in order that the temperature variation would be minor.

1.4.2. Control Architectures (impact on smart appliance functionality)

From the point of view of the smart appliance, 3 approaches exist to establish control of the smart appliances, within the comfort limits set by and agreed upon with the user and in function of the DR objective. Note that a smart appliance may be equipped with the functionality to be interoperable to multiple of these approaches.

External control and external objectives
The smart appliance is connected to an external control system via a generic flexibility interface. This interface allows the control system to read the flexibility status of the appliance, and allows the control system to switch or modulate the electricity consumption or production of the smart appliance. Comfort protection based settings by the smart appliance of those control signals may be possible. Use case 1 (load shifting of heat pump supplied houses) illustrates this scheme.

In this case, the information layer data model (see Figure 5: Data transfers between the appliance and the power system) contains flexibility status information and control actions. It must be extended when smart appliances offer new types of flexible behaviour. This implies updates of the control systems, but not of the installed smart appliances. Different or new uses of flexibility in the energy markets require no data model updates nor smart appliances firmware updates.

As the smart appliance's interface is flexibility based, and not DR control objective based, the appliance can be used for any current or future DR scheme, provided the timing requirements of the control objective can be met by the DR communication and control infrastructure.

The control system can be either a home controller, or a cloud based systems.

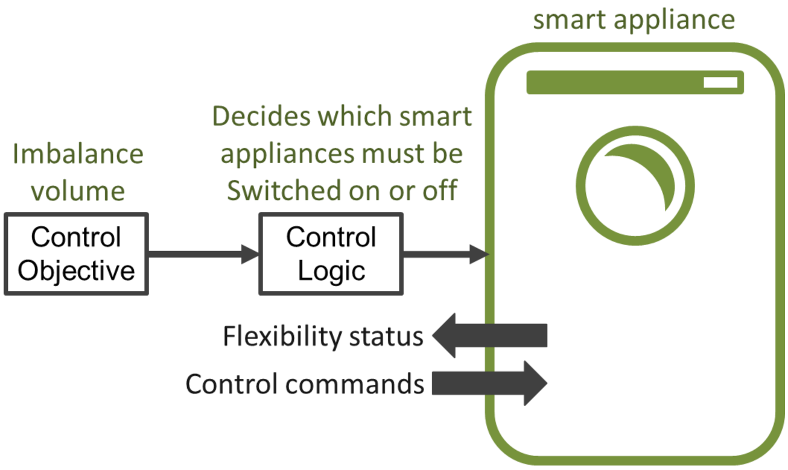

Figure 2 Example: the flexibility of smart appliances is used to maintain the intraday balance between electricity production and consumption, using an external control and external objectives setup.

<u>Internal control and external objectives</u>

The smart appliance is connected to an external control system via a DR objective based interface, e.g., a variable energy price interface. The DR objectives are sent to the smart appliance, and the smart appliance independently adapts its energy profile in function of the sent objectives and the user's configurations and settings. Optionally, the smart appliance may report its actions back to the originator of the control objectives. Use case 2 (variable pricing support by a washing machine) illustrates this scheme.

In this case, the information layer data model contains DR control objective specific data. This implies that the smart appliance must support DR control objective specific functionality and that each smart appliance must support the control objectives it is potentially used for (variable pricing, frequency restoration reserves, emergency reserves, grid congestion reserves, …). New uses of flexibility in the energy markets require data model updates and firmware updates of all smart appliances that participate to this new scheme. These updates include the required optimisation and control logic. When smart appliances offer new types of flexible behaviour, then only those appliances are impacted, but not the data model.

Control objectives can be sent to the smart appliances both using the home energy gateway model or using the cloud model.

As the control decisions reside with the smart appliances, this architecture is mainly suited for open loop control DR, such as dynamic pricing. If the DR response scheme requires closed loop control, e.g., if an exact increase or decrease of the consumption is required, for instance, for intraday BRP portfolio management purposes, then this can only be achieved by iterative control algorithms (if the smart appliances report their actions), or by statistically modelling the response of the smart appliances.

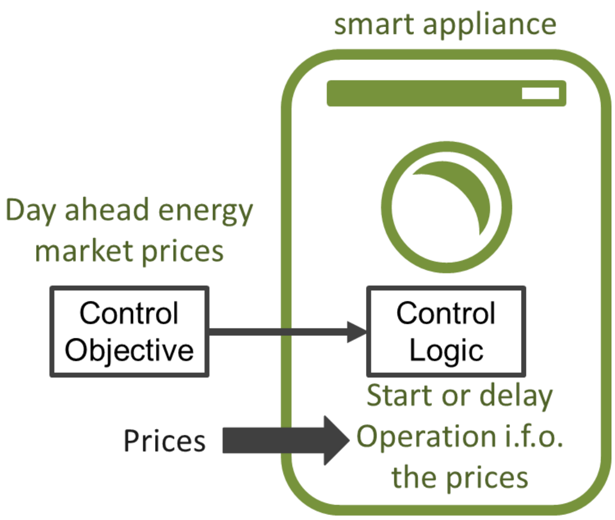

Figure 3 Example: smart appliances respond to day-ahead energy market prices, making use of internal control and external objectives setup.

<u>Internal control and internal objectives</u>
The smart appliance requires no communication links, but rather optimises its energy consumption profile based on locally measured parameters only. Use case 3 (appliance-based system frequency control of freezers) illustrates this scheme.

The number of DR control objectives that can be realised using this scheme is limited, as there must be a correlation with, typically, the voltage and/or frequency as measured by the smart appliance.

New or future control objectives require firmware updates of the smart appliance, and possibly a hardware update, should the supported measurements not suffice.

As the control loop includes no external communications, very fast response is possible. Only open loop control is possible.

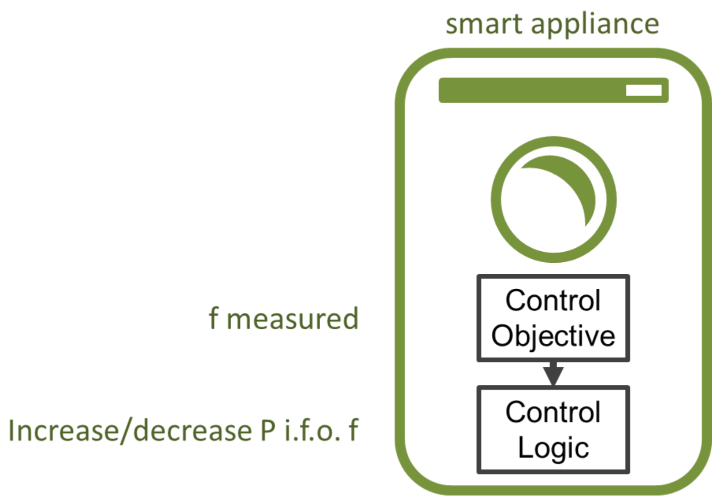

Figure 4 Example: smart appliances realise automated frequency restoration based on local frequency measurements, in an internal control and internal objectives setup.

Conclusions

Both the appliances and the data model (see Section 1.5) must accommodate for the control architecture(s) selected, as each model requires different logic in the appliances and different data communicated. Furthermore, if the control is internalised, as for two of the models, then the use of the flexibility may be limited. Most standardisation efforts today partly support a mixture of the three models. E.g., SEP2 supports both variable prices sent to directly to the smart appliances and direct control.

If the external control and external objectives model is to be supported, additional work is required to define broadly applicable generic flexibility interfaces for the smart appliances.

If the internal control and external objectives model is to be supported, additional work is required to define what control a smart appliance should at least support and how the objectives for each control case are formatted.

If the internal control and internal objectives model is to be supported, additional work is required to define what control a smart appliance should at least support.

1.4.3. Residential DR and the EU energy markets

The organisation of the energy markets has a strong impact on DR/DSM. More specifically, it has an influence on what DR business cases are possible, what the return of those business cases is, and how this return can be distributed over the various actors involved (the end consumer being one of these actors), and on the possible end consumer remuneration mechanisms.

However, there are significant variations in the setup of the energy markets of the Member States. E.g.,:

- the ownership of the smart meter is not harmonised;
- the TSO ancillary service products and access to those services for DR sources is not harmonised;
- the support of variable tariffs and/or the tariff structures vary;

- the role, obligations and rights of DR aggregators is not harmonised;
- the rights and methods of DSO's to interact with DR for the purpose of safeguarding distribution grids from this extra source of variability is not harmonised;
- the mechanisms to alter perimeter of BRPs with the effects of residential DR (settlement) vary or are not yet established.

The focus of this study is on smart appliances and their capability and potential to support an as wide as possible range of DR business cases and energy markets. **This study is not about market design, i.e. what market structure or business cases are to be preferred.** As such, above topics are not in scope of this preparatory study.

1.5. INTEROPERABILITY STATUS

1.5.1. PRINCIPLES

For the purpose of this report interoperability is understood as the link between the individual appliance and the supply side (BRP, aggregator, energy efficiency service provider, grid operator, etc.) via a home energy manager[32] or internet/cloud systems and in some cases also the AMI (Advanced Metering Infrastructure), making it possible to achieve a better balancing of energy generation and energy consumption within the grid and/or to avoid grid congestion.

In the context of the smart home and smart appliances cross-platform, interoperability is an essential requirement to guarantee flexibility and security of possible investment for the customer. An end-customer, who is faced with the choice in case of a smart home set-up, is initially motivated by its intended application goals, such as increasing the living comfort or the saving of energy. When comparing the available technical solutions, the extensibility and upgradability of the system, the compatibility with other systems (of different manufactures and brands), the long-term availability of spare parts and operation security are important criteria, which influence this decision.

Interoperability amongst smart appliances – including those of various manufacturers – must be ensured. The smart appliance should be interoperable and communicate with/to other elements in the home such as the central energy manager, information display and smart phone.

In addition, it will be in the interest of the consumers that the operation of the system is manageable even without expert knowledge, ideally in the sense of a "plug and play"-solution, and this via an intuitively usable, integrated user interface. These system objectives require that the subsystems involved are syntactically and semantically interoperable, so the data is correctly exchanged, information and commands understood and correctly interpreted. The interchangeability of the subsystems requires the use of a technology neutral and standardised language, which is implemented through the relevant communication protocols.

In this section we assess the interoperability issues and gaps while in the next chapter we consider ways of reducing the gaps. We focus on the first link, i.e. from - and inside - the appliance itself to the first component of the DR control infrastructure.

[32] Energy box is a popular name for home energy management systems (HEMS). Note however that the energy manager is a logic function, not necessarily a physical device.

Figure 5 details the data transfers between the appliance, the communication architecture (home energy gateway or cloud service provider), the energy service provider and possibly the aggregator. The 2 upper parts of the illustration show the 2 basic communication models, the Home Energy Gateway model and the Cloud model, respectively. The bottom part of the illustration explains the 3 layers.

The information layer contains the same information content from the aggregator to the appliance. The communication layer contains the specific protocols transmitting the information. Each protocol has its own encoding of the information content. The component layer contains the hardware component varying for each part of the communication system.

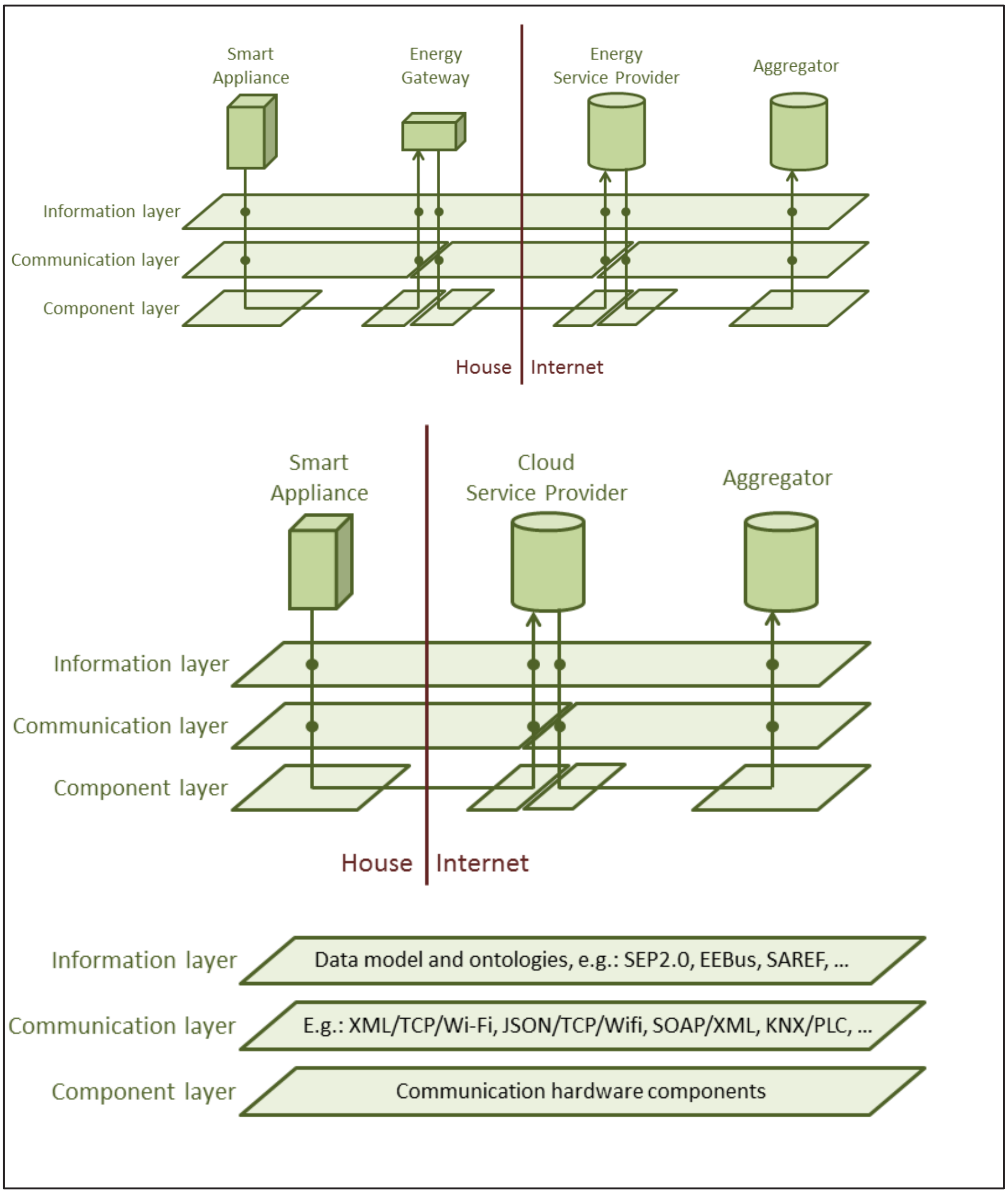

Figure 5: Data transfers between the appliance and the power system

Examples of information content include:

- unique identification of the appliance, which again is related to the consumer;
- control signals from the aggregator to the appliance. E.g., stop now, stop within xx [time period], do not start, reduce load to xx percent, stop if [condition], use own storage etc.;
- information signals from the aggregator to the appliance. E.g., price information;
- control/status related signals from the appliance to the aggregator. E.g., consumption information, state of the product, time to finish a cycle, expected response to DR requests or price signals, etc.;
- information signals from the appliance to the aggregator. E.g., data related to information required to reduce energy consumption or increase appliance energy efficiency, and intended to other purpose, e.g. safety / comfort / maintenance functionalities.

1.5.2. COMMUNICATION ARCHITECTURES

For the purpose of the study, an architecture is defined as the control and communication connection from the communication enabled appliance with demand side flexibility to a hub in the smart grid such as a central building management system, Home Energy Gateway, an aggregator or BRP / DSO (Distribution System Operators) / TSO (Transmission System Operators). The communication submitted could be price signals that the appliances react on and control signals for direct control of the appliances.

In this section we are not assessing the appliance-based system frequency control because it is based on internal measurements and control and does not need have a more extended communication architecture.

There are a large number of initiatives investigating smart grid architectures. Most of the architecture activities have a broader scope than the scope for this study, i.e., demand side flexibility. From the point of view of the appliance, there are two ways for appliances to interact with the energy system:

- The central energy manager model: The application communicates locally to a central energy manager (the Home Energy Gateway, or Building Control Unit[33]). In this case, the interoperability gap is situated at the level of the communication interface between appliance and central energy manager. Note that the smart meter could also take up this role, provided it supports sufficiently timely and reliable backend communications, which is often not yet the case for the current installed base. Also, adapted regulation would be required in many Member States.

- The cloud model: The appliance connects directly to an appliance manager in the cloud, often through the internet via a wireless modem or similar. This appliance manager then communicates in turn with the energy service provider. If the appliance manager is the manufacturer, then the interoperability problem is located on the level of the interface made available at the manufacturer’s backend to allow the energy service provider to control the appliance.

[33] A special example of this are Building Automation and Control Systems (BACS), which already today are used in larger/non-residential buildings to control and optimize the energy consumption of the building. Contrary to typical residential appliances, the communication and control functionality required for DR is already largely available. BACS can support DR through its control of the HVAC, heating, etc. systems in the building, while at the same time optimize the energy efficiency of the building as a whole.

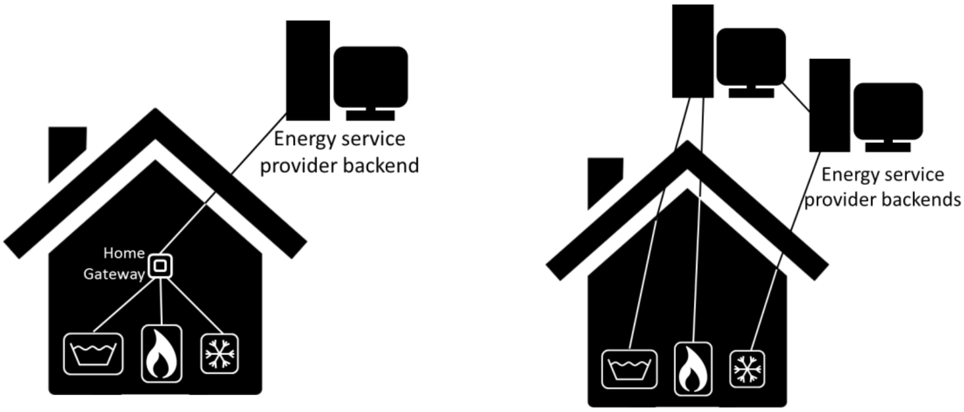

Figure 6: The two communication architectures: left the central energy manager model, right the cloud model.

Both models each have their pros and cons. The gateway model requires the installation of extra hardware. However, the cloud model requires that each smart appliance (and measurement component) guarantees all on-board functionality to establish a stable and secure extra-house communication link (authentication, encryption, handling dynamic IP addresses, handling firewalls, etc.). The gateway model implies interoperable interfaces on the devices, whereas the cloud model shifts this interoperability problem up to the level of the communication between the servers.

An important reason why the cloud model emerged, is that appliance manufacturers are no longer dependent on a gateway provider to integrate their device and that it allows them to provide device specific functionality.

This preparatory study focusses on the smart appliance and its demand side flexibility. What control architecture is more or less suited is out of scope of the study and is best left to the market to decide. However, from the point of view of the smart appliance, the principle is honoured that a as wide as possible range of control architectures should be supported. This includes, but is not limited to:

- **both the cloud model or central energy model;**
- **the option that the central manager could be a BACS that controls the smart appliances, both for DR and energy efficiency;**
- **the option that the central manager could be the smart meter.**

We describe in the following a selection of the most relevant architecture activities.

<u>Common ontology for M2M</u>

The European Commission/DG Connect is collaborating with ETSI (European Telecommunications Standards Institute) on developing an ETSI M2M (Machine to Machine) architecture. A dedicated Technical Committee will develop standards for "Machine to Machine" Communications, ETSI M2M. The group will provide an end-to-end view of Machine to Machine standardisation. More information on this initiative can be found in section 1.5.5.

Besides this initiative, DG Connect has also launched a study carried out by TNO (the Netherlands) "Available semantics assets for the interoperability of smart appliances. Mapping into a common ontology as a M2M application layer semantics". The study aims to provide the material needed to define the semantic tools and unified data models for specific devices to be used in the ETSI M2M architecture. The tools and data models can subsequently be applied by the industry to produce ETSI M2M compliant devices, or interoperability boxes to make existing, non-ETSI-M2M devices interoperable with an ETSI M2M system, while ensuring the fulfilment of user's expectations in terms of performances. The tasks consist of taking stock of existing semantic assets and use case assets, performing a translation exercise of each model or use case to a common ontology language (called SAREF, Smart Appliances REFerence) and subsequently a mapping between these models and finally to propose a common ontology and document it into ETSI SmartM2M/oneM2M architecture. As a common ontology language, SAREF can be adapted for multiple standards and protocols to facilitate interoperability.

The architecture defines various classes being e.g. building objects (door, window), devices (door switch, energy meter, sensor etc.), function (level control function, start stop function etc.), time (day of week) etc.

The ontology specifies recurring core concepts in the smart appliances domain as given by the assets, the main relationships between these concepts, and axioms to constrain the usage of these concepts and relationships. SAREF is based on the fundamental principles of reuse and alignment of concepts and relationships that are defined in existing assets, modularity to allow separation and recombination of different parts of the ontology depending on specific needs, extensibility to allow further growth of the ontology, and maintainability to facilitate the process of identifying and correcting defects, accommodate new requirements, and cope with changes in (parts of) the SAREF ontology. The project has found that there is a good correlation between the ETSI M2M Architecture and SAREF's function-related device categories.

This ontology work is broader than the scope of this study being appliances comprised by the ecodesign and energy labelling regulation, while the ontology also includes sensors, actuators etc.

The final report of the study can be found at https://sites.google.com/site/smartappliancesproject/deliverables.

A first version of Smart Appliances Reference ontology can be accessed here: http://ontology.tno.nl/saref/.

Common language for smart home

AGORA, Energy@Home and EEBus has recently agreed (published November 2014) to establish a common language for the European Smart Home. The organisations have developed a list of key functionalities based on agreed use case scenarios serving as a common base. They have agreed in the context of cooperation to provide extensible functionality in order to adapt the system to future technical developments. These key functions were initially focused on energy management, and to add more specific functionalities of smart homes.

According to the initiatives interoperability will be ensured through an open and standard communication protocol that is technology neutral.

Their goal is to reach a simple plug and play solution, which enables consumers across Europe to connect their devices.

Communication architecture gaps
A main interoperability gap is lack of one data model and communication architecture standard applicable in all Member States for the appliances in scope of this study. The standards should be able to work on top of the various possible hardware carriers, and should carry commonly defined status and command data, such that all possible use cases are supported, e.g. variable tariffs, balancing reserves, grid support, etc.
Many initiatives have been launched within this area with the purpose to define one common data model and reference communication architecture.

1.5.3. COMMUNICATION CARRIERS

The communication carriers from the end-user (home, office etc.) are mainly the internet. The connection can be through broadband (ADSL (Asymmetric Digital Subscriber Line), VDSL (Very-high-bitrate Digital Subscriber Line), DOCSIS (Data Over Cable Service Interface Specification]etc.), GSM (Global System for Mobile Communications), UMTS (Universal Mobile Telecommunications System), LTE (3GPP Long Term Evolution (4G)) etc.

The level of internet access in households in EU28 in 2014 is in average 81%[34]. The range is from 57 % (Bulgaria) to 96 % (Luxembourg and the Netherlands). There are thus Member States where lack of internet access might be a barrier towards full use of the DR enabled appliances.

Within the end-users' premises, the communication carriers are more diversified. The communication between smart appliance and Energy or Internet gateway (in the case of the cloud model), include wired Ethernet, WiFi, Bluetooth, Zigbee, Z-Wave etc. Which carrier is reliable or not depends on the layout of the home, the building style, the location of the smart appliances and energy/internet gateway and the energy consumption. There are already a broad range of products using the above mentioned communication carriers.

Wide adaptation of smart appliances requires that the user (or installer) should be able to use the most/a reliable carrier, based on the criteria mentioned before. Moreover, the communication carriers should support the communication signals transferred.

However, lack of internet access should not be a main gap and further development to support the communication signals should neither be a gap once the common communication architectures have been developed.

1.5.4. SMART METERS

Smart meters are being rolled out in many EU Member States, however, in different speeds and with different functionalities. Smart meters are assumed to continue to be important for the main metering and payment of the energy delivered, and can support the transmission of DR relevant information like for instance consumption/generation limits between the demand and supply side. However, they are not always equipped with the full set of necessary functionalities to play the role of central energy manager, i.e., as live two-ways connection between the supply side and the demand side.
Smart meters are included in the study specifically and only with respect to their energy consumption as part of the overall communication infrastructure.

[34] Eurostat figures on "Level of internet access – households"

1.5.5. STANDARDS (EU, MEMBER STATE AND THIRD COUNTRY LEVEL)

This section presents standards related to smart appliances. The scope of standardisation in the field of smart appliances is strongly related to information exchange for DR and for connecting demand-side consumer equipment and/or systems into the smart grid.

1.5.5.1. Introduction

In the context of the smart home and smart appliances cross-platform interoperability is an essential requirement to guarantee flexibility and security of investment for the customer. An end-customer, who is faced with the choice in case of a smart home set up, is initially motivated by its intended application goals, such as increasing the living comfort or the saving of energy. When comparing the available technical solutions, the extensibility of the system, the compatibility with other systems (of different manufactures and brands), the long-term availability of spare parts and operation security are important criteria, which influence this decision. In addition, it will be in the interest of the consumers that the operation of the system is manageable even without expert knowledge, ideally in the sense of a "plug and play"-solution, and this via an intuitively usable, integrated user interface. These system objectives require that the subsystems involved are syntactically and semantically interoperable, so the data is correctly exchanged, information and commands understood and correctly interpreted. The interchangeability of the subsystems requires the use of a technology neutral and standardised language.

In this context standardisation (CEN-CENELEC-ETSI) is proposing an architecture (Figure 7) where a Customer (Energy) Management function[35] processes and acts upon (DR related) information from the smart grid, smart meter information and information from one or more smart appliances. To handle different communication languages and different information models, all specific information models are translated into a common and neutral information model accessible via an neutral interface.

[35] Note that this CEMS function doesn't necessary need to be located at the customers' premises. It could be part of a backend or cloud system (as many commercial products are heading this way). However, keeping requirements upon data privacy in mind, locating this function at the customers' premises could be a recommendation made in the context of privacy by design. It can also be located in the smart appliance when it is managing just one appliance.

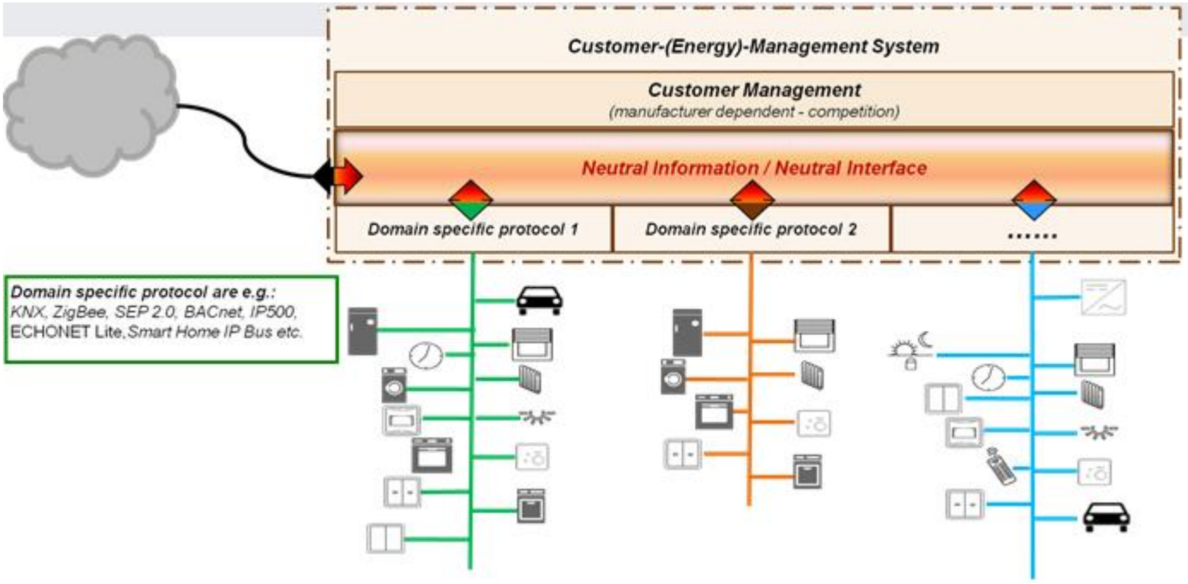

Figure 7: Neutral interface concept[36]

This means that for each domain-specific protocol a translator function (to the neutral information model) has to be implemented. To limit the number of domain specific protocol translators in the gateway manufacturers of smart appliances could integrate this translation step into the smart device (Figure 8).

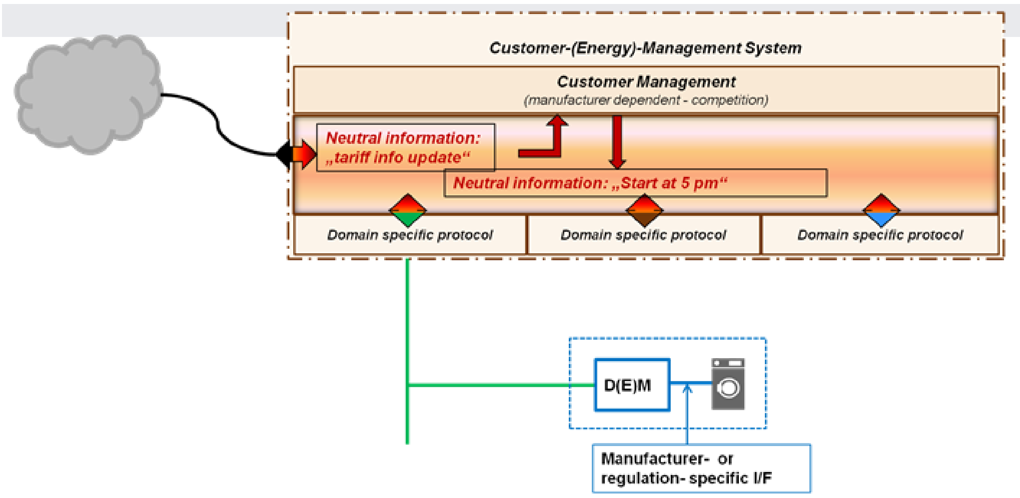

Figure 8: Device with Energy Management function[36]

In this approach all interface signals, functions and mappings are specified in open standards and thus available for all. On the basis of these standards manufacturers can realise their own standards-compliant software platforms.

[36] Josef Baumeister, IEC & CLC Smart Home Standardization – status September 2014

1.5.5.2. Status of Standardisation (EU)

In this section the current most relevant standardisation activities related to smart appliances are described, focusing on activities at EU level (and interaction with international level). Using the flexibility functional architecture as a starting point the standardisation activities related, the CEM - smart meter interface and the Smart Grid - CEM - smart appliance interface are briefly explained.

1.5.5.3. Flexibility functional architecture

On 1 March 2011 the European Commission issued Mandate 490 - Standardisation Mandate[37] to European Standardisation Organisations (ESOs) to support European Smart Grid deployment. To accomplish this task, CEN-CENELEC-ETSI established the Smart Grid Coordination Group (SG-CG), now succeeded by the Smart Energy Grid Coordination Group (SEG-CG) to coordinate standardisation activities in Smart Energy (e.g. electricity, heat, gas) Grid(s). SEG-CG includes interactions between energy systems and interaction with end-users.

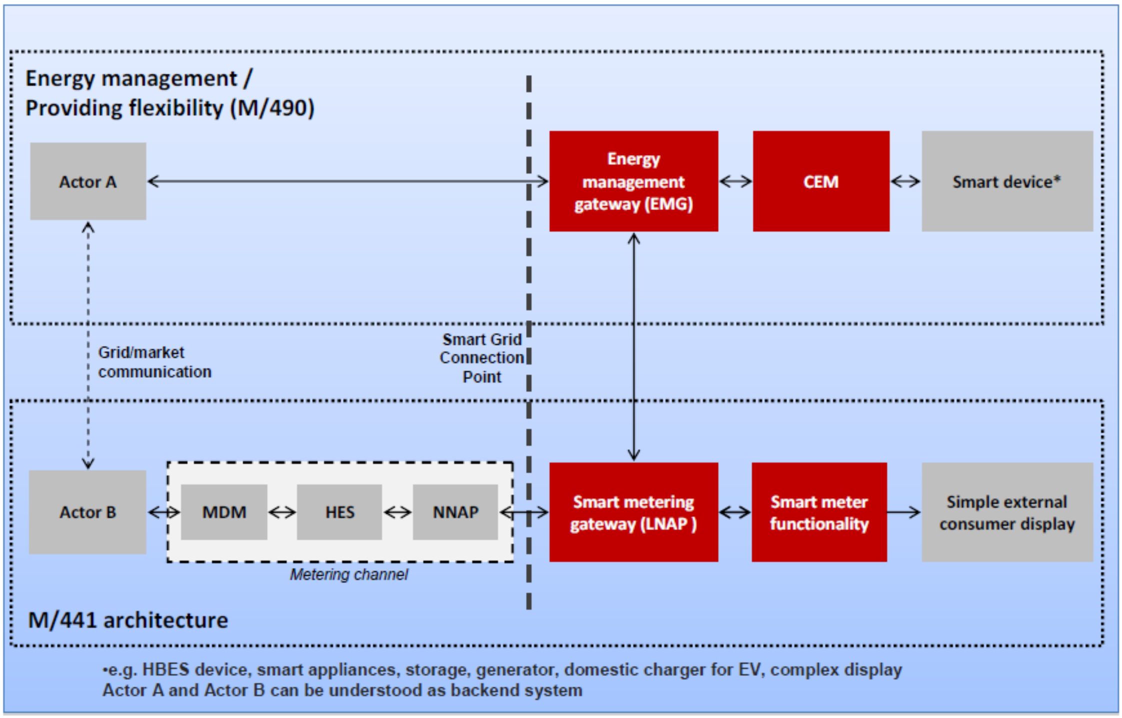

Figure 9: Flexibility functional architecture[38]

The flexibility functional architecture model in Figure 9 has been developed by the SG-CG. In this architecture the Customer Energy Manager (CEM) provides the flexibility of connected smart devices, through the energy management gateway, while the smart meter and the simple external consumer display provide a number of functionalities that are described more detailed in work of the Smart Meters Coordination Group (SM-CG). The energy management gateway communicates with the metering channel and the smart metering through the Smart Metering Gateway. The gateways in this architecture split different networks (Wide Area Network, Neighbourhood Area Network and Local Area Network) and may be integrated with other functional entities. The actors

[37] http://ec.europa.eu/energy/gas_electricity/smartgrids/doc/2011_03_01_mandate_m490_en.pdf
[38] ftp://ftp.cencenelec.eu/EN/EuropeanStandardization/HotTopics/SmartGrids/SGCG_Methodology_FlexibilityManagement.pdf

in this architecture are functional / logical entities, which means that some of them may be part of the same physical device.

Note that the communication path between the smart metering gateway and energy management gateway is optional (as are all communication pathways in this architecture). In the aforementioned case, the information exchange between the metering channel and energy management channel will take place between Actor A and Actor B. The external actors A and B, identified in this functional architecture represent (a bundle of) roles that communicate through the Smart Grid Connection Point. Examples of these roles are a meter data collector, meter operator, aggregator/flexibility operator, supplier etc.

1.5.5.4. Smart meter interface

The following Figure gives an overview of the standardisation activities related to the smart meter interface, mapped onto the flexibility functional architecture.

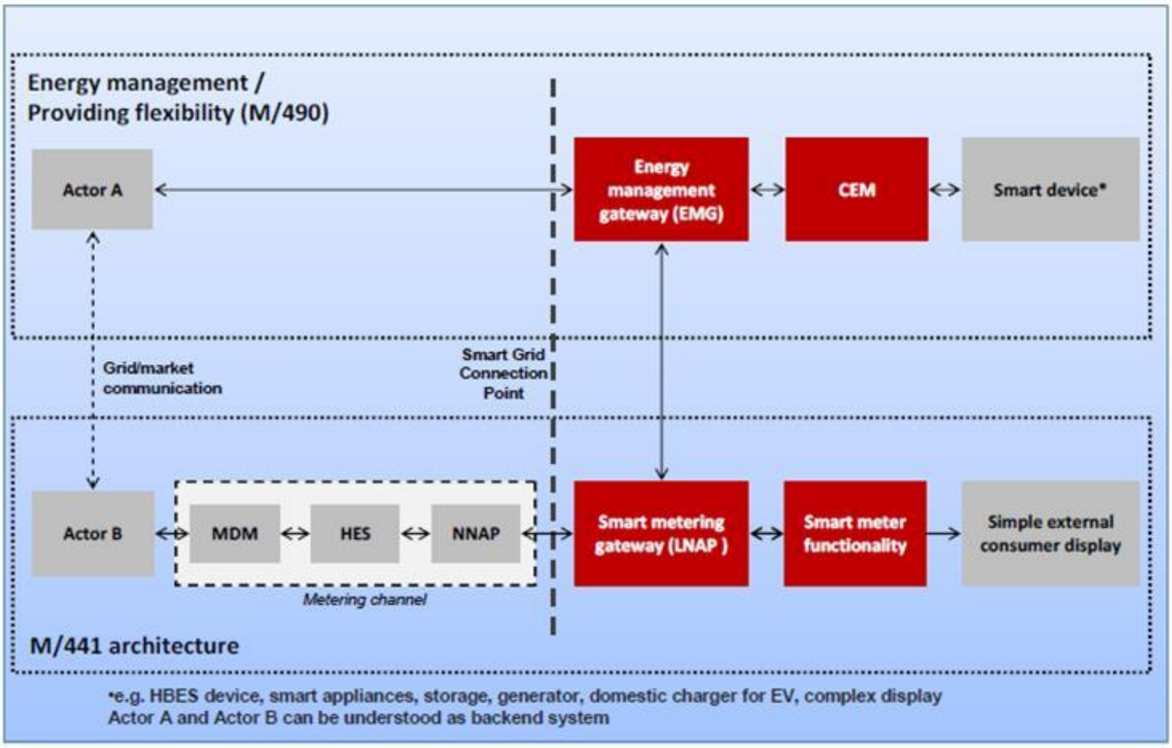

Figure 10: Standardisation activities mapped onto flexibility functional architecture[39]

The interfaces in this architecture **(**Figure 10) relevant for the interaction between the metering end device and end consumer devices are:

- interface H1 for a local connection to a simple external consumer display.
- Interfaces H2 and H3 for interaction with home automation end devices (including more advanced displays). These interfaces support the provision of energy efficiency and demand-side management services.

[39] ftp://ftp.cencenelec.eu/EN/EuropeanStandardization/HotTopics/SmartGrids/Reference_Architecture_final.pdf

Within the SG-CG, a dedicated Task Force looked at the ‘possible need for further standardisation work order to include in the AMI an open interface to provide energy management services beyond the utilities, focusing on consumers’ needs’. In this context, the Task Force performed a technical analysis which focused on the following aspects:

- interfaces 'H2' and 'H3' and the blocks 'EMG', 'CEM', 'LNAP', and 'Smart meter functionality'
- consider functionalities (a) and (b) of the Recommendation 2012/148/EU, and investigate how these are involved in the flexibility architecture.

These aspects are currently covered by the activities of IEC/TC 13 ‘Electrical energy measurement and control’, CEN/TC294 ‘Communication systems for meters and remote reading of meters’, CLC/TC 205 ‘Home and Building Electronic Systems (HBES)’ and IEC/TC 57 ‘Power systems management and associated information exchange’.
According to the Task Force, there is no need for additional standardisation initiatives (e.g. further standardisation mandate) in order to include in the AMI an open interface to provide energy management services beyond the utilities, focusing on consumers' needs (further development is happening in the work of IEC/TC 57 WG 21).

a. IEC/CLC/TC 13 “Electrical energy measurement and control” WG14 (Electricity Metering data exchange)
Working Group 14 of IEC/TC 13 has developed the standards for the exchange of information through the AMI from the Head End System (HES) to the meter: IEC 62056 series. In the first place, these standards are able to transfer consumption information that is registered in the electricity meter. Additional information related to DR that can be transferred concerns for example tariff information, power limitation, connect/disconnect and prepayment settings. Standards developed by IEC/TC 13 are voted in parallel at European level (CLC/TC 13). Working Group 14 has recently developed a new international standard for the (uni-directional) provision of metering data from a meter to an external device, such as an In Home Display: IEC 62056-7-5. This relates to the H1/H2 interface. The status of this standard is currently CDV (Committee Draft for Vote), which implies it should normally be available in 2015.

b. CEN/TC 294 “Communication systems for meters and remote reading of meters”
The work performed in this TC is similar to the work in IEC/CLC/TC 13, but is focussed on the exchange of information to non-electricity (Gas/Water/Heat and beyond) meters and other supporting equipment: EN 13757 series. Standards related to consumption and DR related information transfer are available or under finalisation.

c. CLC/TC 205 Home and Building Electronic Systems WG 18 (Smart Grids) and WG 16 (Display)
CLC/TC 205 current work is centred on two aspects for home & building electronic systems: firstly home displays and the H1 interface in the smart meter reference architecture (prEN 50491-11) and secondly the interface and framework for customers (prEN 50491-12), which concerns the H2/H3 interface. The work of TC 205 envisages the need for sufficiently frequent information updates for the customer depending on the demand . It also anticipates advanced tariff structures, time-of-use registers and remote tariff control, with automatic transfer of information about advanced tariff options to final customers via the interfaces H2/H3. The standards developed by TC205 concerns the definition of data models that can be used on top of the communication profiles identified by IEC/TC 13 and CEN/TC 294. IEC TC13 requested that the data models proposed by CLC/TC 205 are linked to the existing data models of the IEC 62056 series.

The status of the work is as follows:

- prEN 50491-11 is the responsibility of TC 205 WG16. This work item has been completed and the standard EN 50491-11:2015 is published in June 2015.
- prEN 50491-12 is the responsibility of TC 205 WG 18. It is focused on data modelling and is expected to be available mid-2015, beginning of 2016.

1.5.5.5. Smart grid – smart appliance interface

The following Figure provides a situational overview of some relevant standardisation documents related to Smart Appliances and Smart Home interoperability[40]:

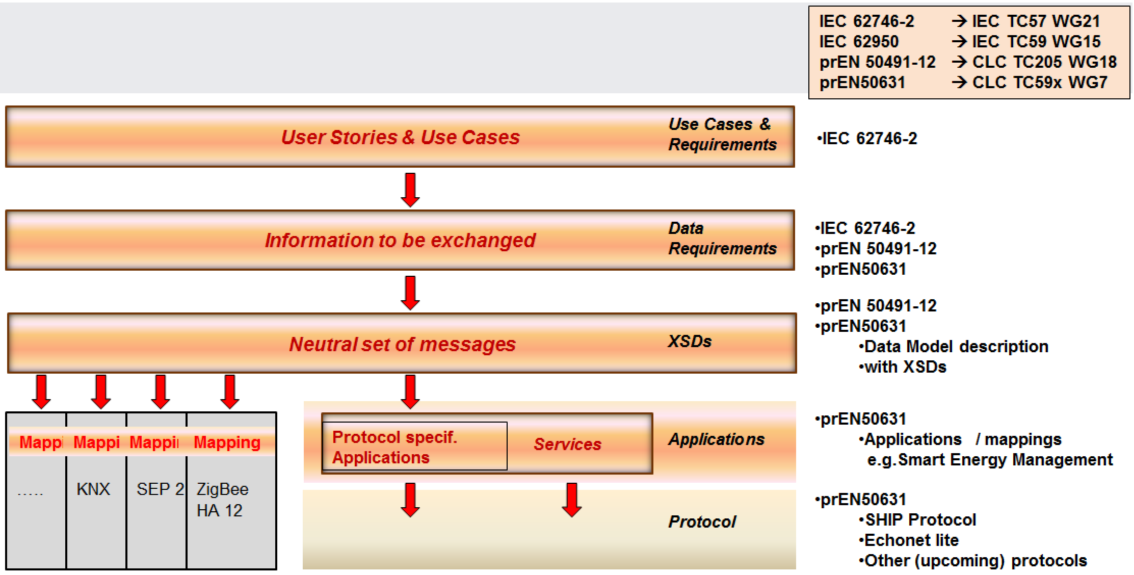

Figure 11: Selection of relevant documents related to Smart Appliances & Smart Home interoperability

a. IEC/TC 57 WG21 "Interfaces and protocol profiles relevant to systems connected to the electrical grid"

IEC/TC 57 addresses the market aspect as well as the grid operation. WG21 of IEC/TC 57 is focusing on the functionalities (Use Cases) and data definitions for DR in its Technical Report IEC TR 62746. These functionalities and data definitions are used by CLC/TC 205 to have a reference for the data and transactions to be supported.

A joint working group of IEC/TC 57 WG21, CLC/TC 205 and CLC/TC 59X has been collecting Use Cases and requirements for Smart Grid/Smart Home. The Use Cases cover for example: providing energy consumption information, controlling smart appliances, EV charging, power limitation, consumer offering flexibility, manage DER, battery management, etc. These Use Cases and requirements are listed in IEC TR 62746-2. The architecture document IEC 62746-3 is currently distributed as Committee Draft to the national committees.

In order to solve the interoperability issue, TC 57 and PC 118 'smart grid user interface' have agreed to continue the development of IEC 62746 towards a CIM-compatible DR standard, by first defining an openADR <-> CIM adaptor, followed by a purely CIM-based version of OpenADR. WG21

[40] Communication from Josef Baumeister, IEC & CLC Smart Home Standardization

is managing the connections with WG16 (energy market information exchange), WG 15 (Cyber Security) and WG17 (DER) of IEC/TC 57. In parallel with the work on functionalities, new work will commence to consider the technologies that should be supported to transfer the data.

b. IEC/TC59 "Performance of household and similar electrical appliances" WG15 "Connection of household appliances to smart grids and appliances interaction"

IEC/TC 59 WG15 is establishing a set of common terms, concepts and criteria, to assist the TC 59 and its Subcommittees in addressing the technical aspects of interaction between household appliances and the smart grid.

IEC/TS 62950 'Household and similar electrical appliances - Specifying and testing smart capabilities of smart appliances - General aspects' (work version) is intended to develop the common architecture which applies widely to different use cases and appliance types, and the principles of measuring smart performance within the context of the common architecture. The use cases considered initially (see previous paragraph) are based on the energy/electricity aspects pf performance, but future revision of this Technical Specification may not be limited to these aspects.

c. CLC/TC59x "Performance of household and similar electrical appliances" WG7 "Smart household appliances"

CLC/TC59x WG7 performs standardisation work to enable domestic appliances to improve functionality through the use of network communication. Examples of network communication include smart grid, smart home and home network. The working group is working on prEN 50631 "Home network and smart grid connectivity ", a first readable draft version is expected soon.

d. ETSI M2M

The European Telecommunications Standards Institute (ETSI) has created a dedicated Technical Committee with the mission to develop standards for "Machine to Machine" Communications, ETSI M2M[41]. The group will provide an end-to-end view of Machine to Machine standardisation. Besides standards at the architecture level, ETSI also works on test specifications to demonstrate end-to-end interoperability.

In ETSI, smart appliances standards are being handled by the **SmartM2M technical committee** and by the **oneM2M** partnership project. In 2013, much of the work of ETSI's M2M committee, including the development of the core M2M specifications, was transferred to the new oneM2M Partnership Project. The committee's new focus is now services and applications, especially aspects of the Internet-of-Things and smart cities, and it has adopted a new name, the Smart Machine-to-Machine Communications Technical Committee (TC SmartM2M), to reflect this new work. TC SmartM2M will also support relevant European policy and regulatory requirements, and handle the conversion of oneM2M specifications into European Standards.

In 2013 collaboration was initiated with the EC specifically related to the interface between service and application layers. ETSI began work on smart appliances – products such as white goods, heating, ventilation and air conditioning (HVAC) systems, storage systems and micro renewables, which are able to communicate with facility management systems, energy management systems, so-called 'Energy Boxes[42]' and other systems using a common language and semantic. In November 2013, TC SmartM2M began to plan its activities for 2014 to support the creation of a standard for

[41] http://www.etsi.org/technologies-clusters/technologies/m2m

[42] Energy box is a popular name for home energy management systems (HEMS). Note however that the energy manager is a logic function, not necessarily a physical device.

smart appliance communication. The plan was expected to include a common data model (see also next chapter on the common ontology for M2M) and identification of a communication architecture and the related protocols. A clear roadmap and milestones were introduced by TC SmartM2M and the first ETSI specifications are planned to be published during 2015.

The planned specifications regarding smart appliances are:

- **TS 103 264** “SmartM2M Smart Appliances Common Ontology and SmartM2M/oneM2M mapping”;
- **TS 103 267** “SmartM2M Smart Appliances Application of ETSI M2M Communication Framework”;
- **TS 103 268** “Conformance testing”.

TS 103 264 has two major objectives:

- To provide a standardised framework for the common ontology derived from the EC Study Group on Smart Appliances[43];
- To map the common ontology onto the elementary ETSI M2M and possibly oneM2M standardised resources and services.

TS 103 267 defines a framework for Smart Appliances communication based on ETSI M2M and (potentially) oneM2M specifications. It will also provide the proper configuration support and adjustments as required by the interested stakeholders.
This TS includes:

- a general description of the ETSI M2M/oneM2M framework;
- the specification of the interworking framework for Smart Appliances with normative reference to ETSI M2M and oneM2M specifications;
- the specification of all the required configurations and settings to assure a full interworking with plug and play support for Smart Appliances.

In this context the study "Available semantics assets for the interoperability of smart appliances. Mapping into a common ontology as a M2M application layer semantics"[43] aims to provide the material needed to define the semantic tools and unified data models for specific devices to be used in the ETSI M2M architecture. The tools and data models can subsequently be applied by the industry to produce ETSI M2M compliant devices, or interoperability boxes to make existing, non-ETSI-M2M devices interwork with an ETSI M2M system. Ideally, the achieved interoperability would comply with the highest levels as defined by e.g. CENELEC[44], but it all depends on the dimension of the protocol interfaces, and how well the implemented data models translate into the unified ones.

e. ISO/IEC JTC 1/SC 25/WG 1 - HES

JTC stands for the Joint Technical Committee of International Standardisation Organisation and International Electro-Technical Commission. The Home Electronic System (HES)[45] is a family of international standards for home systems under development by experts from Asia, Europe, and North America. The experts are organised into a formal Working Group1 that writes the standards and submits them for approval by the member nations.

[43] http://www.etsi.org/images/files/Events/2014/201405_DGconnect_SmartM2MAppliances/Extended_Summary_Smart_Appliances_EU_study_2013-0077.pdf;
http://sites.google.com/site/smartappliancesproject
[44] CENELEC CWA50560:2010 IFRS (Interoperability Framework Requirement Specification)
[45] http://hes-standards.org/

A primary goal of HES is to specify hardware and software that enable a manufacturer to offer one version of a product for connection to a variety of home automation networks. To accomplish this, the Working Group has published an architecture that specifies the following components for HES:

- Universal Interface: An interface module to be incorporated into an appliance for communicating over a variety of home automation networks.
- HomeGate: A residential gateway to link home control networks with external service provider networks.
- Application Interoperability methods and models

ISO/IEC 15067-3:2012 specifies an energy management model for programmes that manage the consumer demand for electricity using a method known as "DR". Three types of DR are specified in this standard: direct control, local control and distributed control.

1.5.5.6. Standards USA

NIST / ANSI

The National Institute of Standards and Technology (NIST) has been given "primary responsibility[46] to coordinate development of a framework that includes protocols and model standards for information management to achieve interoperability[47] of smart grid devices and systems." In response to the urgent need to establish interoperability standards and protocols for the smart grid, NIST developed a three-phase plan:

1) To accelerate the identification and consensus on smart grid standards
2) To establish a robust Smart Grid Interoperability Panel (SGIP) that sustains the development of the many additional standards that will be needed
3) To create a conformity testing and certification infrastructure

As information technologies expand on the electric grid (and to other cyberphysical systems, such as those dealing with natural gas and water), cybersecurity becomes a critical priority. NIST plays a central role in working with industry to develop appropriate guidance for protecting these systems from cyber attacks.

The progress made up till 2014 is documented in the "NIST Framework and Roadmap for Smart Grid Interoperability Standards", release 1[48] (2010), release 2[49] (2012) and release 3[50] (draft, 2014).

In 2009 the Smart Grid Interoperability Panel (SGIP) was established for the further development of consensus-based smart grid interoperability standards. In 2013, the SGIP transitioned to an industry-led incorporated non-profit organisation, sometimes referred to as SGIP 2.0.
As of October 2013, SGIP 2.0 had over 200 members, and 56 standards accepted into the SGIP Catalog of Standards (CoS).

Similar to the work on the new item IEC 62746 "System interfaces and communication protocol profiles relevant for systems connected to the smart grid" by the working group IEC TC 57 WG21

[46] "The Energy Independence and Security Act of 2007" (Public Law 110-140, or EISA)
[47] "Interoperability" refers to the capability of two or more networks, systems, devices, applications, or components to exchange and readily use information—securely, effectively, and with little or no inconvenience to the user.
[48] http://www.nist.gov/public_affairs/releases/upload/smartgrid_interoperability_final.pdf
[49] http://www.nist.gov/smartgrid/upload/NIST_Framework_Release_2-0_corr.pdf
[50] http://www.nist.gov/smartgrid/upload/Draft-NIST-SG-Framework-3.pdf

SGIP started up a priority action plan (PAP) investigating three industrial initiatives: OpenADR 2.0, ZigBee Smart Energy Profile 2.0 and OASIS Energy Interoperation (EI 1.0).

ASHRAE/NEMA SPC201P Facility Smart Grid Information Model (FSGIM)[51]

In US the National Electrical Manufacturers Association (NEMA) and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) have joined forces to develop an industry standard called Facility Smart Grid Information Model (FSGIM), an abstract, object-oriented information model for energy management purposes, providing a generic view on controllable devices.

ASHRAE is accredited by the American National Standards Institute (ANSI) and follows ANSI's requirements for due process and standards development. The standard, being developed by ASHRAE Standard Project Committee 201P (SPC 201P) is also part of the work programme of ISO/TC 205.

The purpose of this standard is to define a model to enable appliances and control systems in homes, buildings, and industrial facilities to manage electrical loads and generation sources in response to communication with a “smart” electrical grid and to communicate information about those electrical loads to utilities and other electrical service providers. It has been particularly drafted for DR purposes, and can be mapped to different Home Automation protocols. Object models from various standards have been reused (CIM, Energy Interop, IEC 61850, etc.). The FSGIM, being a North American initiative, may be less relevant for Europe, but indirectly it may have an impact. The ASHRAE BACnet standard for instance, a building automation standard commonly used in Europe and connection point for DR, is an example of a target protocol standard that will make use of FSGIM.

1.5.5.7. Standards Australia

Australian/New Zealand national standard AS/NZS 4755 “DR capabilities and supporting technologies for electrical products” is a standard for communicating DR commands to residential appliances (airco, water heaters, pool pumps, EV, etc.). Communications end at DR Enabling Device (DRED) external to the appliance. The standard allows communication of basic commands such as turn on, shut off, reduce load, increase load. This standard is currently supported by several Air Conditioning manufacturers. Messages can be communicated across any network, including AMI.

The parts of AS/NZS 4755 published since 2007 cover the physical and electrical connections between the DRED and the following electrical products:

- AS/NZS 4755.1 : Part 1 - Framework for DR capabilities and requirements for DR enabling devices (DREDs)
- AS/NZS 4755.3.1 : Part 3.1 - Interaction of DR enabling devices and electrical products—Operational instructions and connections for airconditioners. This standard describes how manufacturers of air conditioners below 30 kW must adapt their units to enable their controls from the DRED (Communications end at DR Enabling Device). Units must be equipped with standardised connections enabling the activation of different operating modes described in the figure below: compressor off, 50 % of rated power input and 75 % of rated power input.
- AS/NZS 475 5.3.2: Part 3.2 - Interaction of DR enabling devices and electrical products - Operational instructions and connections for devices controlling swimming pool pump-units

[51] https://osr.ashrae.org/Public%20Review%20Draft%20Standards%20Lib/ASHRAE%20201%20APR%20Draft.pdf

- AS/NZS 4755.3.3: Part 3.3 - Interaction of DR enabling devices and electrical products - Operational instructions and connections for electric storage and electric-boosted storage water heaters
- AS/NZS 4755.3.4: Part 3.4 - Interaction of DR enabling devices and electrical products - Operational instructions and connections for grid connected charge/discharge controllers for electric vehicles
- AS/NZS 4755.3.4: Part 3.5 - Interaction of DR enabling devices and electrical products - Operational instructions and connections for grid-connected Electrical Energy Storage Systems

Standards for the DRED (AS/NZS 4755.1), for electric vehicle supply equipment intended for home use (4755.3.4) and stationary storage batteries (4755.3.5) are currently in preparation.

Australian governments[52] (Commonwealth, state and territory) are considering making compliance with the standard mandatory for all air conditioners, water heaters, pool pump controllers and electric vehicle supply equipment (EVSE) designed for residential use, from a date to be determined (probably January 2016). All of these appliances will therefore have to be sold with a built-in standardised interface, which will allow them to connect to a communications system and participate in DR schemes. The economic case for this policy initiative was published in early 2013 and the proposal is still being considered within the Government. Although it would be mandatory for all products sold to have an AS/NZS 4755 interface, it would not be compulsory for consumers to have it activated. It would be up to the electricity utilities to offer consumers DR contracts that are sufficiently attractive.

1.5.5.8. Standards Japan

Regarding smart grid standardisation, Japan is involved in following technical committees and workgroups:

- At International Level (IEC):
  - TC57 WG16, WG21
  - TC59 WG15
  - TC65 WG17
  - PC118

- Via the joint working group (JWG) in:
  - TC57 WG21,
  - CLC TC205 WG18
  - CLC TC59X WG7

- At regional level
  - The Japan Smart Community Alliance (JSCA)[53]
  - OpenADR

[52] Australian government policy on demand responsive ('smart') appliances
[53] https://www.smart-japan.org/english/index.html

In case of DR there are some differences in the viewpoints of Japan and Europe:

- In Japan the focus is on “Grid Request power reduction” scenario whereas SG-CG definition (in SG-CG/M490/L Flexibility Management) of DR seems to be a “Customer Decide” scenario.
- The Japanese User Stories/Use Cases mainly focus on “Plan Based” scenario whereas SG-CG definition of DR seems to be “Near Real time Based” scenario.
- The SG-CG scenarios (Customer Decide & near Real Time based) are intended for future advanced grids whereas Japanese User Stories/Use Cases (Grid Request & Plan based) are based upon conventional grids.

The recommendation made by Japan is that both viewpoints should be covered by the International Standards.

The **Japan Smart Community Alliance** (JSCA) (Figure 12) was established in April 2010 with the aim of resolving and overcoming the obstacles of individual organisations through collaboration of the public and private sectors. JSCA has a wide range of members from various private enterprises and organisations, including public service corporations, universities and local municipalities. In the context of smart home/smart appliances the JSCA Smart House and Building workgroup undertakes activities toward further dissemination of smart houses and smart buildings.

Figure 12: JSCA organisational structure

The ECHONET Consortium[54], formed in 1997 in Japan, promotes the development of software and hardware for home networks that can be used for remote control or monitoring of home appliances. The aim in doing so has been to reduce CO_2 emissions while responding to the increasing sophistication of home security and home healthcare.

The Consortium developed 2 sets of specifications as well as the basic technology for these ECHONET specifications. The original ECHONET specification focused on power line and radio frequency communication to provide a low-cost data transmission implementation without requiring additional wiring. The specification is published as ISO/IEC 14543-4-1 and ISO/IEC 14543-4-2. The consortium continued to developed the home network technologies on home appliances and home facility equipment, and published the “ECHONET Lite Specification” as an open standard interface on HEMS in 2011. Compared to ECHONET, is ECHONET Lite easier to use and able to work on top of other standard protocols. Echonet Lite is an upper layer (application layer) protocol to control home appliances. All smart meters in Japan for instance support ECHONET Lite over IP over the local meter interface. The ECHONET Lite Specification was approved as an international standard (ISO/IEC 14543-4-3), in 2013.

[54] http://www.echonet.gr.jp/english/index.htm

1.5.5.9. Standards China

China established a national SC (TC46/SC15) for smart household appliances and involved leading manufacturers in development.
Two standards on Smart Household Appliances have been published so far:

- GB/T 28219-2011 General rules of intelligentisation technology for intelligent household appliances
- QB/T 2836-2006 General requirements for networked home appliances

Ten national smart household appliances standards are in development and targeting for approval in 2015. Of these 10 national standards 7 are in NP stage:

- Smart household appliance service platform requirement
- Automatic identification and interoperation
- Making the smart household appliance intelligent: test method and evaluation criteria
- special requirement of smart air conditioner
- special requirement of smart refrigerator
- special requirement of smart washing machine
- special requirement of smart wine cabinet

The white paper "Smart Household Appliances White Paper" has been published in June 2014. China is following a somehow different approach looking more on 'intelligence' than on DR.

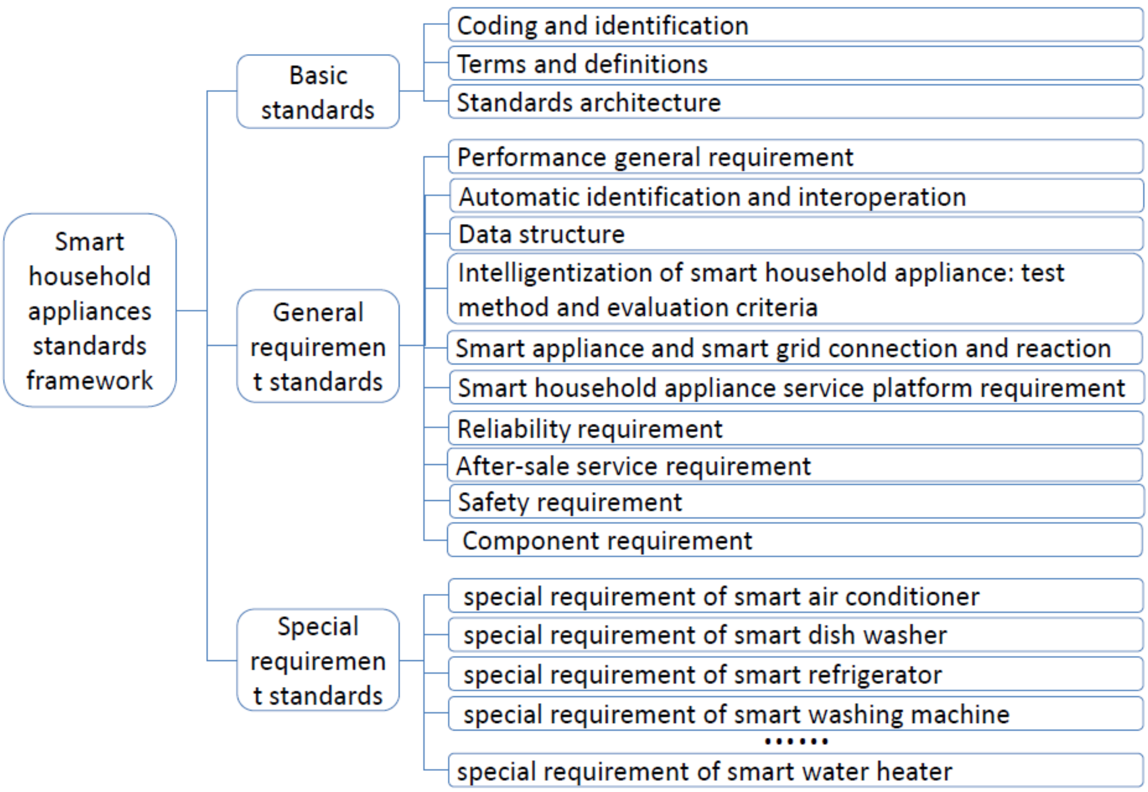

Figure 13: Standards Framework of China TC46/SC15

1.5.5.10. Research & industry initiatives

Considering the large number of initiatives by industry and research that can be noticed in the field of smart appliances, Internet Of Things (IoT), and DR this section will provide a condensed summary of this trend. A more elaborated version can be found in Annex 2.

The Internet of Things (IoT) is the interconnection of uniquely identifiable embedded computing devices within the existing Internet infrastructure. Typically, IoT is expected to offer advanced connectivity of devices, systems, and services that goes beyond machine-to-machine communications (M2M) and covers a variety of protocols, domains, and applications. Smart appliances can be regarded as a subset of these machines, and in the context of this study the focus for these appliances will be on energy management and energy efficiency.

Dozens of consortiums, commercial alliances, and standards groups have been formed in the past few years to address the question of interoperability amongst these devices and systems.

As the AllSeen Alliance outlines, creating common standards for “interoperable products that can discover, connect, and interact directly with other nearby devices, systems, and services regardless of transport layer, device type, platform, operating system, or brand.” will have a tremendous impact on the growth, acceptance and functionality of the IoT. To accomplish this the global technology industry would have to agree on a universal set of technical standards. The important question here is whose standards, as this will give the initiator a head start and significant advantage.

Along the “interoperability” specifications these alliances produce, they generally offer a (open source) software reference framework, and sometimes also a certification process. The goal of these software frameworks is to provide solutions for service discovery, interoperability, security and device management, and to facilitate the work of developers. By doing so, these developers can concentrate on the creation of innovative services without having to be hindered by the complexity of interoperability and security.

In contrast to most alliances, some players try to enter the market by using their market dominance to enforce their ecosystems. In some cases these ecosystems are rather closed, and interested parties have to comply with rules set by the ecosystems’ owner.

Another trend to be noticed is the large amount of start-ups and innovation that is going in the IoT sector. A lot of IoT products like smart bulbs, smart locks, modules to make an appliance smart and so on are being developed. While most of them make use of standard communication technologies and protocols, the information layer used on top of these technologies is often unique and proprietary. In this aspect the lack of interoperability standards is hindering innovation.

To tackle interoperability at the lowest layer of the communication stack some players provide a multitude of communication technologies in their devices, while others provide an interface to different communication modules. Often an additional hub or gateway offered by the manufacturer of the IoT devices is needed to communicate with these devices.

A new trend (in research projects), we see at this level, is to make this layer more software defined. Instead of communication technology solutions being wired into the hardware the functionality is provided by firmware. This way the communication technology (MAC layer, modulation and so) can be remotely reconfigured or even upgraded to the newest technologies and standards. This is certainly important in the case of appliances with a medium to long lifetime like HVAC or even some whitegood appliances.

1.5.5.11. Conclusions

Several standards mentioned in this section are still "work in progress". Initiatives (see annex) like EEBus, energy@home and Agora are evaluating these concepts and contributing to standardisation. Expected is that several of these standards will be released in the 2015/2016. The focus of this standardisation effort is currently on the energy domain, but in the near future this (energy) information model may be merged with other domain information models like Ambient Assisted Living or eHealth models.

This standardisation effort does not only address interoperability but also aspects like ICT security and safety. For instance, the requirements identified in current electrical end-product safety standards for household appliances are intended to address the anticipated risks associated with the product's design or use. However, smart functions may cause potential new safety issues, which may make the smart appliance not comply with the safety requirements of the IEC 60335 series standards, managed by IEC TC61. To judge whether an appliance (both normal appliance and smart appliance) is safe or not, the IEC 60335 series shall be applied. For networked devices or appliances, EN50491 series apply.

At the same time several initiatives from the industry are going ahead. Some actors rely on their market dominance to 'convince' the smart appliance industry to be compliant with their ecosystem, while others like AllSeen and OIC tackle the issue in the IoT context by providing software frameworks addressing connectivity, device/service discovery, security and ease of use for developers.

In general, there is strong progress and convergence on the establishment of a common data model for demand side flexibility. This study will follow this progress closely and will support and encourage the initiatives were required or useful.

1.6. SCOPE SUMMARY

Only energy related products within the scope of the **Ecodesign and Energy Labelling Framework Directives** are in the scope of this study, as these Directives form the legal background for the study and policy measures potentially to be implemented after the study.

This study is not analyzing all communication-enabled appliances. For the purpose of this preparatory study, **a smart appliance is an appliance that supports Demand Side Flexibility**:

- It is an appliance that is able to automatically respond to external stimuli e.g. price information, direct control signals, and/or local measurements (mainly voltage and frequency);
- The response is a change of the appliance's electricity consumption pattern. These changes to the consumption pattern is what we call the 'flexibility' of the smart appliance;

Whereby:

- The specific technical smart capabilities do not need to be activated when the product is placed on the market; the activation can be done at a later point of time by the consumer or a service provider.
- A distinction might be made later in the process between appliances able to communicate and process external signals and (non-communicating) appliances automatically reacting to local power quality measurements.

The following clarifications can be added to this definition:

- Manual start time delay is not considered smart control because it is not automated.
- Automatic actions to safeguard the technical safety of the appliance are not considered smart control.

The focus of this study is on '**end devices**', meaning the appliances that are being controlled and that alter their electricity consumption, as opposed to those devices that control other appliances or end devices. There will be no specification of who or what should activate the DR functionality. All control architectures should be supported.

Smart meters are included in the study specifically and only with respect to their energy consumption as part of the overall communication infrastructure.

The focus of this study is on the smart appliances and the potential flexibility generated, independent of how this flexibility is used in a specific energy market structure. A range of DR business cases and energy markets should be supported that is as wide as possible. This study is not about market design, i.e. what market structure or business cases are to be preferred.

The focus of this study is on the '**end-user**', i.e., residential consumers, because the challenges linked to smart appliances are most relevant for their use by residential consumers:

- residential consumers are not yet aware of demand response functionalities because this is a new market;
- residential consumers need more guidance for the use of digital technologies;
- the "Chicken and Egg Problem", as described in 1.1.2;
- households are more in need of an "any to-any " neutral solution across very different appliances in a household while interoperability problems can be more easily solved within a system approach and with a focus on certain appliances.

However, also commercial and industrial products can potentially benefit from the development of interoperability solutions and measurement standards. Provided that data are available, the following **commercial cases** are included in the scope of the study:

- Commercial refrigeration appliances;
- HVAC in the tertiary sector.

The **appliances in scope** of the study are sorted into 3 categories according to the flexibility potential (based on details in Annex 1):

- High flexibility potential with few comfort and/or performance impacts: dishwashers, washing machines, washer dryers, buffered water heaters, radiators, boilers, heat pumps, circulators, residential and non-residential air conditioners and battery storage systems;
- Smaller flexibility potential and/or larger comfort/health impacts: tumble dryers, refrigerators, freezers, extraction fans, heat recovery ventilation and air handlings units and chargers (low power);
- Only emergency flexibility potential: electrical hobs, ovens, hoods, vacuum cleaners and lighting.

Generally, it can be put that the higher the potential, the more the appliance will be studied in detail in the next Task reports.

An essential part of the study is the connection between the demand side and the supply side, more specifically, the data exchange with the smart appliance and the functions supported by the smart appliance, that implement changes in the electricity consumption. Due to this, the study includes topics regarding interoperability and demand response readiness. Similar appliances of different manufacturers should provide the same demand side flexibility functionality, or a subset of a commonly agreed upon set of functionalities, and should support interoperable communications, such that the demand control system does not need to differentiate between appliances of different brands. This will also maximise the guarantee for the end-consumers that the available DR systems support the appliance of choice.

CHAPTER 2 MARKET ANALYSIS

The objective of Task 2 consists of the assessment of the stock of smart appliances defined in Task 1 within the EU28.

An analysis has been made of current trends regarding the general Internet of Things market and more specifically the market for smart home and smart appliances. Although market reports give a good picture of general tendencies regarding the current and future supply of smart appliances, it was not possible to derive 'smart' shares of individual appliances for the various categories.

Smart appliances as defined in this study have not yet (fully) seized the market and no figures are available specifically for this subcategory of 'smart' appliances. Therefore, the current stock data for all appliances - including non-communication/communication enabled and non-DR/DR enabled appliances – is given as a starting point. Expert judgment estimations have been made per appliance type of the current share of DR enabled stock as well as predictions for 2020 and 2030.

In this Task report an overview is also given of the various types of economic instruments/remuneration mechanisms that could be used to pass the value of flexibility provided by smart appliances on to the end-user. These remuneration mechanisms can provide incentives in order to use more of the flexibility potential and will be combined with the modelling in Task 5.

2.1. MARKET TRENDS

This section describes a number of market trends regarding the general Internet of Things market and more specifically the market for smart home and smart appliances.

Important note: the term 'smart' appliance in this specific section does not stand for a 'DR-enabled' appliance, but reflects the terms used in the market reports that are referred to. The market research reports use different terminology and categories to classify 'smart' appliances or devices[55], which makes it difficult to compare figures and trends. The reports mentioned in this section use the term 'smart' to indicate communication-enabled or 'connected' appliances or devices. Most of these 'smart' appliances or devices come with a smartphone or tablet app, which is indicated as 'app-enabled'. Only some of the 'smart' appliances or devices mentioned provide functionality to enable DR in 2015. Smart homes are sometimes classified as homes with at least one smart device/appliance, or as whole-home multi-function smart homes (based on a traditional home automation system or on an integrated solution of smart devices).

[55] Devices are a broader term compared to appliances and can also include safety and security systems (internet-connected sensors, monitors, cameras and alarm systems) and energy equipment like smart thermostats.

2.1.1. TRENDS IN THE FIELD OF SMART APPLIANCES / SMART HOME DEVICES

Several appliance manufacturers offer smart appliance lines in 2015. IFA (Internationale Funkausstellung) 2015 in Berlin, the global trade show for consumer electronics and home appliances, presented in September 2015 the latest products and innovations and is a unique opportunity to have an overview on the trends in consumer electronics. Smart homes and smart appliances were very prevalent at this years' trade show[56]. Examples of demonstrated available smart home appliances are e.g. the GE WiFi Connect, Hoover Wizard smart appliances range, Candy simply|Fi appliances, Haier's Intelius 2.0 lineup, Grundig's HomeWhiz appliances, Whirlpool's 6TH Sense Live range, Bauknecht (Whirlpool Group) appliances controlled with BLive app, Electrolux, LG, Miele's EditionConn@ct and Miele@Home appliances, and others. Samsung announced to bring all their devices within the IoT ecosystem by 2020. Most appliance manufacturers offer since this year a commercial product line of smart appliances, with a focus on dishwashers, washing machines, washer-dryers and refrigeration products. Other types of smart appliances commercially available in 2015 (or announced) are: the smart coffee machine, the smart robot vacuum cleaner, the smart toothbrush, the smart garden sprinkler, the smart hood, the smart hob or the smart oven.

Some smart appliances are designed in such a way that they can communicate information directly to the service operator. Some of these appliances have the ability to measure and control their energy usage. Promoting the added value of smart appliances towards customers is done by emphasizing the extra comfort (like remote control or status notifications via an app) and energy management functions. For instance Hoover's app monitors each product's energy consumption (energy management function) and can send updates and alerts, e.g. when the dishwasher needs more rinse aid or that the fridge's temperature is rising (comfort function).

The global consumer industry of smart appliances' overall turnover is forecasted to grow by 14% this year, from €783bn in 2014 to €891bn[57] in 2015. The next subsections list several market research reports which give forecasts on the expected evolution of turnover of smart appliances and smart home devices.

2.1.1.1. Source: IHS Technology

IHS Technology predicts the global market for smart connected household appliances to boom from around 1 million units sold in 2014 to 223 million units by 2020 (see Figure 14). The total smart connected major home appliance (MHA) market is forecast to be 470 million units worldwide between 2015 and 2020[58]. IHS calls this forecast "conservative" with an opportunity for the market to grow even more, depending on how rapidly appliance makers educate end-consumers and provide appropriate price-to-value balance.

The penetration of these smart connected appliances is projected to grow from an estimated 0.2% in 2014 to 31.3% in 2020, with that of smart room air-conditioners reaching 52% and smart washing machines 42% in 2020. China is projected to be the leading market followed by the United States. If the smart household category is widened out from kitchen goods, including fridges, washing machines, refrigerators and ovens to all connected household appliances, like coffee machines,

[56] http://www.ifa-international.org/dailies
[57] Hans-Joachim Kamp, Chairman of the supervisory board of Consumer & Home Electronics GmbH (gfu), the organisers of IFA, http://www.ifa-international.org/dailies.
[58] https://technology.ihs.com/549694

robotic vacuums, rice cookers, microwave ovens, air purifiers, and electric toothbrushes, then the market could stretch to 700 million appliances by 2020[59].

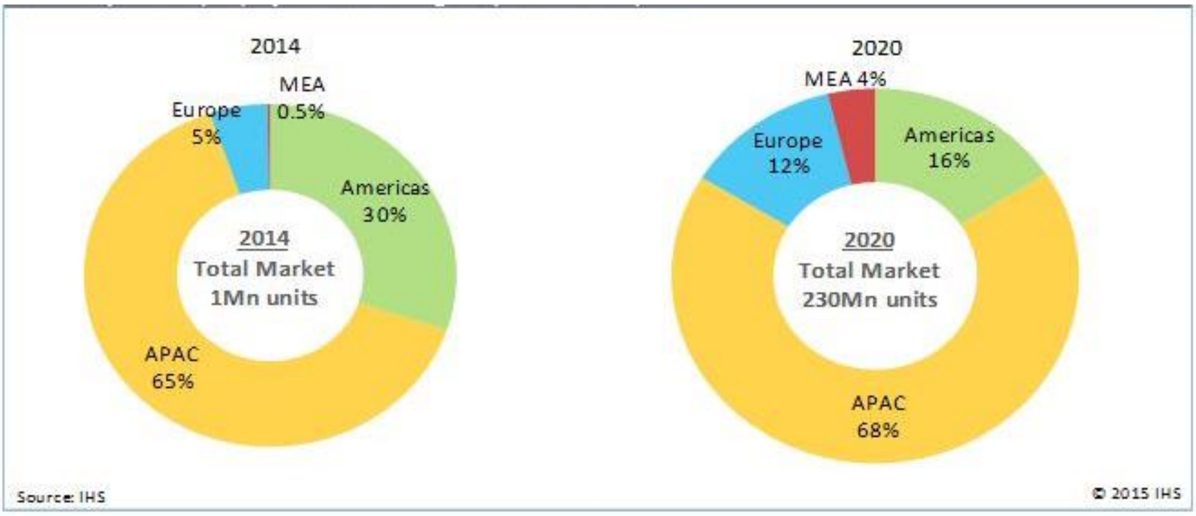

Figure 14 World market for smart connected major home appliances – Unit shipments (Mn) by share and region (2014 & 2020) - source IHS60

The appliance types covered in the IHS research include washing machines (WM), clothes dryers (CD), dishwashers (DW), refrigerators (REF), room air-conditioners (RAC), and large cooking appliances (LCA). Figure 15 shows the world market for smart connected major home appliances in unit shipments and CAGR, split by appliance type.

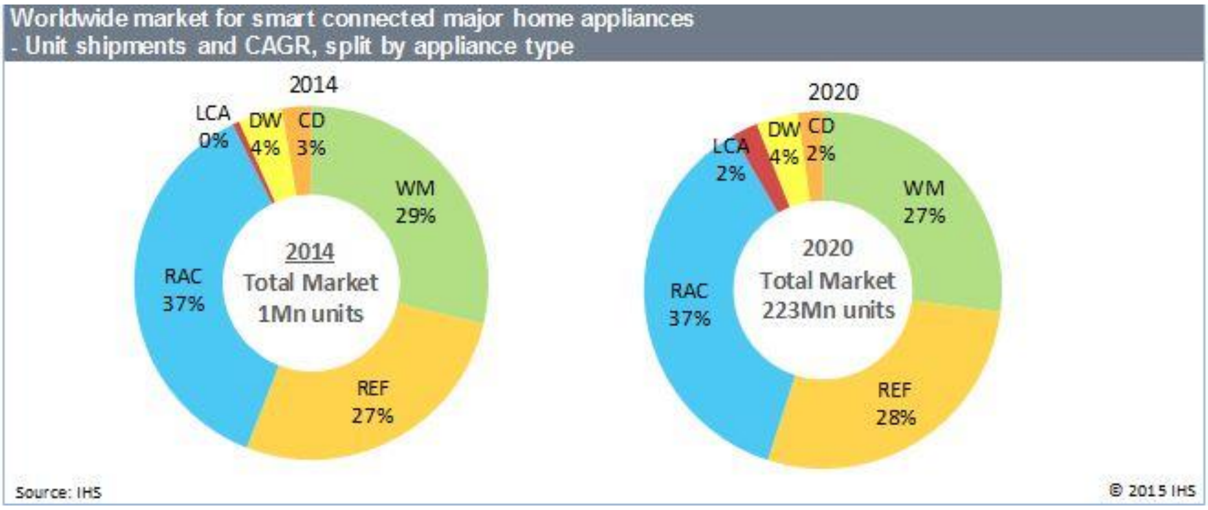

Figure 15 World market for smart connected major home appliances – Unit shipments and CAGR, split by appliance type - source IHS[60]

[59] Dinesh Kithany, senior analyst for home appliances at IHS Technology, IFA 2015, http://www.ifa-international.org/dailies.
[60] https://technology.ihs.com/549694

IHS cites the following reasons for this trend:

- Over the last decade consumers have evolved and quickly adopted new technology products thanks to the higher adoption of smartphones, familiarity with touch controls, the world of apps, and access to the internet.
- As smart appliances are expected to be more energy-efficient than their traditional counterparts, there is a push by governments and regulatory authorities to support and develop this trend[61].
- Many appliance makers are shifting focus from the low-profit, low growth traditional 'non smart' segment toward the high-margin, revenue oriented smart appliance segment.

2.1.1.2. Source: BI Intelligence (Global) [62]

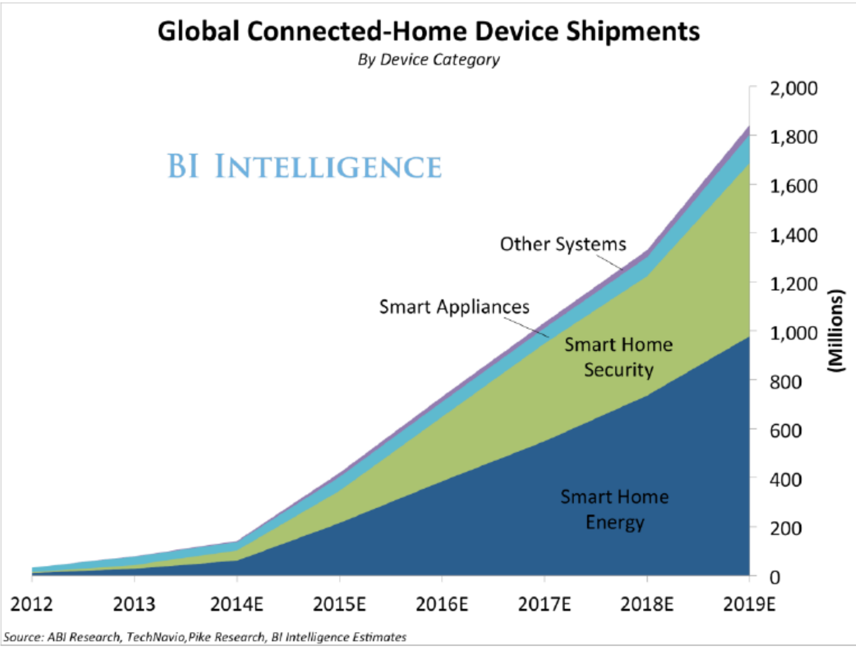

Figure 16: Global connected-home device shipments[62]

Connected home devices include all smart appliances (washers, dryers, refrigerators, etc.), safety and security systems (internet-connected sensors, monitors, cameras and alarm systems)[63], and energy equipment like smart thermostats and smart lighting. As illustrated in Figure 16 home-energy equipment and safety and security systems, including devices like connected thermostats and smoke detectors, are projected to become popular first, leading the way to broader consumer adoption. In 2019, connected-home device shipments will account for roughly 27% of the total global IoT market (23% in 2014). Connected-home device shipments will grow at a compound annual rate of 67% over the next five years according to BI Intelligence estimates. Smart home appliances will be the slowest-growing category, averaging 28% compound annual growth between 2014 and 2019 globally. This category includes products like smart refrigerators, smart washers and dryers and smart dishwashers.

[61] IHS cites this, but other sources do not agree (as demand shift capacity is often the main focus)

[62] BI Intelligence (2014) THE CONNECTED-HOME REPORT: Forecasts And Growth Trends For The Leading 'Internet Of Things' Market http://static1.squarespace.com/static/5129591ae4b0fd698ebf65c0/t/5467dface4b00178423ef007/1416093612167/bii_connectedhome_sept14.pdf

[63] As this is a new product category for many households absolute energy consumption might actually rise

As prices decline over the long run and consumers become more familiar with connected-home devices overall, the smart appliances' growth is expected to accelerate.

2.1.1.3. Source: BI Intelligence US smart home market report

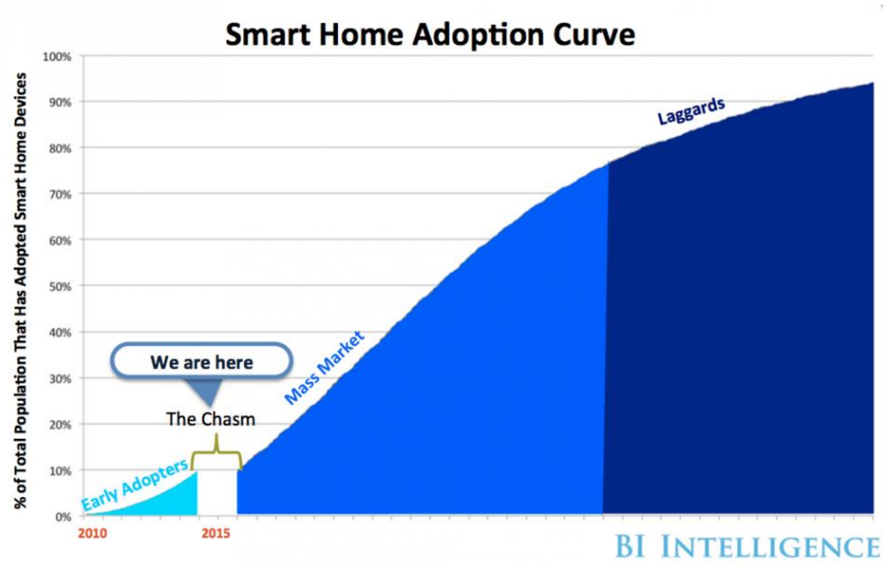

Figure 17: Smart Home Adoption Curve (source: BI Intelligence)

Key takeaways of a recent BI Intelligence report[64] on the US smart home market are:

- Smart home devices[65] are becoming more prevalent throughout the US. Multiple smart home devices within a single home form the basis of a smart home ecosystem.
- Currently, the US smart home market as a whole is in the "chasm" of the tech adoption curve (Figure 17). The chasm is the crucial stage between the early-adopter phase and the mass-market phase, in which manufacturers need to prove a need for their devices.
- **High prices, coupled with limited consumer demand and long device replacement cycles** are three of the four top barriers preventing the smart home market from moving from the early-adopter stage to the mass-market stage. For example, mass-market consumers will likely wait until their device is broken to replace it. Then they will compare a non-connected and connected product to see if the benefits make up for the price differential.
- **The largest barrier is technological fragmentation** within the connected home ecosystem. Currently, there are many networks, standards, and devices being used to connect the smart home, creating interoperability problems and making it confusing for the consumer to set up and control multiple devices. Until interoperability is solved, consumers will have difficulty choosing smart home devices and systems.

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[64] http://uk.businessinsider.com/the-us-smart-home-market-report-adoption-forecasts-top-products-and-the-cost-and-fragmentation-problems-that-could-hinder-growth-2015-9?r=US&IR=T

[65] BI Intelligence uses a very broad definition for a smart home device. It defines a smart home device as any stand-alone object found in the home that is connected to the internet, can be either monitored or controlled from a remote location, and has a non-computing primary function.

- **"Closed ecosystems" are the short-term solution to technological fragmentation**. Closed ecosystems are composed of devices that are compatible with each other and which can be controlled through a single point.

2.1.1.4. Source: Research and Markets: global forecast to 2020[66]

The smart appliances market is witnessing rapid growth. It is expected to reach $37.2 Billion by 2020, and grow at a CAGR of 15.4% between 2015 and 2020. In the smart appliances ecosystem, smart home (Washer, Dryer, Air Conditioner, Vacuum Cleaner) and smart kitchen appliances (Refrigerator, Dishwasher, Freezer) play a vital role. The market for smart home appliances was valued at $7.7 Billion in 2014 and it is expected to grow at a CAGR of 16.8% between 2015 and 2020. Smart washers and smart dryers accounted for a large market share, however the market for smart air conditioners is expected to grow at a high CAGR between 2015 and 2020.

2.1.1.5. Source: Deutsche Telekom & Strategy Analytics[67]

Consumer spending on smart home products and services will hit €90.90 billion globally by 2018 and accelerate from there to €122.77 billion by 2020. Fewer than 25% of homes with broadband connections will have acquired any of these products and services by this time. Strategy Analytics claims that the home market in the EU could be worth over €15.46 billion annually by 2019, with 50 million Western European homes having installed IoT technology.

2.1.1.6. Source: Frost & Sullivan: Analysis of the European Smart Thermostats Market[68]

This analysis from Frost & Sullivan finds that the EU market for smart thermostats earned revenues of $152.5 million in 2014 and estimates this to rocket up to $2,570.6 million in 2019 (more than 15 times the 2014 level). The United Kingdom, Germany and the Netherlands are projected to account for a lion’s share of the market in Europe, while France will be the fastest growing. The report emphasizes that energy utility companies are critical value chain partners for the smart thermostat vendors. Capitalising on their highly convenient and reliable sales channel will facilitate access to the mass customer market in Europe.

2.1.1.7. Source: Berg Insight: Smart thermostats[69]

Compared to 2013, sales of smart thermostats in Europe in 2014 rose by 96% increase for a total of 0.7 million units. Berg Insight forecasts that the number of homes with smart thermostats in Europe and North America will grow at a compound annual growth rate of 64.2% during the next five years to reach 38.2 million units in 2019. North America will remain the largest market at the end of the forecast period, with 24.6 million homes having smart thermostats, whereas the installed base in Europe is expected to reach 13.6 million homes by 2019.

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[66] http://www.researchandmarkets.com/research/zcsgb8/smart_appliances

[67] http://connectedhomeplatform.telekom.net/wp-content/uploads/Telekom_Market_Analysis_Report-How_to_create_Growth_from_the_Connected_Home.pdf

[68] http://www.frost.com/sublib/display-report.do?id=MB01-01-00-00-00&bdata=aHR0cDovL3d3Mi5mcm9zdC5jb20vbmV3cy9wcmVzcy1yZWxlYXNlcy9zbWFydC10aGVybW9zdGF0cy1tYXJrZXQtcm9ja2V0LTI1LWJpbGxpb24tNS15ZWFycy1wcmVkaWN0cy1mcm9zdC1zdWxsaXZhbi9AfkBCYWNrQH5AMTQ0NjU2ODE1NDU5MA%3D%3D

[69] http://www.berginsight.com/ReportPDF/ProductSheet/bi-sh3-ps.pdf

Consumers embrace smart thermostats primarily due to the potential for energy savings, increased comfort and convenience. For energy companies, they open up new possibilities to introduce consumer-friendly demand response and energy efficiency programmes. In 2014 and 2015 several partnerships were announced in the EU between energy service providers and smart thermostat manufacturers[70].

Berg believes that smart thermostats represent a particularly attractive opportunity in the smart home market, as they appeal to consumers, energy companies and HVAC (heating, ventilation and air conditioning) service providers alike.

Important note: the term ‘smart’ appliance in section 2.1 does not stand for a ‘DSF-enabled’ appliance, but reflects the terms used in the market reports that are referred to.

2.1.2. TRENDS IN THE FIELD OF ENERGY MANAGEMENT SYSTEMS

The report “The scope for energy and CO2 savings in the EU through the use of building automation technology”[71] projects the penetration of modern Building Automation Technology (BAT) and management systems to rise from 26% of all service sector floor area in 2014 to 40% by 2028 (BAU, without further policy intervention). In the residential sector, penetration of Home Energy management Systems (HEMS[72]) is projected to rise from 2% of homes today to 40% by 2034 without additional intervention.

2.1.3. TRENDS IN THE FIELD OF SMART HOMES

Smart home solutions have been on the market for several years and yet, for a variety of reasons, have not yet found mass acceptance. Many of the solutions may have been simply too expensive, or have not yet reached full maturity. Over the last few years, industry has made considerable efforts to develop new, cheaper technologies and to keep on improving existing solutions, including numerous communications protocol. Thanks to all the hype surrounding the IoT in 2014 and 2015, the smart home has also achieved much greater visibility among the general public.
Home automation is not the only way to create smart homes. Other players on the market are offering different solutions. A trend now is that smart homes are built more organically by gradually adding connected devices. As a result, more connected home appliances will be introduced and some of them will be DSF-enabled.

[70] Some examples: The North American smart thermostat market is led by Nest, Honeywell and Ecobee. In Europe, the leading smart thermostat vendor is eQ-3, whose smartphone-controlled radiator thermostats have been installed in more than 300,000 homes. Other successful initiatives include the smart thermostat solutions offered by the energy companies British Gas in the UK and Eneco in the Netherlands. British Gas’ Hive solution had approximately 140,000 users at the end of 2014, whereas Eneco had signed up around 100,000 users for its Toon solution. (In the UK) Google-owned Nest is being offered to Npower’s customers, Berlin-based startup Tado has teamed up with SSE, Climote is working with Scottish Power, and French startup Netatmo recently partnered with EDF Energy.

[71] The scope for energy and CO2 savings in the EU through the use of building automation technology, Second edition, 13 June 2014, Waide Strategic Efficiency Limited, http://www.leonardo-energy.org/sites/leonardo-energy/files/documents-and-links/scope_for_energy_and_co2_savings_in_eu_through_ba_2nd_ed_2014-06-13.pdf

[72] HEMS, CEMS (Customer Energy Management System), BEMS (Building Energy Management System) and EMS are commonly used in literature to indicate energy management systems.

In 2015 the smart home has established itself as one of the leading markets in the IoT, as a variety of studies indicate, including those by Berg Insight[73] and BITKOM.
According to Berg Insight, the European market for smart home systems is still in an early stage and 2–3 years behind North America in terms of penetration and market maturity. At the end of 2014, a total of 3.3 million smart home systems were in use in the EU28+2 countries, up from 1.75 million in the previous year. Around 0.34 million of these systems were multifunction i.e. whole-home systems whereas 2.93 million were point solutions of smart devices. This corresponds to around 2.7 million smart homes when overlaps are taken into account (some homes have more than one smart system), meaning that 1.2% of all households in this region were smart at the end of 2014.

Berg Insight expects that by 2017 there will be 17.4 million smart home systems installed in European homes, bringing in projected sales of 2.6 billion euros. The number of European households that have adopted smart home systems is forecasted to grow at a compound annual growth rate (CAGR) of 61% during the next five years, resulting in 29.7 million smart homes by 2019. Market revenues grew by 60% compared to 2013 to € 0.77 billion in 2014. The market is forecasted to grow at a CAGR of 58% between 2014 and 2019 to reach € 7.6 billion at the end of the forecast period.

A point solution will in most cases constitute the consumer's first smart home purchase. In fact, point solutions outsold whole-home systems in 2014 by a factor of six to one and generated 59% of the combined market revenues in North America and Europe. The most successful point solutions to date include smart thermostats, security systems, smart light bulbs, network cameras and multi-room audio systems.

According to the BITKOM Connected Home Working Group[74] by 2020 there could be as many as 1.5 million smart home households in Germany.

According to Argus Insights, home automation was experiencing robust growth in 2014, however data show that as of May 2015 consumer demand for connected home devices experienced a 15% drop below the level of a year ago, a sign that consumer interest may be stagnating[75].

[73] http://www.berginsight.com/ReportPDF/ProductSheet/bi-sh1-ps.pdf
[74] http://www.bitkom.org ; http://blog.bosch-si.com/categories/technology/2015/07/here-to-stay-the-smart-home-needs-standards/
[75] Source: Argus Insights (2015), http://www.argusinsights.com/connected-home-release

In the past the home automation industry was the only player to provide smart home functionality; but in 2015 several market actors are lining up to take a share of the smart home market:

- Telecommunication providers already have a platform at the customers' home, via the broadband router and are very well positioned to enhance this platform towards a smart home platform (E.g. Qivicon product range offered by Deutsche Telecom; in the US Cable TV, Internet & Phone provider Comcast Corporation steps into the smart home market);
- Energy providers are providing smart thermostats and energy boxes[76] to their customers to reinforce the customer-energy provider binding in a liberalized energy market. Some energy providers offer complete smart home solutions (E.g. RWE Smart Home products, Eneco's Toon thermostat, Eni's Anna thermostat);
- In the US, the home security industry is broadening their scope from alarm to smart home offerings. At the base, consumers value safety, but several consumer segments value energy management, especially when bundled with security and safety offerings (see Task 3);
- The traditional home automation industry, previously targeting the high-end market segment, are now offering slimmed down solutions for the middle-end market segment;
- The consumer industry, and especially some dominant and innovative actors like Google/Nest, Apple and Samsung are offering products or platforms for the smart home. These offerings may tie the customer to a particular ecosystem[77].

Regarding the path to the connected home, the Deutsche Telekom published the following conclusions in the 'How To Create Growth From The Connected Home' report[67]:

1. Connected devices will transform our homes over the next decade;
2. The market will be worth billions of euros;
3. The threat of disintermediation is very real with innovative players set to enter the home from adjacent markets;
4. Major players need to 'step up to the plate' in order to drive growth from IoT;
5. To engage consumers, focus on meeting their real needs;
6. The ultimate value for service providers, retailers and manufacturers will be in services;
7. The market is not homogeneous, it is distinct and regional and segment needs must be met;
8. Create a win-win relationship with partners;
9. No one standard will meet the entire needs of the market, and hence an open architecture will be a prerequisite;
10. Platforms that support multiple use cases will be the only ones that succeed.

2.1.4. TRENDS/STATUS OF SMART METERS

2.1.4.1. EC Benchmarking Report (2014)

The Commission Benchmarking Report (2014[78]) reflected on progress in the roll-out of smart metering across the EU and found a mixed picture. Three Member States were advanced in their roll-out plans (Finland, Italy, Sweden), installing close to 45 million meters. Another thirteen Member States declared their intention to proceed with large-scale roll-out of smart meters by 2020, although

[76] Energy box is a popular name for home energy management systems (HEMS). Note however that the energy manager is a logic function, not necessarily a physical device.

[77] For instance a customer may decide not to buy a certain DSF-enabled appliance because it cannot be integrated in a particular ecosystem at home. And the manufacturer of that particular ecosystem may decide DSF-capability is not important for its revenue.

[78] Benchmarking smart metering deployment in the EU-27 with a focus on electricity, COM(2014) 356 final, http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014DC0356&from=EN

they are at different stages of the process. In seven Member States, the cost-benefit analyses (CBA) proved negative or inconclusive (Belgium, Czech Republic, Germany, Latvia, Lithuania, Portugal, Slovakia). In Germany, Latvia and Slovakia, smart metering was found to be economically justified only for particular groups of customers. These countries now expect to roll out smart meters to around 23% of household consumers. Four Member States (Bulgaria, Cyprus, Hungary, Slovenia) did not produce CBAs or rollout plans at all. Although enthusiasm for smart electricity metering is not uniform across the EU, a majority of Member States still intend to proceed with large-scale deployment by 2020.

Based on the national CBAs, the estimated cost of installing smart electricity meters was identified to vary widely between different Member States, from €77 to €776 per customer. The Commission's benchmarking report expects that smart metering will lead to substantial cost savings in the longer run: the average consumer can reduce their energy costs by around 3%, while some types of consumers could reduce them by up to 10%. Evidence from Member States that have extensively deployed smart metering in the EU would suggest savings are likely to be more modest. Finland found the average savings to be only 1-2%, while Sweden gave a range of 1-3%. Other CBAs conducted by Member States predicted energy savings to be insignificant or as low as 1% per customer. Therefore some stakeholders argue that smart meters should only be installed for consumers with high energy usage, reducing the costs of deployment while keeping the average savings higher. The Commission argues[79] that smart meters with broad functionality are able to provide a wider range of information to customers, which is more frequently updated and more easily accessible, thereby facilitating demand side response[79].

According to the estimates in this report[78], the roll-out commitments amount to an investment of around €45 billion for the installation by 2020 of close to 200 million smart meters for electricity (representing approximately 72% of all European consumers) and 45 million meters (around 40% of consumers) for gas.

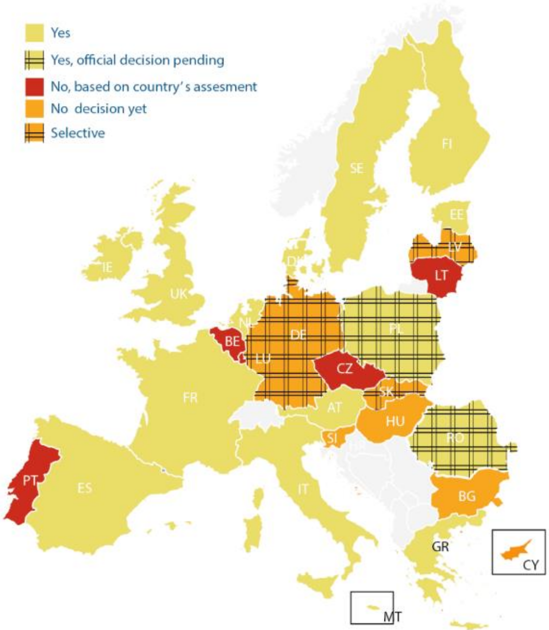

Figure 18: Deployment of smart electricity meters in EU Member States by 2020

[79] http://www.europarl.europa.eu/RegData/etudes/BRIE/2015/568318/EPRS_BRI(2015)568318_EN.pdf

2.1.4.2. European Smart Grids Task Force Expert Group 1 report (2015)

In October 2015, the Expert Group 1 on Standards and Interoperability of the European Smart Grids Task Force issued a report covering a survey regarding interoperability, standards and functionalities applied in the large scale roll out of smart metering in EU Member States[80]. The report assesses the current roll-out of smart metering systems in seventeen Member States with reference to i) their degree of interoperability with other components/operations of the energy system, meaning in practice the implementation of the M/490 standardised local interfaces (H1, H2 and H3)[81]; and ii) checking whether these smart metering set-ups are equipped with functionalities for the provision of energy management services, i.e. examine compliance with the EC recommended, and consumer-benefitting, functionalities (a), (b) and (f) (EC Recommendation 2012/148/EU), where

- Functionality (a) means: Provide readings directly to the customer and any third party designated by the consumer.
- Functionality (b) means: Update the readings referred to in point (a) frequently enough to allow the information to be used to achieve energy savings.
- Functionality (f) means: Support advanced tariff systems. This functionality relates to both the demand side and the supply side.

The conclusions of this report are the following:
All 17 Member States that responded implement functionality (a). 3 out of 17 Member States (18%) do not implement functionality (b) as it was specified by the Commission in its Recommendation (with at least 15 minute update frequency). 2 of them will do so on consumer request.

Five Member States will not use the smart metering system to implement functionality (f). In these cases it is important to understand if consumers will be able to check their consumption per tariff zone on the meter, if tariff zones are used for billing.

16 Member States will implement the H interfaces initially, later or on consumer request, and the majority intends to roll-out interface H1.

7 Member States indicated that they currently use a web-portal as an alternative or complementary to the H1, H2, H3 interfaces although these interfaces might be implemented later or on consumer request.

A majority of Member States did not make additional definitions for improving interoperability on the H interfaces. That leads to the conclusion that more attention should be drawn to the approach of reaching interoperability on various layers through profiles / companion standards.

In the references made to standards for the H interfaces, the CENELEC TC205 standards (EN 50491-11 and -12) are never mentioned. Since they deal with data definitions, there is a risk that the data and its format provided by the Advanced metering infrastructure (AMI)[82] is not aligned with the data and formats required by in-home energy management.

[80] Report on a survey regarding Interoperability, Standards and Functionalities applied in the large scale roll out of smart metering in EU Member States; European Smart Grids Task Force Expert Group 1 – Standards and Interoperability, October 2015
[81] See Standards section in Task 1
[82] Advanced metering infrastructure (AMI) is an integrated system of smart meters, communications networks, and data management systems that enables two-way communication between utilities and customers.

2.1.5. Trend: Traditional roles will change

Upgrading appliances to smart appliances is more than just adding a communication hardware module and communication software to the appliance. Connectivity with the end-consumer could have a substantial impact on the business models of manufacturers. Several market research analysts indicate that traditional appliances manufacturers will have to approach the market more as technology providers instead of as manufacturing companies. The manufacturers need to engage not only with distributors, sales depots, retailers, and OEM players as they have done in past, but also with end-consumers. Manufacturers, distributors or retailers may take up the role of service provider and may provide a variety of services towards the consumer:

- Provide a maintenance service related the smart appliance or smart home systems. For instance a smart washing machine can proactively request maintenance ahead of failure;
- Provide an energy service. For instance smart home thermostat providers may offer the flexibility of the connected smart homes, with consent of the owner, to the energy market or utilities;
- Provide a sales channel to tertiary products; a smart fridge may order extra milk when run out of milk; a washing machine[83] may order or send a message to your smartphone prompting you to order more when supplies of its detergent run low;
- The setup of these smart appliances may not be so easy for the average consumer. Setting up a single smart appliance may be not so difficult, but integrating several smart appliances to work together creating a smart system or smart home may be much harder. In this case the retailer for instance may take up the role of integrator or consultant of smart appliances/systems.

Obviously these companies will try to convince consumers to buy into connected devices from the same brand rather than shop across the category. The big advantage for those companies that succeed in making the right connected machines, is that upgrades can be simply plugged in to existing devices therefore keeping customers' loyal and potentially happy to stay with the brand long term. The new services, however, do not only provide new opportunities but also new obligations. For instance to convince the consumers these companies must assure the consumers that any data they share with their connected appliances will be handled securely.

2.1.6. Emerging business models related to the Internet of Things

In its report "Monetizing the Internet of Things: Extracting Value from the Connectivity Opportunity"[84] Capgemini Consulting indicates that there are four distinct business models that are emerging (Figure 19):

1. "Hardware Premium" is the most basic form of business model. Organizations add connectivity options to an existing or new product and offer remote device management in the form of mobile apps. This basic level of connectivity and control enables organizations to charge a premium for their product.
2. The service model offers a recurring revenue stream and, more importantly, creates a relationship with the customer long after they have purchased a product.
3. Connected devices generate large volumes of sensor data. For many organizations, the ability to capture, package and sell this data offers a potential business model. Once this data has been aggregated and anonymized, organizations can choose to sell it raw, package insights from it or monetize it using advertising.

[83] Miele's new Edition Conn@ct washing machine
[84] https://www.capgemini-consulting.com/resource-file-access/resource/pdf/iot_monetization_0.pdf

4. The IoT thrives in a connected ecosystem – the bigger the ecosystem, the greater is the value generated for all stakeholders. In an ecosystem, the focus is not on selling a product or a service, but on providing a shared platform to other players in the ecosystem – hardware manufacturers, software developers, service providers and related stakeholders. In such a model, the platform promoter ideally makes money from both, end customers as well as other platform users. Platform users pay the promoter for listing and the promoter also gets a share whenever a product is sold to the end customer on the platform.

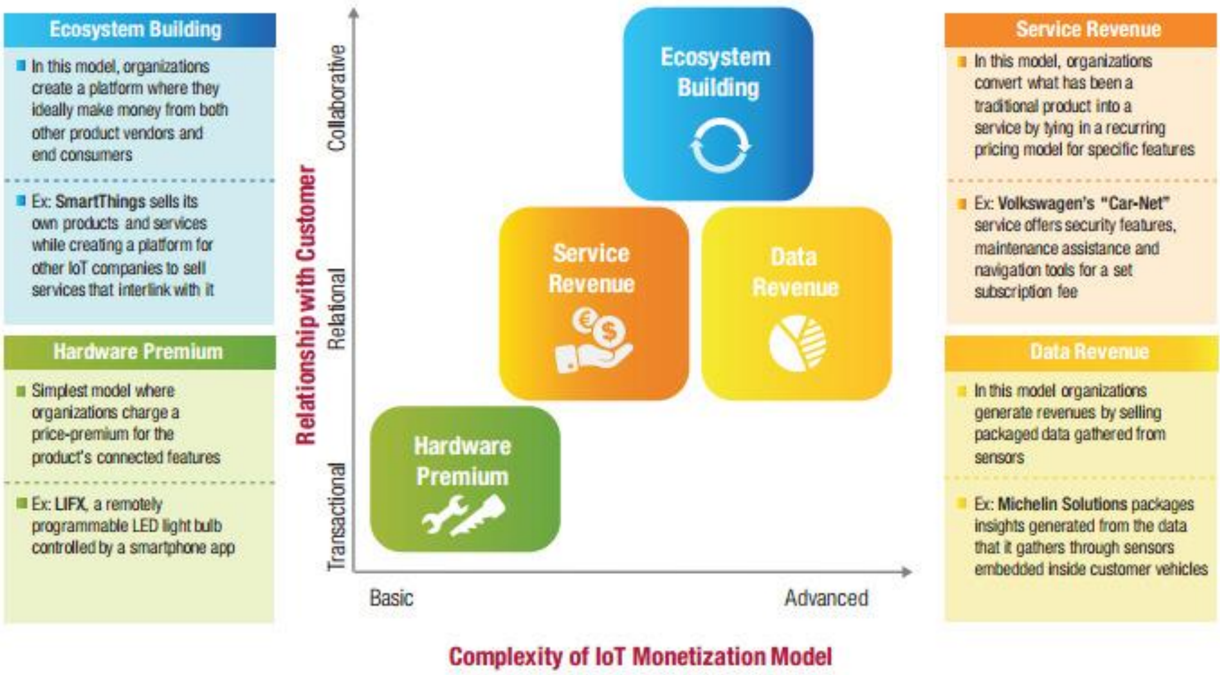

Figure 19 Business models related to IoT (source: Capgemini Consulting[84])

2.1.7. CONCLUSIONS

The terminology 'smart' used in market reports on the IoT and the smart home refers in most cases to 'connected' (communication-enabled) and 'app-enabled'[85]. Only some of the 'smart' appliances or devices mentioned provide functionality to enable DSF in 2015. It generally means that the device/system is connected to a digital communication network and provides the user with the ability to control the device/system by means of an app on a PC, smartphone or tablet. Although DSF is not the focus of this market trend, this trend adds communication functionality to these devices which will facilitate the enabling of DSF. Figures of DSF ready smart appliances sales or stock are not publicly available.

Based upon trends and the forecasts by market research companies, one can conclude that digital communication functionality will be a common (commodity) function in most appliances sold from 2020 onwards. Manufacturers will most likely include digital communication functionality in all or special product series for all product categories in the scope of this preparatory study. However, this tendency does not imply that these appliances will be interoperable or will provide DSF functionality.

[85] Most of these 'smart' appliances or devices come with a smartphone or tablet app, which is indicated as 'app-enabled'.

In 2015 most of the smart appliances in this context (thus communication-enabled) are not part of a DR program. However, for two categories of these devices one can already see a path towards DR: smart thermostats and energy management systems.
Several European energy service providers are partnering with smart thermostat vendors and are offering smart thermostats to their customers. Some of these energy providers already offer along with the smart thermostat a DR program. Besides these offerings, customers are also buying off-the-shelf smart thermostats. Most of the smart thermostats are connected to a cloud and provide the necessary functionality to enable DSF. With market research companies estimating an installed base of more than 10 million homes with smart thermostats in 2019, smart thermostats are likely to be the first smart appliances to offer significant DSF capacity.
A second trend related to smart thermostats is that the thermostat is evolving into a residential energy management gateway or hub. In this role the smart thermostat is not only controlling the space heating and cooling, but it is also managing other energy using systems in the home like water heaters, pool pumps, smart plugs, EV chargers, etc.
Besides potentially helping increase the overall energy efficiency, depending on the context and its use, energy management systems provide also the opportunity to offer DSF capacity based upon the resources managed by the EMS.

According to the estimations made by the EC, 200 million smart meters for electricity will be installed in 2020, representing approximately 72% of all European consumers. The EC recommends that these intelligent metering systems should enable demand response and other energy services to evolve[78].

The trend towards 'connected' devices will have a significant impact on the business models, the roles, the sales channels and service channels in this market. Instead of a one-time contact (sales) with the customer, the manufacturer/vendor/service provider will in the IoT scenario have a permanent link with the customer for the entire lifetime of the product.

2.2. CURRENT STOCK OF APPLIANCES AND ESTIMATION OF SHARE OF SMART APPLIANCES

Smart appliances as defined in the context of this preparatory study have not yet (or only to a very limited degree) seized the market and no figures are available specifically for this subcategory of 'smart' appliances. Therefore, the current stock data for all appliances - including non-communication/communication enabled and non-DSF/DSF enabled appliances – is given as a starting point. Per appliance type, expert judgment estimations have been made per appliance type of the current share of DSF enabled stock as well as predictions for 2020 and 2030 in a BAU scenario.

2.2.1. PERIODICAL APPLIANCES

An overview of the installed units of **dishwashers** in 2010 and estimates for 2015, 2020, 2030 is given in Table 1. The (Kemna, 2014) data originate from the "Omnibus" Review Study on
Cold Appliances, Washing Machines, Dishwashers, Washer-Driers, Lighting, Set-top Boxes and Pumps (VHK et al., 2014). In this Omnibus Review study, the combination of sales data and assumptions on penetration and product life have led to the estimation of stock or installed base of products. Sales of dishwashers have been derived from an analysis of the following sources:

- The impact assessment underlying the Commission Regulation (EU) No 1016/2010 of 10 November 2010 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for household dishwashers
- The CLASP (2013) study "Estimating potential additional energy savings from upcoming revisions to existing regulations under the ecodesign and energy labelling directives

- GfK sales data from 2011-2012 for 23 EU-countries.

For 2020 and 2030, educated estimations were made of the share of smart appliances.

Table 1: Installed units of dishwashers in 2010 (reference) and 2015, 2020, 2030 (estimates)

Appliance group	**Dishwashers**			
Reference Year	2010	2015	2020	2030
Installed base	82,799,000	98,345,000	115,036,000	148,553,000
Source	Kemna, 2014	Kemna, 2014	Kemna, 2014	Kemna, 2014
Number of smart appliances		0	575,180	29,710,600
Source		Conservative estimation of 0% of installed base	Estimation of 5% of installed base	Estimation of 20% of installed base
Reference countries		EU28	EU28	EU28

An overview of the installed units of **washing machines** in 2010 and estimates for 2015, 2020, 2030 is given in Table 2. The (Kemna, 2014) data originate from the "Omnibus" Review Study (VHK et al., 2014). In this Omnibus Review study, sales figures of washing machines from the IA and CLASP (2013) data have been supplemented by GfK data for sales in 2011 and 2012 for 23 EU-countries.
have been derived from an analysis of the following sources:

- The impact assessment underlying Commission Regulation (EU) No 1015/2010 of 10 November 2010 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for household washing machines
- The CLASP (2013) study
- GfK sales data from 2011-2012 for 23 EU-countries.

In (GfK 2015[86]) an estimation is made of the German market in terms of 50,000 smart washing machines sold in 2014/2015. Based on the installed base in Germany of 39,000,000 washing machines, this comes down to a penetration rate of 0,13%. If this share is multiplied by the total EU28 stock, a total sales amount is estimated of 252,335 smart washing machines in 2015. Note that this should rather be considered as a maximum amount considering the progress of the German market (see next section).

Table 2: Installed units of washing machines in 2010 (reference) and 2015, 2020, 2030 (estimates)

Appliance group	**Washing machines**			
Reference Year	2010	2015	2020	2030
Installed base	185,828,000	196,821,000	200,805,000	204,744,000
Source	Kemna, 2014	Kemna, 2014	Kemna, 2014	Kemna, 2014
Number of smart appliances	0	252,335	10,040,250	40,948,800

[86] Presentation by Christiane Schoenwetter from GfK during the symposium "Die Vision der 2000-Watt-Gesellschaft" on 20th of October 2015 in Kupferzell/ Germany

Appliance group	Washing machines			
Reference Year	2010	2015	2020	2030
Source	Estimation of 0% of installed base	Extrapolation based on 0.13% penetration of German market (Gfk, 2015)	Estimation of 5% of installed base	Estimation of 20% of installed base
Reference countries	EU28	EU28	EU28	EU28

An overview of the installed units of **tumble dryers** in 2010 and estimates for 2015, 2020, 2030 is given in Table 3. The (Kemna, 2014) data have been based upon the data in the PriceWaterHouse et al. Ecodesign Study – Lot 16 (2009) which were derived from GFK sales data from 2006 and 2007 for EU 27, completed with results extracted from the 2006 CECED Model Database.

For 2020 and 2030, educated estimations were made of the share of smart appliances.

Table 3: Installed units of tumble dryers in 2010 (reference) and 2015, 2020, 2030 (estimates)

Appliance group	Tumble dryers without heat pump technology / Heat pump tumble dryers*			
Reference Year	2010	2015	2020	2030
Installed base	62,723,000 (total)	45,572,060 / 22,45940*	35,900,500 / 35,900,500*	3,888,900 / 73,889,100*
Source	Kemna, 2014	Kemna, 2014; assumption: 2/3 of all TD are without heat pump technology	Kemna, 2014 assumption: 1/2 of all TD are without heat pump technology	Kemna, 2014 assumption: 5 % of all TD are without heat pump technology
Number of smart appliances	0	0	1,795,025 / 1,795,025*	155,560 / 2,955,640*
Source	Estimation of 0% of installed base	Conservative estimation of 0% of installed base	Estimation of 5% of installed base	Estimation of 40% of installed base
Reference countries	EU28	EU28	EU28	EU28

- Note: TD = tumble dryers

Washer-dryers accounted for approximately 2.5% of total washing machines sales in Europe a few years ago (CLASP 2013 in TopTen, 2015[87]). However, according to current market observations by Topten there are more and more manufacturers offering and promoting them. (Euromonitor International, 2014)[88] mentions a penetration rate of about 4% for washer-dryers in the EU[89]. Applying this penetration rate to the 216,13 million households in EU-28 (most recent Eurostat

[87] http://www.topten.eu/uploads/File/Topten_recommendations_Washing_machines.pdf

[88] Euromonitor International, 2014 quoted in http://susproc.jrc.ec.europa.eu/Washing_machines_and_washer_dryers/docs/Prepstudy_WASH_20150601_FINAL_v2.pdf

[89] It is not clear for the authors of Euromonitor International whether the 4% is expressed as a share of the total washing machine market or of the total number of households. For this study we took the more conservative 2nd assumption.

figures available from 2014[90]) results in a total number of 8,640,000 appliances. An overview of the estimated installed units is given in Table 4. For 2020 and 2030, educated estimations were made of the share of smart appliances.

Table 4: Installed units of washer-dryers in 2010 (reference) and 2015, 2020, 2030 (estimates)

Appliance group	**Washer-dryers**			
Reference Year	2010	2015	2020	2030
Installed base		8,640,000	10,800,000	17,300,000
Source		Estimated based on Euromonitor International, 2014		
Number of smart appliances		0	540,000	3,460,000
Source		Conservative estimation of 0% of installed base	Estimation of 5% of installed base	Estimation of 20% of installed base
Reference countries		EU28	EU28	EU28

Note: Some appliances (dishwashers, dryers, washing machines) already offer the possibility of using different energy carriers/commodities (electricity, hot water, gas) in parallel or alternatively. Such hybrid appliances are able to reduce their electricity consumption and instead shift to other energy carriers. In this way, they offer additional chances for energy management and have potential for creating flexibility. Currently, the market for such hybrid products is still very small. Together with the fact that no data are available on the installed base of this product range, the flexibility potential of this subgroup cannot be isolated in the analysis.

2.2.2. CONTINUOUS APPLIANCES

An overview of the installed units of **household refrigerators and freezers** in 2010 and estimates for 2015, 2020, 2030 is given in Table 5. The (Kemna, 2014) data originate from the "Omnibus" Review Study on Cold Appliances, Washing Machines, Dishwashers, Washer-Driers, Lighting, Set-top Boxes and Pumps (VHK et al., 2014). In this Omnibus Review study, the combination of sales data and assumptions on penetration and product life have led to the estimation of stock or installed base of products. Sales of refrigerators have been derived from GfK sales data from 2012 for EU23.

In (GfK 2015[86]), an estimation is made of the German market in terms of 25,000 smart household refrigerators sold in 2014/2015. Based on the installed base in Germany of 40,000,000 refrigerators, this comes down to a penetration rate of 0.06%. If this share is multiplied by the total EU28 stock of 236,496,000 refrigerators (Kemna, 2014), a total sales amount can be estimated of 147,810 smart refrigerators in 2015. Note that this should rather be considered as a maximum amount considering the progress of the German market (see next section). For 2020 and 2030, educated estimations were made of the share of smart appliances.

[90] http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Private_households_by_household_composition,_2014_(number_of_households_in_1_000_and_%25_of_household_types).png

Table 5: Installed units of household refrigerators and freezers in 2010 (reference) and 2015, 2020, 2030 (estimates)

Appliance group	**Household refrigerators and freezers**			
Reference Year	2010	2015	2020	2030
Installed base	297,800,000	303,200,000	308,000,000	317,600,000
Source	Kemna, 2014	Kemna, 2014	Kemna, 2014	Kemna, 2014
Number of smart appliances		147,810	15,400,000	63,520,000
Source		Extrapolation based on 0.06% penetration of German market (Gfk, 2015)	Estimation of 5% of installed base	Estimation of 20% of installed base
Reference countries		EU28	EU28	EU28

An overview of the installed units of **commercial refrigerators and freezers** in 2010 and estimates for 2015, 2020, 2030 is given in Table 6.

Table 6: Installed units of commercial refrigerators and freezers in 2010 (reference) and 2015, 2020, 2030 (estimates)

Appliance group	**Commercial refrigerators and freezers**			
Reference Year	2010	2015	2020	2030
CF supermarket segment display cabinet (remote)	2,360,000	2,660,000	2,920,000	3,430,000
CF supermarket segment display cabinet (plug-in)	1,160,000	1,310,000	1,440,000	1,690,000
CF non-supermarket segment plug-in beverage cooler	7,060,000	7,310,000	7,380,000	7,910,000
CF non-supermarket segment plug-in small ice cream freezer	3,030,000	3,130,000	3,160,000	3,390,000
CF non-supermarket segment plug-in vending machine	1,560,000	1,370,000	1,250,000	1,290,000
Source	JRC, 2014	JRC, 2014	JRC, 2014	JRC, 2014
Reference countries	EU28	EU28	EU28	EU28

Note: CF = Commercial refrigeration products

An overview of the installed units of **water heaters** in 2010 and estimates for 2015, 2020, 2030 is given in Table 7. The number for water heaters includes electric storage and instantaneous water heaters, gas-and oil fired storage and instantaneous water heaters as well as solar-assisted water heaters (note: instantaneous water heaters are part of 'behavioural' appliances).

According to estimates by JRC, the installed stock of **electric storage water heaters** in EU-27 in 2007 was 90 million units. Electric storage water heaters with a capacity of more than 30 litres represent 27 % of the installed base of primary water heaters. (Bertoldi and Anatasiu, 2009[91]).

No data are available on the share of smart water heaters. There is a study from Sweden[92] investigating the flexibility of water heaters, but it is not possible to extrapolate these data for EU-28.

Table 7: Installed units of water heaters in 2010 (reference) and 2015, 2020, 2030 (estimates)

Appliance group	**Storage water heaters continuously heating / night storage***			
Reference Year	2010	2015	2020	2030
Installed base	157,293,000 (total)	53,000,000 / 20,000,000*	50,000,000 / 19,000,000*	45,500,000 / 17,200,000*
Source	Kemna, 2014	Ecodesign study (VHK, 2007) and industry estimation[93]	Ecodesign study (VHK, 2007) and industry estimation[93]	Ecodesign study (VHK, 2007) and industry estimation[93]
Reference countries	EU28	EU28	EU28	EU28

2.2.3. BEHAVIOURAL APPLIANCES

According to estimates by JRC, the installed stock of **instantaneous water heaters** in EU-27 in 2007 was 29 million units. Instantaneous water heaters (> 12 kW) represent a share of 6.6 % of the installed base of primary water heaters. In view of secondary installations, instantaneous water heaters have a share of 7 %. (Bertoldi and Anatasiu, 2009[94])

An overview of the installed units of **electrical hobs** in 2010 and estimates for 2015, 2020, 2030 is given in

[91] Bertoldi, Atanasiu (2009). Electricity Consumption and Efficiency Trends in European Union – Status Report 2009, European Commission DG Joint Research Centre
[92] http://publications.lib.chalmers.se/records/fulltext/195330/195330.pdf
[93] Communication from Ariston Thermo Group
[94] Bertoldi, Atanasiu (2009). Electricity Consumption and Efficiency Trends in European Union – Status Report 2009, European Commission DG Joint Research Centre

Table 8. Electrical hobs only have an emergency flexibility potential.

Table 8: Installed units of electrical hobs in 2010 (reference) and 2015, 2020, 2030 (estimates)

Appliance group	Electrical hobs			
Reference Year	2010	2015	2020	2030
Installed base	133,781,000	149,114,000	163,566,000	188,544,000
Source	Kemna, 2014	Kemna, 2014	Kemna, 2014	Kemna, 2014
Number of smart appliances	Only emergency flexibility potential	Only emergency flexibility potential	Only emergency flexibility potential	Only emergency flexibility potential
Reference countries	EU28	EU28	EU28	EU28

An overview of the installed units of **electrical ovens** in 2010 and estimates for 2015, 2020, 2030 is given in Table 9. Electrical ovens only have an emergency flexibility potential.

Table 9: Installed units of electrical ovens in 2010 (reference) and 2015, 2020, 2030 (estimates)

Appliance group	Electrical ovens			
Reference Year	2010	2015	2020	2030
Installed base	191,823,000	199,332,000	209,502,000	232,059,000
Source	Kemna, 2014	Kemna, 2014	Kemna, 2014	Kemna, 2014
Number of smart appliances	Only emergency flexibility potential	Only emergency flexibility potential	Only emergency flexibility potential	Only emergency flexibility potential
Reference countries	EU28	EU28	EU28	EU28

An overview of the installed units of **range hoods** in 2010 and estimates for 2015, 2020, 2030 is given in Table 10. Range hoods only have an emergency flexibility potential.

Table 10: Installed units of range hoods in 2010 (reference) and 2015, 2020, 2030 (estimates)

Appliance group	Range hoods			
Reference Year	2010	2015	2020	2030
Installed base	92,371,000	97,111,000	102,060,000	112,741,000
Source	Kemna, 2014	Kemna, 2014	Kemna, 2014	Kemna, 2014
Number of smart appliances	Only emergency flexibility potential	Only emergency flexibility potential	Only emergency flexibility potential	Only emergency flexibility potential
Reference countries	EU28	EU28	EU28	EU28

An overview of the installed units of **vacuum cleaners** in 2010 and estimates for 2015, 2020, 2030 is given in

Table 11. Vacuum cleaners only have an emergency flexibility potential.

Table 11: Installed units of vacuum cleaners in 2010 (reference) and 2015, 2020, 2030 (estimates)

Appliance group	**Vacuum cleaners**			
Reference Year	2010	2015	2020	2030
Installed base	364,226,000	388,857,000	419,407,000	545,178,000
Source	Kemna, 2014	Kemna, 2014	Kemna, 2014	Kemna, 2014
Number of smart appliances	Only emergency flexibility potential	Only emergency flexibility potential	Only emergency flexibility potential	Only emergency flexibility potential
Reference countries	EU28	EU28	EU28	EU28

2.2.4. HVAC

This category comprises heating and cooling appliances. As for heating, there are direct effect electric radiators (with or without built-in heat storage capability), electric heat pumps, and electric boilers (including pump circulators). As for cooling, air conditioning systems consist in residential air conditioners (mainly split) and non-residential air conditioners (chillers, multi-split systems with variable flow). Both categories are treated separately, electric heating and air conditioning.

2.2.4.1. Heating

Joule heating

From the EuP DG ENER Lot 20 study (BIOIS, 2012), it is possible to extract the estimated stock of installed electric heating appliances in Europe and European consumption in 2010. Individual data for electric appliances are not available in the policy scenario analysis. Probably this population of electric heaters is no longer increasing anymore, due to the effect of the national building regulations.

Table 12: Electric heater units, power installed and consumption, Source: (BIOIS, 2012)

Electric heating type	**EU-27 stock (in 1000 units)**	**TOTAL (GW) Installed capacity**	**Hours**	**Energy (TWh)**
NO INERTIA, PORTABLE	61,400	63	324	20
NO INERTIA FIX	159,200	166	1,130	188
WITH INERTIA	13,800	37	1,324	49
TOTAL	**234,400**	**266**		**257**

Probably most inertia storage heaters are in the residential sector, while for units without inertia it is not clear. Indeed, according to (Bertoldi, 2009), the total residential and tertiary electric space heating consumption was close to 270 TWh in 2007. It probably means that both residential and tertiary electric radiators are included in the figures above.

Electric boilers
Electric boilers are simply water storage electric heating boilers similar to hot water electric storages for which the electric element is larger in order to be able to supply the heating needs of a dwelling. According to (VHK, 2007), the stock of units was around 1.1 million in 2004, with average size between 4 and 15 kW[95] or about 10 GW installed capacity / power (keeping a median 10 KW value per unit).

Electric heat pumps
(EHPA, 2014) gives an estimate of the market and stock for heat pumps in Europe. The total stock of heat pumps is estimated to 4.5 million units in 2010 and 6.7 million units in 2013. With an average of about 30 kW output (according to EHPA, 2014) and assuming a base temperature of - 7°C, this capacity reaches about 18 kW and the COP of approx. 2 (assuming most heat pumps are of the air source type), it leads to about 9 kW electric peak load per unit, resulting in 40 GW (at peak conditions i.e. for - 7 °C outside) for the total stock of heat pumps in 2010 and already about 60 GW in 2013. This is probably a conservative low-end figure because only a minor part of reversible air conditioners is taken into account as being really used as a heat pump. But at the same time, the share of non-residential units is not known. Nowadays there is an upcoming technology of hybrid heat pumps (products that combine a gas or liquid fuel boiler and an electric heat pump) that can shift from electricity to gas when required and may shift almost completely their energy consumption to gas if this is required. Currently, the market for such hybrid products is very small. Together with the fact that no data are available on the installed base of hybrid heat pumps, the flexibility potential of this subgroup cannot be isolated in the analysis.

Boiler circulators
There were about 103 million circulators installed in Europe in 2005 (VHK, 2007), serving all directly the boiler systems. Their energy consumption was estimated to be around 50 TWh/a (Stamminger, 2008). This total energy consumption is thought to decrease by at least a half by 2025, as the stock of boiler will have been replaced and newer boilers use circulators whose consumption can be 4 times less than for older boilers as consequence of the respective EU regulation. For most old circulators in the stock, the flow rate is constant during all the heating season, whereas in newer installations, circulators only work when there is a heat demand. With variable flow technology being the new standard, the power drawn by the circulator will more and more depend on the actual heat load as well as the outdoor temperature.
For an average heating season of 9 months, assuming a constant power drawn over 9 months (c.a. 6500 hours), the total power installed is close to 7.5 GW (equals to 50 TWh / 6500 h) for the residential sector.

Total installed base of electric heating (estimation from market research) in EU27
In 2010, the total installed base of electric heating systems is assumed to be close to 325 GW in Europe. A summary table for the whole group of electric heating systems is presented below. This figure probably contains a large part of the tertiary electric heating installations for joule heating and for electric heat pump.

[95] http://www.boilerguide.co.uk/articles/electric-boilers

Table 13: Electric heating units, installed power, summary table

	Million units	GW	GW Probable trend after 2014
Electric heating, without built-in inertia (2)	**226.2**	**279**	Decreasing
Joule fix residential + tertiary () 2010	159.2	166	Decreasing
Joule portable (residential + tertiary) 2010	61.4	63	Decreasing
Elec. Boiler (residential) 2005	1.1	10	Decreasing
Elec. Heat pump (residential + tertiary) 2010 (1)	4.5	40	Strong increase
Electric heating, with built-in inertia	**13.8**	**37**	Decreasing
Circulation pump	**103**	**7.5**	Strong decrease

(1) At -7°C full capacity
(2) Probably contains also part of tertiary building heating systems

Total installed base of electric heating (estimation from the grid)
Figure 20 is an interesting figure that is worth being compared with what is seen at the electricity grid level. RTE[96] is in charge of ensuring matching consumption and generation of electricity and releases information about the temperature sensitivity of electricity consumption in France every year.
Figure 20 shows the correlation between average daily outdoor temperature (weighted average temperature over 30 cities in France[97]) and daily national energy consumption. The derivative of the heating slope is evaluated to be 2400 MW / °C (RTE, 2013). It means that below a certain threshold of around 15 °C, each decrease of 1 °C will increase the national electricity load by 2400 MW / °C. In 2012, the peak day in France occurred on February 8 with a daily average required power of about 93 GW. This is coherent with calculations based on the average daily temperature of about -4 °C, leading to an average load of 93.5 GW (1150/24 + (15-(-4))*2400 = 93.5 GW)

[96] RTE (Réseau de transport d'électricité) - French electricity transmission system operator.
[97] Please note: To make this correlation, RTE filters the effect of nebulosity during the day, i.e. the load reduction due to solar radiation is not accounted for, although it has most likely only little impact during the coldest days of the year.

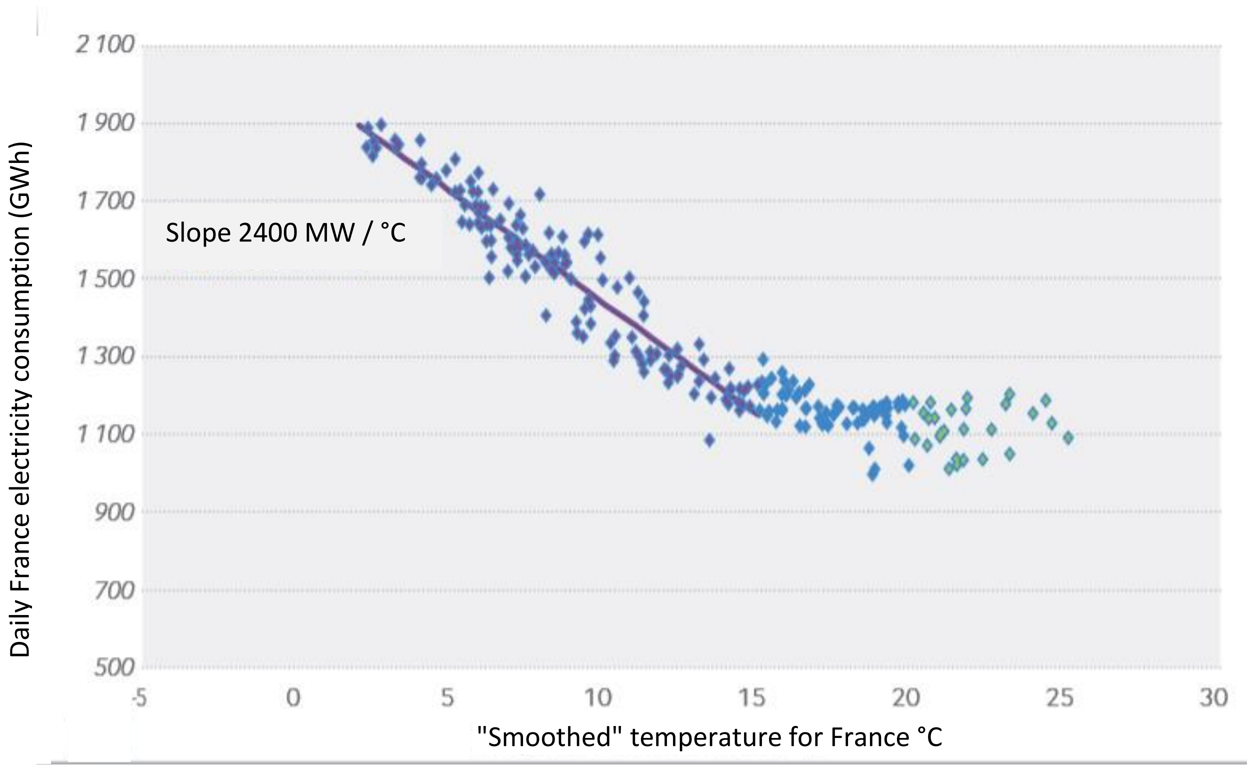

Figure 20: Temperature sensitivity of electricity consumption in France in 2013 - daily average electricity consumption VS smoother average France temperature and slope, from (RTE, 2013)

On Figure 21, the same slope is indicated for several EU countries and at EU level. It can be seen that France alone accounts for close to 50 % of the total temperature sensitivity of the EU electricity consumption as consequence of the widespread usage of electric heating systems.

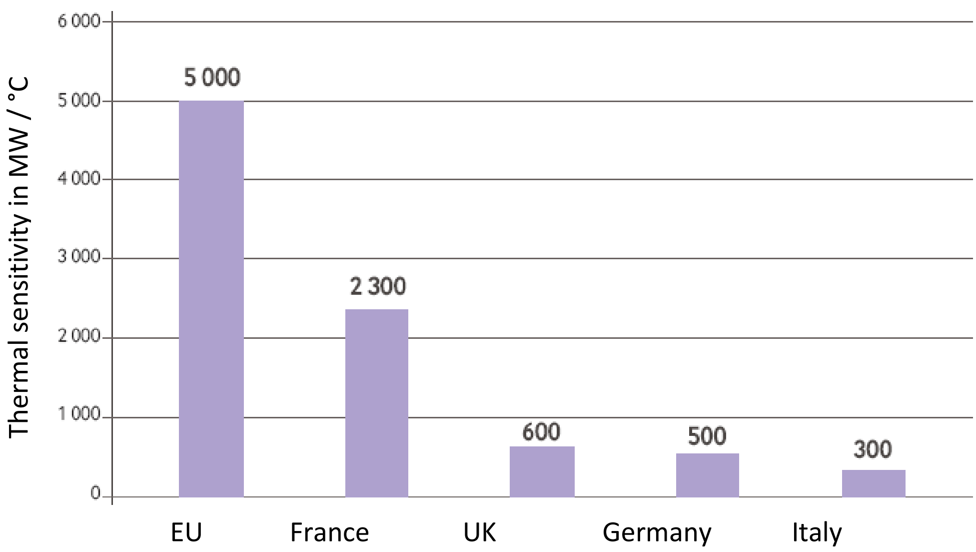

Figure 21: Temperature sensitivity of electricity consumption in France and other countries in Europe in 2012, from (RTE, 2012)

Assuming the same threshold temperatures apply for Europe and that EU average on February 8 was close to - 4 °C like in France, it gives a total electric heating contribution of around 5 * 19 or 95 GW. This is only to give an order of magnitude.

However, this estimation is noticeably much less than could be inferred from the market data, which indicated a total installed stock power close to 325 GW for electric heating. There may be many reasons for this important difference:

- Circulation pump consumption profile is probably not temperature sensitive nowadays (as most circulators are still with constant flow) so that the signal from the grid is underestimated by about 10 GW.
- Probably, some of the heaters are not in use (the case of many portable heaters probably, heating systems in secondary houses, secondary or backup systems).
- It is likely that many installations are oversized by 20 to 50 % because of local design habits.
- Others may be operated at peak conditions all year long (probably the case of some fan heaters in the industry) and thus their consumption is not sensible to the outdoor temperature.

Although this is a very rough estimation, it is most likely that the maximum electric demand in winter peak conditions for an typical meteorological year is close to 100 GW despite an apparently much larger installed base.

2.2.4.2. VENTILATION

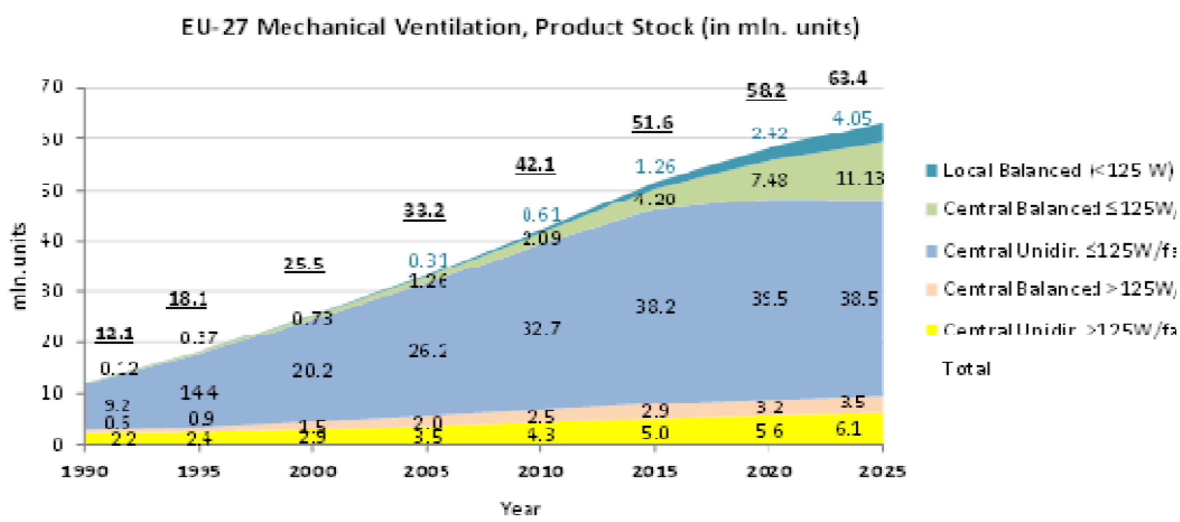

Figure 22: Stock of ventilation units in the EU 1990-2010 and projections 2010-2025 (BAU, source: preparatory studies), from (EU, 2014)

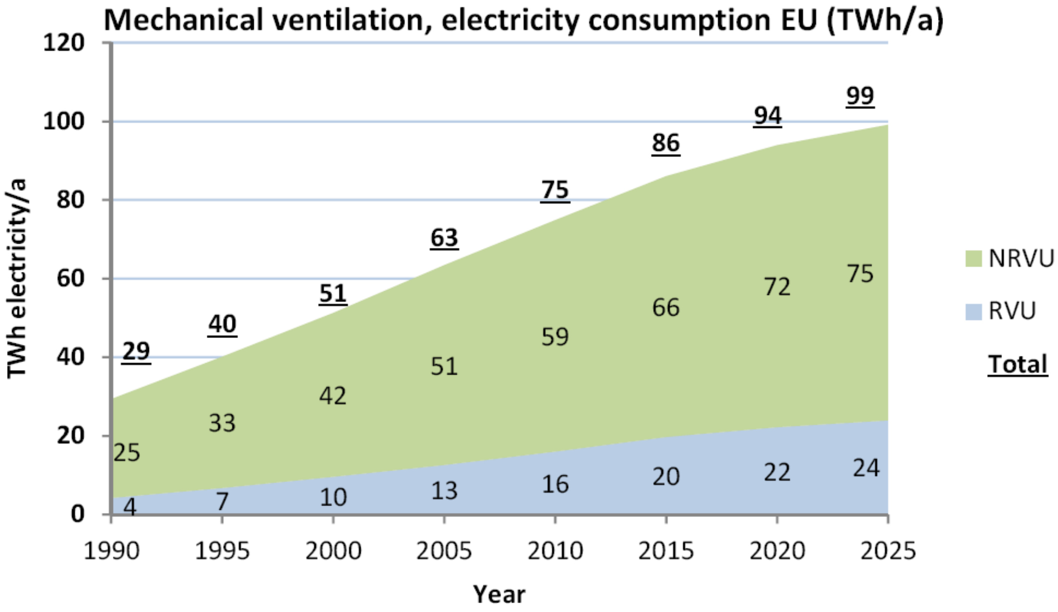

Figure 23: Mechanical ventilation, EU electricity consumption 1990-2010 and projections 2010-2025 (BaU) in TWh electricity per year (EU, 2014)

Please note that in comparison with figures in (Bertoldi, 2009), the presented electricity consumption is much lower (in 2007, 67.5 TWh/a on

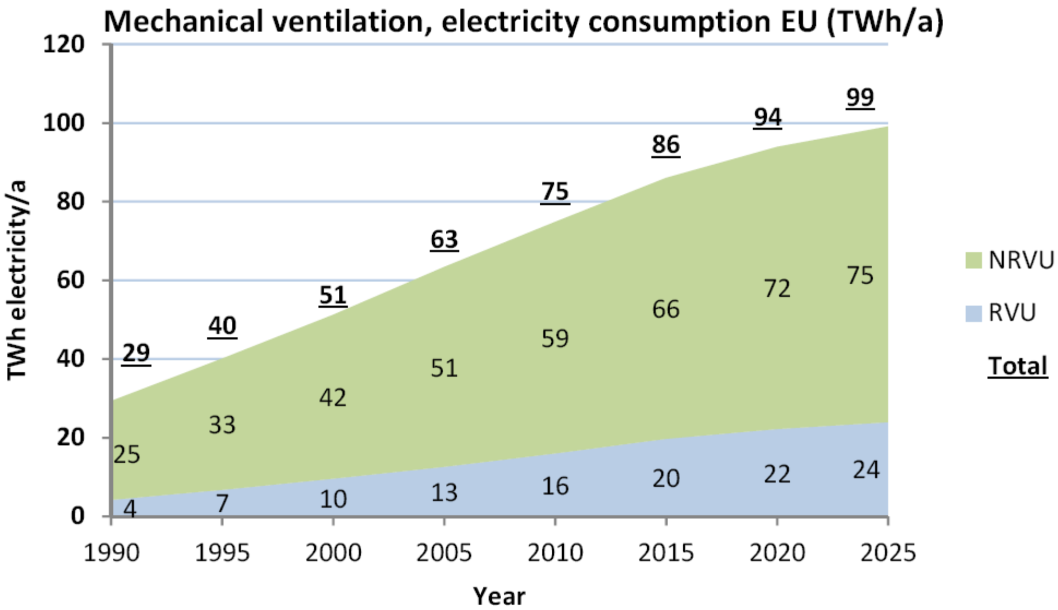

Figure 23 versus 118 TWh/a in (Bertoldi, 2009)). But in total, the sum of air conditioning consumption estimated in preparatory studies[98] and of ventilation in (Eu, 2014) is quite close to (Bertoldi, 2009) estimates.

This consumption represents a near constant electric load of 1.8 GW for the residential sector. In the non-residential sector, ventilation is controlled at night and during weekends. The load is thus probably closer to 10 GW during the day (6.7 GW on average over 24 hours). These figures are expected to increase by 50 % between 2010 and 2025.

2.2.4.3. Air Conditioning

Table 14: EU stock of air conditioning systems in GW of cooling capacity, source (Rivière, 2007) and (Rivière, 2012)

Peak power GW	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**
Air conditioners < 12 kW (w/o portable)	8,8	21,2	37,9	61,8	85,7	89,3	99,6	108,1
Air conditioners > 12 kW	5,2	11,9	22,9	33,0	39,5	42,6	46,2	51,0
Chillers	31,1	40,0	49,2	61,2	72,8	81,9	90,1	97,3
Total	**45,1**	**73,1**	**110,1**	**156,0**	**198,0**	**213,8**	**235,9**	**256,4**

Energy consumption TWh	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**
Air conditioners < 12 kW (w/o portable)	3,1	7,6	13,3	20,0	25,9	24,8	27,6	30,3
Air conditioners > 12 kW	2,2	5,3	10,2	15,6	19,7	20,8	21,9	23,8
Chillers	14,3	17,3	21,7	27,3	32,9	37,3	40,5	42,3

[98] Air conditioning preparatory studies : Central air conditioning systems (Rivière, 2012) and room air conditioners (Rivière, 2009).

Total	**19,7**	**30,2**	**45,2**	**62,8**	**78,5**	**82,9**	**89,9**	**96,3**

Portable air conditioners are not considered in this evaluation of the air conditioning potential for DSF. Please note that post 2005 figures for units <12kW and post 2010 figures for the rest of cooling appliances are BAU scenarios.

(Bertoldi, 2009) shows lower estimates for tertiary air conditioning: in 2007, it is estimated to 21.6 TWh versus 42.5 TWh in (Rivière, 2012) but residential figures are matching. In addition, the sum of tertiary air conditioning and ventilation are relatively close in both (Bertoldi, 2009), and in (VHK, 2012) and (Rivière, 2012).

Please note that as opposed to the heating load, there is little information regarding the impact on the European grid, so it is difficult to make a reality check of these figures.

2.2.4.4. Estimation of smart appliances' penetration rate

HVAC smart appliances' penetration rate nowadays can be estimated as extremely low, according to the feedback of one HVAC manufacturer.

Air conditioners and heat pumps

Table 15: Total sales of Air conditioners by the Japanese Refrigeration and Air conditioning industry (2014)

Region & Country		2009	2010	2011	2012		2013		2014	
		-	-	-	window	split	window	split	window	split
World wide		**61,336**	**73,420**	**84,565**	**13,157**	**64,869**	**14,193**	**69,563**	**14,380**	**68,524**
Japan		6,775	8.242	8,279		8,487		9,013		8,500
China		24,787	30,424	38,425	356	30,321	348	33,124	325	32,461
Asia		9,216	10,856	11,056	1,991	9,832	1,897	10,482	1,853	11,152
Middle east		3,297	3,474	3,639	1,635	2,046	2,480	2,187	2,480	2,223
Europe	**sub total**	**4,441**	**5,741**	**7,037**	**116**	**6,153**	**104**	**5,944**	**92**	**4,951**
	Russia	860	679	2,523	38	1,846	33	1,738	29	1,320
	Turkey	545	679	916	0	1,025	0	944		773
	Italy	906	983	977	6	866	6	909	5	726
	Spain	443	609	521	8	416	9	404	8	371
	France	268	316	305	4	265	5	274	4	271
	Ukraine	113	365	403	8	345	7	318	4	221
	Greece	353	260	225	0	266	0	219		178
	UK	61	70	76	1	72	1	72	1	76
	Germany	74	75	83	4	78	4	80	4	81
	Bulgaria	64	83	101	1	110	1	92	1	85
	Romania	82	76	87	1	99	1	95	1	79
	Portugal	83	118	97	0	60	0	59		58
	Poland	43	57	59	1	56	1	55	1	55
	Norway	47	70	69	0	63	0	59		54
	Sweden	64	61	62	0	52	0	50		54
	Netherlands	30	38	37	0	33	0	34		35
	Others	375	500	496	36	501	36	542	34	514
North America		6,270	6,550	6,726	7,082	463	7,372	522	7,647	590
Latin America		4,298	5,750	6,661	1,568	5,016	1,568	5,577	1,564	5,829
Africa		1,501	1,585	1,910	344	1,824	351	1,943	347	1,990
Oceania		781	798	832	65	727	73	771	72	828

It can be seen from Table 15 that the annual sales for air conditioning in Europe (excluding Russia and Turkey) from Japanese manufacturers correspond to approximately 3,2 million units. For one air conditioner / heat pump manufacturer, the sales of smart air conditioners (communication-enabled, with future prospects for demand side flexibility) were 23% of its total sales in 2014. Extrapolating the share of demand-side flexibility air conditioners of Japanese manufacturers to other manufacturers (for every 100 air conditioners produced by any manufacturer, 23 of these are considered smart enabled) and assuming that communication-enabled air conditioners appeared with the wide use of Smartphones in 2010, the stock of smart air conditioners would represent only about a third (7%) of the estimated percentage of sales of smart air conditioners in 2014 (for a lifecycle of 15 years). This result can be used as well for heat pumps, due to the fact that controlled variables and the machine's technology are nearly identical. The stock previsions of smart air conditioners and heat pumps for 2020 and 2030 are based on the following sales' data and assumptions:

- Figures for heat pump sales for the period 2000-2015 have been made available by EHPA
- 12% annual increase for sales from 2016 to 2030. This assumption was based on the hypothesis that the development of the heat pumps and their energy efficiency will absorb

the decreasing sales of electric radiators. This assumption keeps the global heating appliances' stock constant for the period 2015-2030.

- Extrapolating the figure of 23% of smart air conditioners sales in 2014, smart sales for the different time periods are estimated at 10% in 2010-2015, 25% in 2015-2020, 40% in 2020-2025 and 55% in 2025-2030.

Applying these sales assumptions to the total stock of 4.500.000 heat pumps in Europe for 2010 (source: EHPA) leads to the following estimations of the stock of smart enabled heat pumps.

Table 16: Estimation of installed base of smart enabled heat pumps

Technology	2015	2020	2025	2030
Smart heat pumps and air conditioners (%)	7%	16%**	30%**	45%**
Total heat pumps (units)	7.400.000	9.750.000**	10.430.000**	10.930.000**

** Previsions following the hypotheses described above

Electric Radiators (including built-in inertia radiators)

The same rationale is used for estimating the previsions of smart radiators (communication-enabled, with future prospects for demand side flexibility): actual sales and stock values and future sales' trends. The following data and assumptions are used:

- 12.000.000 sales of electric radiators and 240.000 sales of built-in inertia radiators in 2010 EuP DG ENER Lot 21 study "Central heating products" (BIOIS, 2012)(2010 Stock of electric radiators and built-in inertia radiators: 221.000.000 and 13.800.000 respectively from EuP DG ENER Lot 20 study (BIOIS, 2012).
- Decreasing sales for low energy efficiency, at a constant rate of 100.000 units for electric radiators and 24.000 for built-in inertia radiators.
- Unfortunately, there is no feed-back from the market regarding the share of smart radiators nowadays. The assumption that this share is nearly zero, accompanies the fact of the low cost of the appliance itself (around 300€ for a 1000 W electric radiator) which does not incentivise manufacturers to develop a high-tech communication system that would represent an important share of the product's cost. Nevertheless, mostly communicative radiators in France (following curtailment programs and studies of RTE, Direct Energy, Voltalis) only operate in "slave mode" or only on-way communication. Given this fact, it may be possible that a small share of radiators would be smart today, even if the figures are estimated to be extremely low. The following figures were used for sales of smart enabled radiators: 1% in 2010-2015, 5% in 2015-2020, 20% in 2020-2025 and 50% in 2025-2030. As for built-in inertia radiators, the increase is more pronounced, due to the fact that these appliances can stock energy and are more suitable for distance piloting and communication: 1% in 2010-2015, 5% in 2015-2020, 30% in 2020-2025 and 60% in 2025-2030.

These assumptions and data give the following penetration of smart radiators in the market:

Table 17: Estimation of installed base of smart enabled radiators

Technology	2015	2020	2025	2030
Electric Radiator (% smart)	0,2%**	3%**	9%**	21%**
Built-in inertia Electric radiator (% smart)	0,05%**	1%**	4%**	8%**
Total Electric Radiators (units)	221.000.000**	220.920.000**	213.000.000**	203.275.000**
Total Built-in inertia electric radiators (units)	13.800.000**	13.775.000**	13.700.000**	13.550.000**

** Previsions following the hypotheses described above

Electric Boilers (including built-in inertia radiators)

The same rationale is used to estimate the share of smart electric boilers (communication-enabled, with future prospects for demand side flexibility) and the installed base prediction for 2020 and 2030. The following data and assumptions are used:

- Stock of electric boilers: 1.100.000 units in 2004 from EuP DG ENER Lot 1 study "Boilers" (VHK, 2007).
- Known sales of electric boilers for 1990 and for 2004: 40.000 per year (VHK, 2007). These figures are used to extrapolate constant sales from 2010 to 2030.
- There is no available information on the share of smart enabled electric boilers, but again, the current share is presumed to be very small. Nevertheless, given that electric boilers are big energy consumers, there is a potential for enabling smart boilers. Also, given that energy can be stored (in a water tank for example), there could be an interest in monitoring and piloting boilers. Therefore, the sales of smart electric boilers might have an important increase, even if their share of the actual electric heating market is relatively low. The following sales figures of smart boilers are used to estimate the stock: 1% in 2010-2015, 5% 2015-2020, 20% 2020-2025 and 60% in 2025-2030.

These assumptions and data give the following penetration of smart radiators in the market:

Table 18: Estimation of installed base of smart enabled electric boilers

Technology	2015	2020	2025	2030
Electric boiler (% smart)	0,4%**	2%**	7%**	18%**
Total electric boilers (units)	1.100.000**	1.100.000**	1.100.000**	1.100.000**

** Previsions following the hypotheses described above

2.2.4.5. BATTERY OPERATED RECHARGEABLE APPLIANCES

The installed base of battery operated rechargeable appliances is very high. For smartphones only the expected sales figures (IDC, Gartner and JPMorgan) worldwide have gone from 300 million in 2010 to more than 650 million in 2012 and is expected to grow above 1 billion in 2016. The estimated total installed base for smartphones only will exceed 2 billion. For the complete cellular phones market figures range to over 2 billion in 2016 and even 3 billion in 2024[99]. The situation is similar for tablets worldwide, with sales growing from 200 million in 2013 to an expected 350 million in 2016 (Gartner, 2012). Laptop sales in 2014 were 173 million with sales decreasing since 2008[99]. Estimates for the coming years state a stable or slightly decreasing market.
For Europe (EU28), the sales of all mobile phones (smartphones and regular mobile phones) range from 227 million in 2009 to 213 million in 2013. Sales of personal navigation devices (PNDs) in Europe peaked at 17 million units in 2008 and fell to less than 10 million units by 2012. Digital camera figures remained around 30 million till 2012. It is expected that this figure will decrease in the subsequent years in favour of smartphones with advanced integrated cameras.
Figures for other appliances are harder to find, but it is estimated that all together they represent annual sales of more than 50 million units in the EU[100].

2.2.5. RESIDENTIAL ENERGY STORAGE SYSTEMS

In 2015, approximately 25,000 batteries are expected to be operational in Germany[101]. The German market can currently be considered as the only mature market of home battery storage applications (in combination with PV-installations). In Germany, a large amount of solar panels in combination with a subsidy scheme for residential energy storage (up to 30% of initial investment is subsidized), makes a home battery system attractive. Estimates predict that by 2018, the German market will have stabilized with on average 100,000 units per year. As a result, by 2020, a total of 500,000 units are estimated to be installed by 2020 in Germany[102].

Recent information provided by Panasonic in the press shows the intention of battery suppliers to target other European markets as well, including France and the UK[103]. However from the available information today, based on current policies, subsidy schemes and costs, no mature market can be expected by 2020 in EU28 apart from Germany.

Few information exists on the potential of residential energy storage systems for 2020 and 2030. Estimates by Roland Berger, Avicenne and BCG indicate that the global market for residential energy storage systems could grow up to 3 to 10 GWh in 2020 and 6 to 15 GWh in 2025[104]. This large range of estimated future potentials makes it clear that experts find it very difficult to make clear projections for the period between 2020-2030. An important reason for this is that the success of residential energy storage systems in 2030 is highly dependent, on the one hand, on the national subsidy schemes for both renewable energy (feed-in tariffs) and home battery systems and on the other hand on the evolution of the purchasing cost of home battery systems.

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[99] AVICENNE ENERGY, The Rechargeable Battery Market and Main Trends 2014-2025
[100] Framework Service contract ENTR/2008/006/Lot 1, Study on the Impact of the MoU on Harmonisation of Chargers for Mobile Telephones and to Assess Possible Future Options
[101] http://www.insightenergy.org/ckeditor_assets/attachments/48/pr1.pdf
[102] http://www.insightenergy.org/ckeditor_assets/attachments/48/pr1.pdf
[103] http://www.greentechmedia.com/articles/read/Panasonic-Enters-Europes-Burgeoning-Home-Battery-Market
[104] http://www.insightenergy.org/ckeditor_assets/attachments/48/pr1.pdf

In the framework of this study the assumption has been made that in 2015 and 2020 the EU28 market will have a size that is comparable with the size of the German market which may be considered as a conservative estimation. For 2030, the penetration level of residential energy storage systems is highly depending on evolutions in technology and policy decisions therefore no clear assumption can be put forward. In Task 7 (as part of an ongoing second phase of this Preparatory Study), a sensitivity analysis will be presented analysing several scenario's with respect to the penetration rate of residential energy storage systems by 2030.

Regarding uninterruptible power supply (UPS), the total installed base for 2011 was calculated as 7.5 million UPS units105 in EU27, represented by the following size categories:

- Below 1.5 kVA products: 53% of the total installed base
- 1.5 to 5 kVA products: 41% of the total installed base
- Above 5 kVA products: 6% of the total installed base

The above figures include mainly UPS systems used in data centres and larger organisations (companies, hospitals, etc.), which are however out of the scope of this study. In Western Europe, in 2013 the annual data centre load requirement was an estimated 79 TWh. So only a very small fraction of these systems is located in residential and small business setups. No exact figures were found for these specific products.

2.2.6. LIGHTING

Please find below an overview of the estimated stock year 2013 based on the Ecodesign Preparatory Study on Light Sources (ENER Lot 8/9/19 (VITO, 2015):

- LFL: Linear fluorescent lamp: 2209 million units
- CFL: Compact fluorescent light: 4406 million units
- Tungsten: 2569 million units
- GLS: General lighting service ('incandescent'): 561 million units
- HID: High intensity discharge lamp: 84 million units
- LED: Light emitting diode: 144 million units

Separately, the estimated number of street lighting luminaires in EU-25 is about 60 million (2004 figures) (VITO, 2007).

2.3. ECONOMIC INSTRUMENTS - REMUNERATION MECHANISMS

The pre-conditions for an uptake of smart appliances and implementation of smart grids are:

- that the EU Member States have provided access to demand side resources according to the Energy Efficiency Directive art. 15, item 8. The requirement is that the TSOs and DSOs treat DR providers including aggregators, in a non-discriminatory manner, on the basis of their technical capabilities. This is however subject to technical constraints inherent in managing networks.

- that the smart appliances need to be in the homes, offices etc. and the end-users must also have accepted that the BRPs, aggregators etc. control their energy usage in the DR perspective, which again requires sufficient incentives and remuneration for the end-users.

[105] ErP Lot 27 – Uninterruptible Power Supplies, Preparatory Study - Final Report

In order to boost the market for demand response, the EC emphasizes the importance of market-based and dynamic and transparent incentives that reward participation through dynamic prices without unnecessary constraints[106].

First, it should be used to transfer (part of) the value of the flexibility of smart appliances to end-consumers[107]. Second, it is a key to incentivize end-consumers to shift their consumption and offer the flexibility of smart appliances when the value for society is high. This is the case when the system is under stress and prices (day-ahead prices and/or imbalance prices) are high. A proper remuneration system will also increase the level of self-consumption of households that have a combination of local production (e.g. solar panels), storage (e.g. batteries) and flexible consumption (e.g. smart appliances) at their disposal. To note that financial incentives through a dynamic pricing scheme on itself are not sufficient to establishing a structural change in consumer behaviour[108]. Task 3 of this report will discuss more in detail the drivers for consumer behaviour, besides financial incentives.

In this section, an overview is given of the most important remuneration mechanisms existing today. A proper implementation of these dynamic tariffs requires smart meters that enable the communication between the meter of the end-consumer and the utility.

2.3.1. USE CASES

As will be further explained in Task 3, smart appliances can be used for different use cases. Two distinct use cases can be defined, based on two important time blocks in the market: day-ahead versus real-time.

1) Day-ahead use case

In day-ahead, the schedule of electricity production and consumption is determined. In order to match supply and demand, balance responsible parties have several possibilities. First, they can adapt their production volume by optimizing own generation units or by participating to the various European Power Exchanges that enable them to trade volumes in the short term (day-ahead). The prices on the power exchange are determined on an hourly basis and are published in a transparent way. The prices on the day-ahead market reflect the marginal cost of the last unit that is needed to produce these volumes.

DSF could directly participate in the day-ahead market platform. The Balancing Responsible Parties (BRPs) have also the possibility to modify the load in order to match supply and demand. Load reduction or load shifting can avoid costs of additional production during hours with high prices. In this case, the demand side flexibility is directly integrated in the portfolio of the BRP. Independent of how demand side flexibility through the use of smart appliances is offered in day-ahead, it will

[106] https://ec.europa.eu/energy/sites/ener/files/documents/com_2013_public_intervention_swd07_en.pdf

[107] The value of smart-appliances is also beneficial for consumers without smart appliances or dynamic remuneration scheme. These consumers will benefit indirectly from the flexibility offered by flexible consumers, via an average decrease of system costs for balancing which could be passed through towards all consumers via a reduction in grid tariffs or a reduction in fixed costs of the energy supplier.

[108] Boork M, Thomtén M, Brolin M, Uyterlinde M, Straver K, Kraan C, Kleine-Hegermann K, Laes E, Valkering P, Maggiore S. Key success factors and barriers to end-user engagement in smart grid projects. Paper presented at the 2014 BEHAVE conference, London. Available from: <http://behaveconference.com/wp-content/uploads/2014/08/F_Magdalena_Boork_Technical_Research_Institute_of_Sweden.pdf>

support the matching of supply and demand at a lower cost. In case of high estimated production of RES during certain hours, load could be shifted or increased during these hours. In case of high estimated load, a decrease or shift in load will have a downward effect on prices.

2) Imbalance use case

In real-time, deviations are observed between supply and demand. Different reasons can explain these deviations. Changing weather conditions are the primary source of these deviations. The realised production of renewable energy sources (wind and solar) is highly dependent on the weather. The demand or load is also affected by weather conditions such as temperature and cloud cover. In addition, non-weather related causes such as sudden outages of generation units or human errors e.g. in load forecasts can also explain why there is an imbalance between supply and demand in real-time.

The TSO is responsible for the stability of the grid and security of supply at the lowest cost in real-time or in near real-time. It will monitor in real-time the deviations of the grid and activate the necessary ancillary services in order to balance the system. Ancillary services can be provided by both, generation and load management, dependent on the type of ancillary service product. Dependent on the country, ancillary services are contracted by the TSO via yearly, monthly or weekly tenders. Today, the three categories of ancillary services are FCR[109], FRRa[110] and FRRm[111]. The relevant ancillary services for demand response today are FCR and FRRm. FRC is used by the TSO to ensure that the grid frequency stays within a certain range within the interconnected high-voltage European system. FRRm is used by the TSO to cope with major imbalance and congestion issues.

The cost of the activation of ancillary services (FRRa and FRRm) is reflected in the imbalance price published afterwards. As each BRP is responsible for the balance of its own portfolio, their individual imbalances will be invoiced based on the imbalance prices.

Similar to the day-ahead use case, demand side flexibility can be part of the imbalance use case in different ways. First, demand side flexibility can participate directly in the market of ancillary reserves (FCR and FRRm). An example of demand side flexibility participating to the market of FRRm is the product R3DP in Belgium (see later). The response time for FRRm is on average 15 minutes, which is sufficient for demand side flexibility to participate. In general, it is more difficult for demand side flexibility to participate in the market of FCR. In most countries, the required volumes, product characteristics (fast response time (15 seconds), duration, symmetrical product) and the requirement to be connected at the transmission grid are important barriers for demand side flexibility to participate in the market for primary reserve[112]. Applications that respect these constraints are for example applications based on batteries, connected at the transmission grid. Nevertheless, efforts are made by TSOs to enable demand side flexibility to participate. An example is the Belgian TSO Elia who created a specific product (R1 Load) that takes into account the characteristics of demand side flexibility and allows participation of demand side flexibility via aggregators to the market of FCR[113]. Today, the product R1 load is only possible for resources connected at the transmission grid.

[109] FRC = frequency containment reserves or currently called primary reserves. FCR are continually activated and have a fast response time (15 sec).

[110] FRRa = automated frequency restoration reserves or currently called secondary reserve. FRRa is activated on automated basis.

[111] FRRm = manual frequency restoration reserves of currently called tertiary reserves.

[112] http://www.smartenergydemand.eu/wp-content/uploads/2015/09/Mapping-Demand-Response-in-Europe-Today-2015.pdf

[113] http://www.elia.be/~/media/files/Elia/Products-and-services/Ondersteunende%20diensten/R1-load_general_framework_2015-2018-update_February_2016.pdf

Alternatively, demand side flexibility can be used by the BRPs in order to optimize the balancing of their portfolio which results in a decrease of their imbalance costs.

3) Other use cases

Besides the two main use cases discussed above, DSF could serve other objectives as well, such as DSO grid congestion cases, reactive power voltage support in the transmission grid,….

The focus of this study will be on the impacts for the day-ahead use case and imbalance use case, however additional use cases exist where the flexibility of smart appliances would have significant value. A use case with a lot of potential is the use of flexibility by distribution system operators (DSOs) to solve local grid constraints (congestion management and voltage control) in specific areas of the distribution grid. Although today it is not yet possible to build a sound evaluation of the extent of these opportunities due to a lack of data, (preliminary results of) several research projects show that they are expected to become promising in the future.

2.3.2. OVERVIEW OF REMUNERATION MECHANISMS[114]

The dynamics of different remuneration mechanisms are defined by the number of time periods per day, the price update frequency, the price difference between periods and the presence of special events (with limited duration and occurrence) that trigger higher or lower prices. Responses to price signals by end-users can be manual or fully automated.

Most tariff structures can be classified in following categories:

1. Time-Of-Use Pricing (TOU)

Time-Of-Use Pricing divides the day into a predefined set of timeperiods (typically periods of 3 to 6 hours). The price for each period is constant and predetermined. The most basic form of Time-Of-Use Pricing is the day/night tariff where two periods with different prices are distinguished. More advanced TOU-schemes (with more time periods) could be introduced in order to shift the average consumption pattern in such a way that it follows closer the estimated production profile of RES and reduces peak demand. This static pricing mechanism does not take into account the dynamic real-time system conditions. The price the end-consumers receive for the energy that is shifted will reflect the average system cost over a certain period of time.

2. Real Time Pricing (RTP)

Dynamic Real-Time Pricing is based on real-time hourly or quarter-hourly prices or on day-ahead hourly prices. Real Time Pricing is reflecting the actual state of the system and the related system costs. Real-time Pricing provides a dynamic temporal resolution in passing through real-time prices to

[114] Additional information on tariff schemes can be found in: http://www.aemc.gov.au/getattachment/04f6b84c-d839-4cc5-9f4b-35f9e321c3c5/The-Brattle-Group-%E2%82%AC%E2%80%9C-Managing-the-costs-and-benefi.aspx and on the project website of the S3C ("Smart Consumer, Smart Customer, Smart Citizen") project www.s3c-project.eu. The S3C project analyses new options deriving from smart grid technologies for the activation and long-term engagement of end-users.

consumers. However, as it requires a continuous monitoring of prices, an adequate and automated control system is required.

3. Critical consumption pricing (critical peak pricing CPP" and critical peak rebate)

In case of high anticipated load and resulting prices or high production of RES, a critical event is defined during a specified time period by the utility. During this time period, the energy price is raised or decreased significantly. As a result, critical peak pricing is used to reduce the critical peak load (in case of grid overload) or to increase the load (in case of excess power from RES). Critical peak rebate is a similar concept where end-consumers receive a rebate in case they consume less than expected (in case of grid overload) or in case they consume more than expected (in case of excess power from RES). These remuneration mechanisms are only used for a limited number of major events during the year.

4. Variable Peak Pricing (VPP)

This pricing mechanism is a hybrid form of TOU Pricing/CPP Pricing and RTP Pricing. The time blocks are predetermined, such as within the TOU pricing mechanism/or for a CPP event. However, the price for each block is not predetermined and is based on real-time market conditions.

5. Capacity remuneration

The pricing schemes explained before will remunerate the flexibility by pricing the energy shifted (€/MWh). It is also possible to remunerate the owner of a smart appliance upfront based on the available capacity (€/MW). This capacity remuneration can be fixed on an annual base, or even on shorter time periods such as a monthly base. Historically, capacity remuneration mechanisms were used in the context of the remuneration of ancillary services for balancing purposes. This capacity remuneration can be combined with energy remuneration in case of activation of the flexibility.

6. A combination of several tariff schemes

As explained, smart appliances can be used for different use cases. Therefore, dependent on the category of smart appliances, several of the remuneration mechanisms can be combined. A common combination is a TOU-tariff together with a CPP mechanism for special events.

7. Distribution grid fee power component minimization

The distribution grid fee may consist of a power component which means that the fee paid by the end consumer is at least partially based on the highest power consumption and/or production at the connection of the end consumer, where this highest power is then for instance the highest average quarter hour power value measured in an interval of, for instance, 1 month. In this case, it may be profitable for the consumer to use DSF to minimize this highest power value and in this way reduce his/her distribution grid costs.

8. Feed-in tariffs lower than consumption tariff

If the tariff to buy electricity is higher compared to the reward received by consumers for their (PV) production, then it may be profitable for the end consumer to use DSF to maximize local consumption of locally produced energy. This is, for instance, already the case in Germany.

9. Other incentives (e.g. reduction purchase price)

Besides remuneration for the offered flexibility, additional incentives to stimulate the investment in smart appliances could be considered. For example a reduction in the purchasing price of eligible appliances could lower the barrier for end-consumers to buy smarter appliances. Note should be taken of the fact that additional measures (see 2.3.4) are necessary to guarantee that consumers will actually use the flexibility inherent in the appliance they have purchased.

A dynamic remuneration mechanism will not only enable consumers to modify their consumption pattern, based on the requirements of the grid (peak demand, profile of RES). Remuneration measures such as the power component in distribution grid fees (see 2.3.2) will also stimulate consumers, who have local production via e.g. solar panels, to match as much as possible their local production profile with their local consumption profile.

2.3.3. EXAMPLES OF EXISTING (DR) PRACTICES

The Smart Energy Demand Coalition (SEDC) has assessed the DR activities for EU Member States, Norway and Switzerland and reported the results in a report published in April 2014[115]. SEDC is an industry group dedicated to the development of demand side program development. SEDC has assessed the access for DR providers. In addition, there may exist DR activities in not-open power markets performed by the national energy regulatory operators though these typically would be targeted larger energy consumers such as manufacturing industry.

The report has mapped the progress of the Member States in meeting the requirements of Article 15, item 8 and reviewed the regulatory structures of 13 Member States, Norway and Switzerland.

The report summarizes the progress of the EU Member States as:
- Commercially active: Great Britain, Ireland, France, Belgium, Finland;
- Partial opening: The Netherlands, Austria, Sweden;
- Preliminary development: Germany, Poland, Denmark, Slovenia;
- Closed: Spain, Italy;
- No thorough regulatory review, but on first review, DR development not visible in the remainder of the Member States.

The conclusion is that only five Member States have reached a level with access for commercial DR providers.

There has however been development from 2013 to 2014 and it is expected to continue developing. Examples of dynamic tariff schemes that are tested or applied for the residential segment are listed below. The first dynamic pricing mechanisms are mainly developed within countries that experience a need for demand side flexibility. For example countries with a high share of renewable energy (Nordic countries, Germany, Belgium, Italy) or an important share in electric heating, resulting in high peak demand during winter (e.g. France, Nordic countries), have taken the first steps towards introducing dynamic pricing in the market.

[115] "Mapping DR in Europe Today. Tracking Compliance with Article 15.8 of the Energy Efficiency Directive". Smart Energy Demand Coalition. April 2014.

- Sweden: In Sweden, the roll-out of smart meters has been completed. Since 2012, energy providers started to offer retail consumers electricity contracts based on day-ahead hourly prices[116]. Until now, only a small part of customers have adopted real-time-price contracts. This is an example of real-time pricing. In general, there is an evolution to energy contracts based on hourly prices. An important condition is that hourly metering for these consumers is available. A study on the impact of these dynamic pricing schemes in Sweden highlights the fact that not only RTP-tariffs are needed, they have to be accompanied by appropriate home automation technologies on the one hand and the necessary feedback strategies in order for consumers to understand and modify their daily consumption pattern[117].

- France: EDF offers the Option Tempo product to consumers. Days are categorized according to three colours: blue, white and red reflecting the state of the system. On a daily base, the colour of the day is defined and communicated and prices vary accordingly. This is an example of critical pricing where the utility determines a special event during a limited number of days[118]. The consumption of consumers is not automatically adapted based on these prices.

- The Netherlands: Eneco organizes the automated smart charging of Tesla electric vehicles based on energy market prices[119]. A special app keeps track of the energy prices (via direct communication with the energy exchange) and controls automatically the charge speed of the battery.

- Belgium: Pilot project Linear[120] tested in a field test a TOU pricing mechanism. There were 6 fixed time periods defined upfront. Prices were determined on a daily base, based on Belpex day-ahead market prices and the predicted generation of wind and solar. The average daily price spread was around 0,08€/kWh.

- Belgium: the Transmission System Operator in Belgium has designed a new product for tertiary reserve 'R3Dynamic Profile'. This product targets sheddable load and production at distribution grid level. The remuneration is based on a capacity fee[121]. The average capacity fee for R3DP is estimated around 3,38 €/MW/h.

- Germany: the AlpEnergy project (Allgaeu trial site)[122] tested two types of TOU tariffs. The first tariff was a more static tariff type with 2 time periods with a yearly price update. The second tariff was a more dynamic tariff with 5 time periods with an update of the price every 36 hours. The price spread was in both TOU tariffs equal to 0,05€/kWh. Results showed an average load shift of 2% for the more static tariff and an average load shift of only 1% for the more dynamic tariff, indicating that in case of manual response, tariffs should not be too complex.

[116] http://energia.fi/sites/default/files/dokumentit/ajankohtaista/Tapahtumat/2013/ST-pooli/esitys_soderbom.pdf
[117] http://www.researchgate.net/publication/254864389
[118] https://particulier.edf.fr/fr/accueil/facture-et-contrat/contrat/consulter-les-jours-ejp-et-tempo/option-tempo.html
[119] http://cleantechnica.com/2015/03/18/eneco-smartcharging-app-dutch-tesla-drivers-charge-price-low/
[120] http://www.linear-smartgrid.be/en
[121] http://www.elia.be/~/media/files/Elia/Products-and-services/ProductSheets/S-Ondersteuning-net/S_Grid%20support_En.pdf
[122] http://www.alpenergy.net/images/stories/AlpEnergy_Final_Guideline.pdf

- Germany: the German smart grid project eTelligence[123] developed a combination of a TOU tariff with two price levels (price spread of 0,26€/kWh), and in addition so-called bonus (0€/kWh) and malus events (1,2€/kWh) that were based on the availability of RES (announced day-ahead). Consumers had to respond manually on the observed prices. Electricity savings up to 20% in case of malus events and additional electricity consumption up to 30% during bonus events were observed.

- Germany: The E-DeMa trial project offered end-users the choice to switch their remuneration mechanism on a monthly basis. Most end-users opted eventually for a relatively static and simple TOU tariff, again emphasizing that tariff structures that are too complex hinder the adoption of dynamic pricing in case of manual response[124]. The average price spread was between 0,10 and 0,20€/kWh.

- Germany: The MoMa project[125] tested a RTP tariff with daily price updates (price spread of 0,075€/kWh). The project, amongst others, wanted to test the flexible relationship between price changes and the behavioral changes of consumers who respond to prices manually. Results showed that on average a price increase of 100% gave a decrease in demand of around 10%.

- Norway: Nord-Trøndelag Elektrisitetsverk (NTE), announced in March 2014 that it would partner with Swedish ICT company Maingate to run a pilot project investigating customers' manual response on real-time electricity prices.[126]

- Italy: A simple TOU tariff is introduced to all households in Italy, consisting of two time blocks per day (peak and off peak), with quarterly price updates. Consumers respond manually to the observed prices. The maximum price spread was equal to 0,02€/kWh. The results showed a shift of 1% of total energy consumption from peak to off-peak hours with respect to the period prior to the introduction of the TOU tariff [127]. Results have shown that consumers barely changed their consumption pattern. Main reason was the fact that the price spread was not sufficient to stimulate consumers to shift their consumption[128].

- UK: The CLNR project (Customer Led Network Revolution) in the UK uses a three-rate TOU tariff which is updated once a year. The average price spread between the highest and the lowest price was around 0,20€/kWh. Consumers respond manually to the observed prices. Preliminary field trial results showed that the average half-hourly load reduced by 14% during the peak period (between 4pm-8pm)[129].

- US: In the state Illinois, the two main state-utilities (ComEd and Ameren Illinois) have introduced RTP-programmes as from 2007, but in the course of 2014, only 1% of their

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[123] Agsten M. *et al*. eTelligence Abschlussbericht. Neue Energien brauchen neues Denken. Oldenburg: EWE AG; 2012.

[124] Becher S *et al*. Verbundprojekt E-Energy: E-DeMa, Entwicklung und Demonstration dezentral vernetzter Energiesysteme hin zum E-Energy Markplatz der Zukunft. Essen: RWE AG; 2013.

[125] Kießling A. Modellstadt Mannheim Abschlussbericht. Beitrag von moma zur Transformation des Energiesystems für Nachhaltigkeit, Beteiligung, Regionalität und Verbundenheit. Mannheim: MVV AG; 2013.

[126] http://www.m2mnow.biz/2014/03/27/19247-maingate-nte-together-towards-tomorrows-energy-market/

[127] Maggiore S, Gallanti M, Grattieri W, Benini M. Impact of the enforcement of a Time-of-Use tariff to Residential customers in Italy. Paper presented at the CIRED 22nd International Conference on Electricity Distribution, June 2013

[128] http://www.slideshare.net/drsea/07-maggiore-simoneieadsmgrazoctober2014

[129] British Gas. Initial Time of Use tariff trial analysis. Report CLNR-L015, London: British Gas; 2013.

customer base had adopted the new tariff [130]. Several reasons have been mentioned why these programs are not yet embraced by a large audience. Elements highlighted in order to increase the number of participants are: increasing awareness and understanding of dynamic pricing by using simple communication, easy enrolment in the program and proof towards customers that participation is not complex in case of manual response[131].

- US: Austin Energy and CPS Energy offer consumers a free thermostat or a thermostat rebate in exchange for the automated control on the air-conditioning. This could be considered as an example of an alternative remuneration mechanism to incentivize consumers to offer the flexibility of their smart appliances[132].

- Australia: Consumers are offered a rebate on the cost of an air conditioner, compliant with a demand response platform and activated at installation. The load of the air conditioner is than automatically modulated by a third party[133].

- UK: Retailer Tempus Energy offers electricity consumers a flat rate tariff, significantly below normal market prices. In exchange, Tempus Energy is allowed to install a smart meter and demand response equipment at the user's residence and to manage the user's flexibility automatically. Tempus Energy uses this flexibility to obtain lower prices at the day-ahead energy market and to reduce balancing costs. The reduced flat tariff can thus be seen as a very simple and easy to understand demand response capacity fee[134].

2.3.4. FACTORS FOR THE ESTABLISHMENT OF A SUCCESSFUL DR REMUNERATION MECHANISM

The analyses of different smart grid pilot project within the context of the S3C project[135] highlighted some key elements that determine the success of a Demand Response remuneration mechanism[136].

- The information from the remuneration mechanism has to be clear and understandable
- The price updates and special events has to be announced timely
- The financial incentives need to be high enough
- Additional incentives (besides financial) support behavioural change (such as providing the end-user with a feeling of achievement)
- Manual control can support end-user acceptance as it is the first step in the learning process
- Automated control can prevent response fatigue, especially in case of more complex remuneration mechanisms

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130 http://www.power-technology.com/features/featuredynamic-energy-pricing-will-the-public-buy-in-4294096/

131 http://aceee.org/files/proceedings/2010/data/papers/1967.pdf

132 https://nest.com/energy-partners/austin-energy/

133 https://www.energex.com.au/__data/assets/pdf_file/0006/126375/PeakSmart-Air-Con-Terms-and-Conditions.pdf

134 tempusenergy.com

135 S3C consortium. Report on state-of-the-art and theoretical framework for end-user behaviour and market roles. S3C project Deliverable 1.1. Available from: < www.s3c-project.eu >

136 Additional information can be found in: Kim J-H, Shcherbakova A. Common failures of demand response. Energy 2011; 36: 873-880. and Faruqui A, Hledik R, Sergici S. Piloting the Smart Grid. The Electricity Journal 2009; 22: 55-69.

For both use cases described earlier, the state of the system needs to be taken into account in the pricing system. This makes a remuneration mechanism only based on Time-of-Use Pricing less appropriate. However, TOU pricing could be combined with other more real-time pricing mechanisms.

In the case of the day-ahead use case, TOU pricing would allow to change the average daily pattern of consumption in order to match it better with the available generation. In addition, CPP pricing could incentivize an additional load shifting in case the system is under stress due to extreme events (power plant outage, extreme weather conditions,…).

TOU pricing is in theory not appropriate for the imbalance use case, as no predictable patterns should be present in the imbalance market. In order to allow smart appliances to value their flexibility for this use case, real-time pricing is needed. This can be only real-time-pricing, or a combination with for example a capacity fee.

Independently of the remuneration mechanism, the price incentive should be large enough, not too complex and reflecting the underlying cost of the energy system. These elements will make it easier for the end-user to understand the pricing mechanism and as a result, respond in the most optimal way. In addition, it is important to analyse in depth the typical smart appliance-related practices in order to determine the optimal remuneration mechanism.

CHAPTER 3 USER ANALYSIS

Task 3 is about describing and quantifying the current situation for the users which will be impacted by making appliances Demand Side Flexibility (DSF) enabled.

The first part of this Task report handles the perspective of the end-user of smart appliances. An overview of the main drivers and barriers in taking up smart appliances is given along with possibilities to overcome the barriers and raise consumer's acceptance. Furthermore, an in-depth analysis is provided of the user behaviour in view of the smart appliances defined in Task 1. A separate section addresses data protection, data security and consumer rights.

The use of DSF can serve multiple objectives from an energy system perspective which is covered in the second part of this Task report. It can be used to optimize the day-ahead scheduling of electricity production and consumption. Second, it allows in real-time to match supply and demand in case of deviations in scheduling. These use cases are explained in detail and the role of smart appliances as provider of flexibility is discussed. In Task 5, for these use cases a model will be developed allowing the environmental product assessment and definition of the base cases.

Note that the core focus of this Task report is on the impact of the use of smart appliances on the end consumer and the resulting flexibility generated to feed into the use cases, making abstraction of any specific energy market structure.

3.1. END-USER PERSPECTIVE

3.1.1. DRIVERS AND BARRIERS FOR THE UPTAKE OF SMART APPLIANCES

Shifting loads in private households by using smart appliances may require behavioural changes and some adaptations of consumer's everyday routines. Consequently, the potential of smart appliances depends on the consumer acceptance and the use of smart appliances, which are among the most crucial key factors to make this new technology being successful.

The degree to which consumers tend to implement smart appliances will depend on technical, behavioural and economic drivers and barriers and their interaction. In the following, this report gives a general overview of the current state of consumer acceptance in view of smart appliances. It points out major barriers and provides strategies to overcome these objections, to raise the consumer acceptance and for a successful market penetration of smart technologies. Economic drivers/ barriers linked to business models are discussed more in detail in section 2.2.4 in Task 2 of this report.

The S3C project[137], which aimed at research of "best practice end-user engagement strategies and tools", took both, a theoretical and an empirical approach to gain information on drivers and barriers for implementing smart appliances. From a theoretical point of view, the S3C project analysed the process of behavioural changes, which is required for the implementation of smart appliances. As most energy –related processes (e.g. operating dishwasher or washing machine, cooking etc.) are

[137] S3C project: D1.1 FINAL WP 1: "Framing – Development of the theoretical framework". Deliverable 1.1: "Report on state-of-the-art and theoretical framework for end-user behaviour and market roles".

rather habitual processes, the project concluded that consumers first have to be activated to become engaged in load shifting and using smart appliances. At the beginning of this process, the behaviour is no longer habitual, existing routines have to be reconsidered and the behaviour is changed towards a higher consciousness ('disruptive phase'). The next phase targets at an active participation of consumers. They should explicit reflect their old and new practices ('activation phase'). In the third phase ('continuation phase'), new practices and routines are already adapted and the new behaviour becomes more and more habitual. However, new practices have to be supported and reinforced. According to the findings of the S3C project[137], drivers and barriers play a decisive role in the 'activation' and 'continuation phase'. The drivers and barriers identified in the framework of this project are discussed in the respective subsections.

Current available information from empirical studies implies that consumer acceptance in view of smart appliances and related to this, smart home technologies, is relatively high. Except for one study[138], preliminary findings indicate that consumers are willing to shift loads to off-peak hours by rescheduling certain household activities[139,140,141,142,143,144,145]. However, it is important to note that the results of these studies are mainly based on questionnaires or interviews and not on consumer experiences. Thus, they reflect the expected and not the real consumer behaviour and acceptance. This means that the figures should be treated with caution.

One of the first pilot projects implementing a smart energy grid, the PowerMatching City II project[146] situated in the Netherlands, encompassed a sample of 40 households to demonstrate the energy system of the future. The connected households were equipped with smart appliances and smart meters, some of them have additional solar panels or micro CHP to generate energy or heat. In this project, two different energy services were created and allocated randomly to the households, one focussing on cost savings ('smart cost savings') and one focussing on sustainability ('more sustainable together'). Experiences gained showed that participants preferred the 'smart cost savings' energy service as cost savings (expressed in euros) were more tangible for consumers as sustainability gains. This was also reflected in the fact that the active engagement (e.g. manually setting start times of household appliances) of participants allocated to this energy service was much more pronounced. As far as they had confidence in the system, participants had a bias towards automatically controlled devices because of more convenience and higher cost savings. Comprehensibility of the system and its function was identified as the main factor influencing the confidence of the participants. While using the energy monitor to control the devices at the beginning of the project, participants became familiar with the right times to turn on appliances and got on without the energy monitor over time.

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[138] Fraunhofer-Institut für Solare Energiesysteme ISE (2011): Nachhaltiger Energiekonsum von Haushalten durch intelligente Zähler-, Kommunikations- und Tarifsysteme.

[139] Mert, Tritthart (2008): Get Smart! Consumer acceptance and restrictions of Smart Domestic Appliances in Sustainble Energy Systems. IFZ – Inter-university Research Centre for Technology, Work and Culture, Graz, Austria.

[140] Kobus, Klaassen, Mugge, Schoormans (2015): A real-life assessment on the effect of smart appliances for shifting households' electricity demand. Applied Energy. 2015; 147:335-43.

[141] Saele, Grande (2011): Demand Response From Household Customers: Experiences From a Pilot Study in Norway. IEEE Transactions on Smart Grid. 2011; 2:102-9.

[142] Mert, Watts, Tritthart (2009): Smart domestic appliances in sustainable energy systems—Consumer acceptance and restrictions. ECEEE 2009 Summer Study 2009. p. 1751–61.

[143] Thiemann, Passenberg, Suer (2007): Preis, Verbrauch und Umwelt versus Komfort – der mündige Energieverbraucher.

[144] Stamminger, Anstett (2013): The Effect of Variable Electricity Tariffs in the Household on Usage of Household Appliances. Scientific Research, online Journal. 2013; 4:353-65.

[145] Cardinaels, Borremans (2014): Linear Intelligent Networks - Demand Response for Families.

[146] PowerMatching City II project (2015): http://www.powermatchingcity.nl/data/docs/PowerMatching%20City_brochure_final_UK_29-04-2015_lowres.pdf

Consumer studies carried out within the framework of the "Energy Intelligent Europe" project „Smart Domestic Appliances in Sustainable Energy Systems (Smart-A)"[147], which was conducted in five European countries (Austria, Germany, United Kingdom, Slovenia and Italy) revealed that about 90 % of the respondents would accept different options of smart appliances. However, the acceptance is dependent on the respective device and smart operation mode and could not be generalized for all appliances. In terms of willingness, the highest load shifting potential was found for washing machines and dishwashers, whereas the willingness to shift cooking or entertainment applications or the operation of appliances ensuring comfort is vanishingly low140'141'142'143'144'[148]. For more detailed information, refer to subtasks 3.2.1 and following.

3.1.1.1. DRIVERS TO BUY/ USE SMART APPLIANCES

There are a couple of studies investigating motivations for consumers to engage in smart appliances. In general, the drivers can be divided into economic and ecological drivers as well as product-related drivers.

Economic and ecological drivers

In a study by Paetz et al.148, a total number of four test-residents lived in a fully equipped smart home laboratory to assess smart home technologies (feedback systems, automated energy management system, dynamic pricing) in everyday life. The study revealed that dynamic pricing and related to this, monetary savings, are the main drivers for shifting loads. Because of the complexity and variability of the dynamic prices, the study participants preferred an automated energy management system. Reasonable pay-back periods for investments were identified as crucial preconditions for consumer's acceptance of smart home technologies.

In the same smart home laboratory, focus group interviews were conducted with 29 participants to get an insight into consumer perceptions in view of smart appliances, smart metering, variable tariffs and home automation[149,150]. The results show again the importance of monetary savings.

A questionnaire-based survey and focus group interviews in several European countries as part of the Smart-A project139'142 produced similar results. Also here monetary savings were the most important requirement for buying and using smart appliances. The second point is the reduction of the environmental burden.

Product related drivers

Besides economic and ecological benefits, also some product related drivers could be identified in former studies. The maturity of smart technologies, maintenance or enhancement of comfort (e.g. making housework less time consuming), good usability and higher security were found in the Smart-A consumer studies to play a decisive role for consumers to accept smart appliances. Expert interviews conducted within the framework of the Smart-A project additionally identified monitoring features (e.g. diagnosis of correct function of appliances) or "all power off"-switches as potential benefits.

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[147] Mert et al. (2008): Consumer acceptance of smart appliances. D 5.5 of WP 5 report from Smart-A project. Available online: http://www.smart-a.org/WP5_5_Consumer_acceptance_18_12_08.pdf

[148] Paetz, Becker, Fichtner, Schmeck (2011): Shifting Electricity Demand with Smart Home Technologies – an Experimental Study on User Acceptance. 30th USAEE North American Conference 2011.

[149] Paetz, Dütschke, Fichtner (2012): Smart Homes as a Means to Sustainable Energy Consumption: A Study of Consumer Perceptions. Journal of Consumer Policy. 2012; 35:23-41.

[150] Paetz, Duetschke, Fichtner, Wieschtel (2011): Tomorrow's households: How do consumers react to a smart-home environment? In: Bertoldi P, editor. Energy Efficiency in Domestic Appliances and Lighting. Copenhagen, Denmark 2011. p. 657-69.

In the S3C report[137], five major categories of drivers were identified besides economic and ecological benefits: increase in comfort, increase in control (e.g. advances control of appliances via smart phone or tablet, further possibilities to participate in energy market), knowledge and information (e.g. feedback on energy use or energy consumption relevant parameters, more frequent billing), improved security (e.g. improved reliability of energy supply) and social process (e.g. social role, community feeling or fun).
In other studies[151,152], new services (e.g. monitoring of or support for elderly people) were named as a further motivators to buy and use smart appliances.
According to Mert et al.147, the majority of consumers would only buy a smart appliance if they need to replace their old one anyhow.
Even though financial incentives (for instance through a dynamic pricing scheme) seems to play an important role as a driver, it can be concluded that they are not sufficient to establishing a structural change in consumer behaviour[153].

3.1.1.2. BARRIERS TO BUY/ TO USE SMART APPLIANCES

Although results of customer research have shown that consumers have a positive attitude towards smart appliances and would be willing to adopt them, there are many objections which have to be solved before a market penetration is possible (Mert et al., 2008147). In the following, two main categories of barriers are distinguished: barriers in view of economic aspects and regulatory framework and product/service-related barriers.

Barriers in view of economic aspects and regulatory framework
The rollout of smart meters and informing about smart functions are definitely main barriers to uptake smart appliances (cf. Task 2, subtask 2.1.2 for more information on rollout of smart meters). A Forsa study[154] showed that even 91 % do not know the term “smart meter”.

In 2010, more than 9,000 individuals in 17 countries across the globe were surveyed by Accenture[155] to get consumers attitudes and opinions toward electricity management programs. According to this survey, the three major barriers, which discourage consumers from adopting smart appliances, are costs, mistrust in providers and concerns about data privacy.

In view of the costs, consumers are in general willing to accept higher initial prices for smart appliances, but some of them fear hidden costs (e.g. costs for installation or repairs) as well as unreasonable and excessive pay back periods (Mert et al., 2008147).

This mistrust in energy providers represents the next major barrier in adopting smart appliances. On average, only 29 % of the consumers trust in utilities or energy providers. Nearly the same percentage has no trust and about half of the consumers are undecided. Environmental associations,

[151] Balta-Ozkan, Davidso, Bicket, Whitmarsh (2013): Social barriers to the adoption of smart homes. Energy Policy. 63:363-74.
[152] Balta-Ozkan, Amerighi, Boteler (2014): Comparison of consumer perceptions towards smart homes in the UK, Germany and Italy: reflections for policy and future research. Technology Analysis & Strategic Management. 2014; 26:1176-95.
[153] Boork M, Thomtén M, Brolin M, Uyterlinde M, Straver K, Kraan C, Kleine-Hegermann K, Laes E, Valkering P, Maggiore S. Key success factors and barriers to end-user engagement in smart grid projects. Paper presented at the 2014 BEHAVE conference, London. Available from: <http://behaveconference.com/wp-content/uploads/2014/08/F_Magdalena_Boork_Technical_Research_Institute_of_Sweden.pdf>
[154] Forsa (2010): Erfolgsfaktoren von Smart Metering aus Verbrauchersicht, Berlin.
[155] Guthridge (2010): Understanding Consumer Preferences in Energy Efficiency - Accenture end-consumer observatory on electricity management, Amsterdam.

academics/ schools/ scientific associations as well as consumer associations in contrast have the highest trust level. (Guthridge, 2010[16])
Consumers have the impression that economic goals of electricity providers are hidden behind a "green washing" attitude (Mert et al., 2008147). Because of that, they prefer independent institutions like governmental institutions at national and European level and consumer organisations to inform them.
Changes in electricity prices and programs by energy utilities reduce the level of trust in them. From the users view, there is also a lot of scepticism about the motivation of energy suppliers to promote smart appliances. As the knowledge of consumers about renewable energies and the energy system in principle is limited, consumers often fear that economic goals are hidden behind the aforementioned "green washing" attitude and energy suppliers use the ecological benefit as a sales argument. Combined with growing doubts about control, data privacy and data protection, consumers trust in energy providers is further minimised. (Mert et al., 2008147)

Product/ service-related barriers
A further objection of consumers is an expected loss of control[137]. Consumers have certain mistrust in high tech solutions. In most cases, they lack knowledge about energy grids and the underlying concept of smart appliances, and consequently have concerns in view of technical failures and system reliability. On the one hand, many consumers are afraid of dependency on technology and on the other hand they do not like the idea of energy providers having control over their devices. This could be deeply rooted in the fact that consumers are accustomed of available electricity all the time and they can operate their appliances whenever they want. Consumers do not want to be restricted on electricity usage because for them, this means a loss of comfort. Another point is that consumers fear a certain stress to change their behaviour and daily routines. In the case of automatic regulation, consumer favour solutions that tie to existing platforms like smartphones and tablets[156] and they want to maintain control over their devices. Thus, it appears consumers prefer to have the possibility to override the smart operation mode any time they want (for example with an option to operate their appliances manually). (Mert et al., 2008147; Paetz et al., 2012[149])

The safety of smart appliances is also questioned by some consumers and plays a big role for their adoption as well. Users might be afraid of break-downs for example in case of fire or flooding. Doubts about leaving the appliances switched on during absence exist in the consumers mind. Among others, this is why manuals of traditional electrical appliances often warn consumers not to operate the devices unattended and sometimes even recommend unplugging it from mains after usage. To make things worse, insurances usually do not cover damages in absence. So consumers worry that they have to cover the costs of possible damages by themselves. (Mert et al., 2008147)

In other studies139′149′150′151′152, concerns expressed include a lacking interoperability, a too complicated handling (especially important for elderly and people with disabilities), error-proneness of appliances because of additional technical components and shorter life times of appliances due to short interruptions during operation. It has to be mentioned at this point that upgradeability and the length of manufacturer's support might also be decisive factors in view of product life time (even though not named in the aforementioned studies). Additionally, the reparability of the product might be affected as more complex technology such as electronics becomes part of the product design.

According to the S3C report[137], social processes (e.g. free-rider effects or job losses) and lack of information and knowledge (e.g. perceived health risks) may be named as an additional barriers.

[156] Panasonic, IFA 2015

Besides that, there are some appliance-specific concerns (e.g. concerns about food safety in the case of refrigerators and freezers or about damages of textiles in the case of washing machines and tumble dryers), which are described more in detail in subtasks 3.2.1-3.2.7.

Results from an online survey by Geppert and Stamminger[157] indicate that the probability of having concerns in view of smart appliances might be related to the degree of automation and technical complexity. Whereas only about 1/3 of participants stated to have concerns in view of a dishwasher, whose start is triggered by an external signal (e.g. via power line), half of all respondents expressed concerns in view of a remote control (e.g. interruptions or altered consumption pattern in the case of refrigerators, freezers, air condition, heating pumps or electric water heaters).

3.1.1.3. ADDITIONAL COSTS AND EXPECTED FINANCIAL GAINS

Studies by Mert et al.147 as well as Geppert and Stamminger157 revealed that almost all consumers are in general willing to pay a slightly higher price (up to 50 €) for smart appliances than for conventional ones when buying an appliance. An absolute statement about additional costs accepted by consumers is not possible as these costs much depend on the absolute price of the appliance, the expected payback time, the expected gain in comfort, potential additional costs (e.g. installation and upgrading) and potential future savings.
According to Mert et al. (2008)147, the majority of consumers would certainly not approve a payback time of 5 years and some of them might not accept even 3 years.
The online study by Geppert and Stamminger157 has shown that almost 80 % of participants would buy a smart appliance under the precondition of getting incentives from their utilities (e.g. cheaper energy tariff). A reduced purchase price for the appliances would only convince about 16 %. When asked about their expected reduction in energy price, most participants stated a percentage in the range of 1 to 30 (mostly 11 to 20 percent). By trend, the expected reductions are higher in the case of remote control (e.g. interruptions of appliances, altered consumption patterns) than in the case of external signals, which trigger a delay in start time (e.g. frequency control).
A point-of-indifference analysis by Paetz et al.149 determined savings of 80 € per year as the point at which changes in behavioural patterns start to be worthwhile for consumers.

3.1.1.4. POSSIBILITIES TO RAISE CONSUMER ACCEPTANCE

As described before, consumer acceptance is a key factor for smart appliances being successful. The future market penetration of smart appliances depends to a great extent on the likelihood to overcome existing consumer objections. Following aspects could help to overcome concerns and raise consumer acceptance.
As financial aspects were identified as the main driver for the use of smart appliances, attractive and transparent energy tariffs of the utilities are inevitable. Studies have shown that a reduction between 11 and 20 % in energy price is expected by the consumers as an incentive for operating appliances in a smart mode. It can be assumed that Time of Use tariffs are more suitable to motivate consumers to use appliances during off-peaks than cheaper flat tariffs. As short payback times are also essential for consumer acceptance, rebates on the purchase price of smart appliances could be another option to increase the attractiveness. However, discounts should be given in addition to attractive energy tariffs because otherwise only a minority of consumers will be convinced. In general, consumers should be adequately informed about all costs resulting from smart appliances (including installation, infrastructure, repairs, …). Hidden costs should be completely avoided to build trust in a long term.

[157] Geppert and Stamminger (2015): Online study on consumer acceptance and perceptions of smart appliance. Not published yet.

Major concerns are related to safety aspects and the technology. Consumers are afraid of fire or flooding or any failures if appliances are operated during absence. Potential measures to overcome these objections include additional safety mechanisms in view of appliances (improved protection against fire or flooding), the possibility to remotely monitor different operation parameters (e.g. temperatures) and an alert via smartphone or email in the case of failures. But also the insurance can plays a decisive role to overcome the safety barrier by covering damages occurring during unattended operation (for instance manufacturers offering own insurances for aqua-stop etc.). (Mert et al., 2008147)

As consumers also fear error-proneness of appliances and a shorter life span due to interrupted operation and more technical components, realistic life time and fatigue tests should provide information for consumers. Extended warranties could be a further possibility to overcome this concern.

Another aspect to increase the consumer acceptance is that providers need to build trust and credibility before they see a broad adoption of smart appliances. So first they have to improve their customer relationships. In order to create trusted advisor relationship, providers need to be more transparent in their activities. In addition to that they need to match consumer's requirements for a good data protection and should also delete consumer's data after some time. As many consumers remarked that they are afraid to lose control over their devices, consumers should have the possibility to override the smart operation mode any time they want (for example with an option to operate their appliances manually) and should have access to their own data. Further it will be necessary for energy providers to build relationships with governments, regulators and associations, which are able to push the energy-efficiency agenda forward (Guthridge, 2010155). Alternatively, a regulated or government body could undertake the management of the smart appliances and the interaction with end consumers.

As many consumers have doubts concerning the ecological benefit of smart appliances, it should be assessed and verified by independent institutions as for example environmental associations, academics/ schools/ scientific and consumer associations, which enjoy a high level of trust.

Additionally, consumers expressed concerns about lacking interoperability of appliances and systems. They want to have the possibility to choose appliances from different brands and to change their energy supplier without any problems or adaptions. Uniform standards on a European basis could help to overcome these objections.

Upgrades which can be simply plugged into existing devices, may also raise consumers' acceptance. However, the risk that smart appliances can update their software after installation and could increase their energy consumption (e.g. different default standby mode, higher wash temperature, brighter screen, etc.) exists in principle.
As such, the "out-of-the-box" setting would become less and less relevant.

If the smart appliance has a display, it should be a simple yet visually appealing display. The display should have an accessible and ergonomic design as suggested by studies (e.g. Consumer Focus, Smart meter in-home display design, 2012; DIN Consumer Council, Study on usability and ergonomics of smart meters, 2011). Especially in view of elderly and disabled people, special features should be foreseen. This relates to a simple handling (e.g. plug-and-play) as well as text-to-speech or other audio functions (at least the possibility to connect one should be given). (ANEC/ BEUC)

Moreover, additional functionalities and gains in comfort may raise consumer acceptance regarding smart appliances, especially if expected financial gains are low. Such functionalities may include the possibility to:

- start, control or monitor appliances remotely, e.g. via smartphone,
- switch off power of all appliances at once,
- monitor and support elderly people in their living environment,
- get informed (e.g. via smartphone) about necessary repairs or failures of appliances at an early stage,
- enable remote diagnostics and maintenance for mechanics,
- enable home energy analysis
- enable automatic adaption
- etc.

A promotion of such functionalities at the point of sale may help to increase the attractiveness of smart appliances.

3.2. End-use parameters and user requirements of appliances

The following subtasks 3.2.1 - 3.2.7 inform about product-specific end-use parameters and user requirements by focusing on daily and seasonal use pattern, comfort constraints, expected flexibility and typical scenarios of application.

3.2.1. Periodical appliances

3.2.1.1. Usage Behaviour

Periodical appliances are appliances that periodically execute a user initiated cycle. The user is actively involved in loading and unloading the machines, whereas there is no interaction with the user while running. In this category there are the following appliances destined for private use:

- Dishwashers
- Washing machines
- Tumble dryers
    - Electric vented
    - Electric condenser
    - Heat pump dryer
- Washer-dryers

In view of periodical appliances, energy is mainly needed for heating processes. In the case of washing machines, dishwashers and washer-dryers, water is heated up for cleaning purposes. In view of tumble dryers and washer-dryers, hot air is produced, which is required for drying wet laundry. The temperatures vary according to the respective programmes. The rated power of the heating devices is shown in Table 17.

Table 17: Rated power of heating devices (source: Stamminger et al., 2009170)

Appliance	Rated power of heating device
Dishwashers	1,800-2,500 W
Washing machines	1,800-2,500 W
Conventional tumble dryers	2,000-2,500 W
Heat pump tumble dryers	800-1,000 W
Washer-dryers	2,000-2,500 W

Additional energy is needed to operate circulation pumps, motors, fans and displays/ user interfaces. During spin-drying, motors of washing machines and washer-dryers reach power peaks of up to 950 W, whereas their typical operational power input is about 100 W. The rated power input of water circulation pumps is about 15-30 W. (JRC, 2015[158])

Periodical appliances have a relatively high volume of installed base in EU-28 (some of them still growing).

For dishwasher, penetration rates vary extremely between different countries with ownership rates of 40-50 % in EU-15 (2012) and 10-15 % in new Member States. For EU-28, this results in 46 %. According to estimations, ownership rates in EU-28 will increase during the next decades reaching 60-70 % in 2030. (VHK, 2014[159])

The average ownership rate of washing machines (EU-27) is about 90 % with only marginal differences between countries (Bertoldi et al., 2012)172.

According to estimations in 2010, the stock of tumble dryers in Europe was about 54 million appliances (Bush, Damino, Josephy, 2013[160]) corresponding to an average ownership rate of about 32 %. In 2015, estimations indicate an amount of about 63 million appliances in stock (VHK, 2014[161]) and a corresponding penetration rate of 29 %. Penetration rates are much higher in Western than in Eastern European countries (Lefèvre, 2009[162]).

Washer-dryers are a small category of wet appliances. Because they are relatively new on the market, their ownership rate is only about 4 % in Europe, but still increasing (Euromonitor 2014, cited by JRC, 2015158).

For more information on stock data, please refer to Task 2.

Given the comparatively high power consumption and the large installed base volumes, the potential of periodical appliances for load shifting is assessed to be high. Therefore, appliances of this category are described more in detail in this chapter.

[158] JRC (2015): Ecodesign and Energy label revision: Household Washing machines and washer-dryers. Draft. Available online: http://susproc.jrc.ec.europa.eu/Washing_machines_and_washer_dryers/docs/Prepstudy_WASH_20150601_FINAL_v2.pdf

[159] VHK (2014): "Omnibus" Review Study on Cold Appliances, Washing Machines, Dishwashers, Washer-Driers, Lighting, Set-top Boxes and Pumps. Final report

[160] Bush et al. (2013): Heat Pump Tumble Driers: New EU Energy Label and Ecodesign requirements in Europe, MEPS in Switzerland, Initiatives in North America. Available online: http://www.topten.eu/uploads/File/EEDAL_heat_pump_driers_2013.pdf

[161]VHK (2014): ECODESIGN IMPACT ACCOUNTING Part 1 – Status Nov. 2013

[162] Lefèvre, 2009: Ecodesign of Laundry Dryers, Preparatory studies for Ecodesign requirements of Energy-using-Products (EuP) – Lot 16

3.2.1.2. User behaviour concerning periodical appliances

Daily and annual use pattern

Dishwashers

According to an online survey in 10 European Countries (EUP LOT 14[163]), the average number of dishwashing cycles per week is 4.06, corresponding to 211 cycles per year. The same average number was reported for German households by Bichler et al. (2014)[164].
The European Commission estimated the total electricity consumption of dishwashers in Europe to be around 25.3 TWh in 2010 (Bertoldi et al., 2012)172. Dishwashers with a capacity of 13 settings currently available on the European market consume between 194 and 290 kWh/year (http://www.topten.eu). Stamminger et al. (2009)170 reported on an average consumption of 241 kWh/year corresponding to 1.19 kWh/cycle.

Assuming a normal cleaning programme and an energy consumption of 1.19 kWh per cycle, the power demand curve of a current average dishwasher follows the pattern shown in Figure 24.

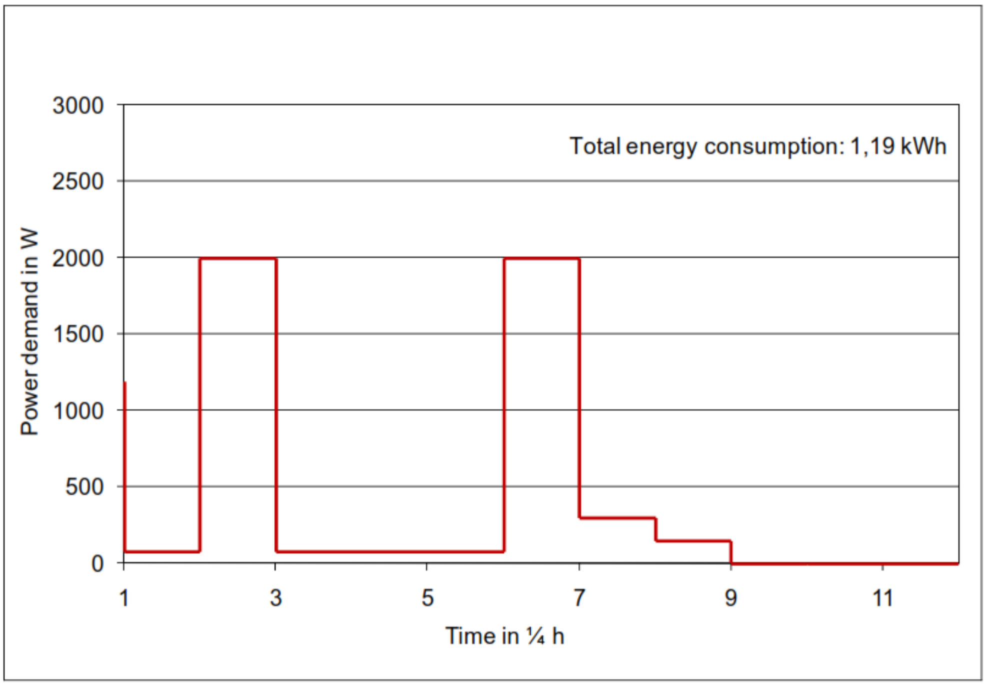

Figure 24: General pattern of a power demand curve of an average dishwasher operating in a normal cleaning programme (source: Stamminger et al., 2009[170])

Due to the Energy Label and other political measures, the total energy consumption of dishwashers in Europe is expected to further decrease within the next years. Assuming lower cleaning and rinsing temperatures, the power demand curve of an average dishwasher in 2025 may change towards a lower power demand in the cleaning and rinsing phase and increased cycle times.

It is assumed that use patterns of dishwashers vary on a daily, but not on a seasonal basis. According to results of an online survey in ten European countries in 2007 (n=2500), dishwashers are preferably

[163] Preparatory Studies for Ecodesign Requirements of EuP's, LOT 14: Domestic Washing Machines and Dishwashers, Task 3: Consumer Behaviour and Local Infrastructure.
[164] Bichler S. (2014): Verbraucherakzeptanz von Energieeinsparpotentialen an automatischen Geschirrspülmaschinen. Shaker Verlag, Aachen.

switched on in the afternoon/ evening period after dinner (Figure 25). At present, there is no reason per se to expect that the daily use pattern of dishwashers will change in the near and medium-term future.

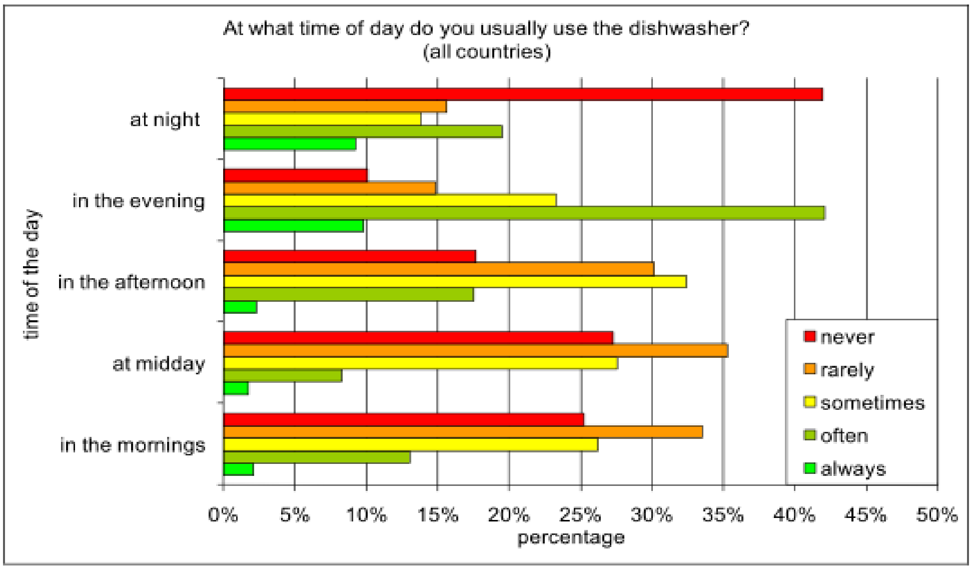

Figure 25: Frequency of operation of dishwashers during the day (Source: EUP LOT 14163)

Within the framework of the Smart-A project (Stamminger et al., 2009)170, this information was used to deduce the probability of start time of dishwasher operation for the ten European countries investigated (cf. Figure 26).

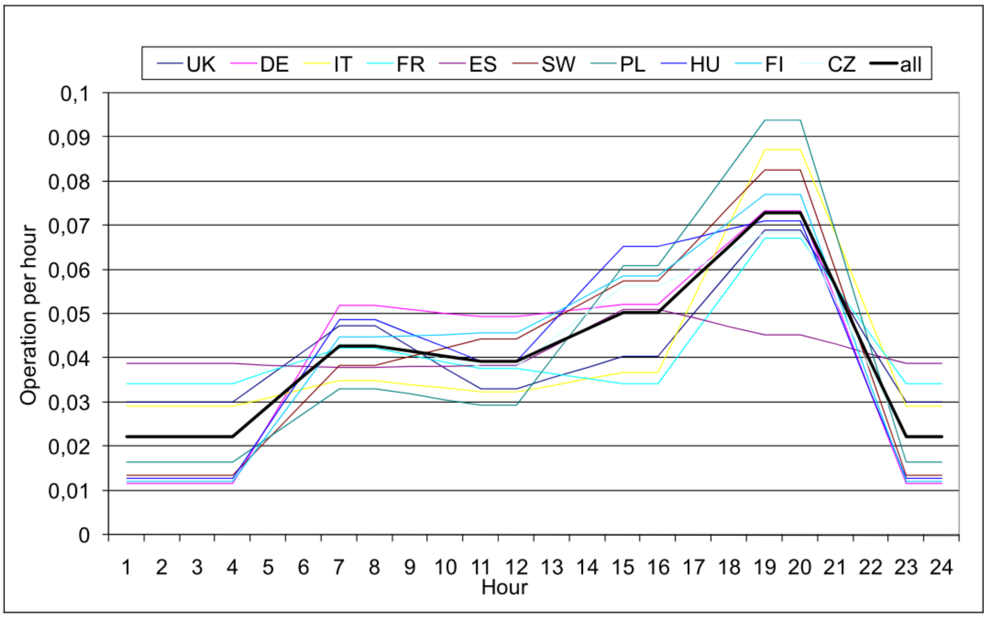

Figure 26: Probability of start time of the dishwasher operation for the ten European countries investigated (source: Stamminger et al., 2009170)

In view of dishwashers, just one major scheduling period can be identified in the late afternoon/ evening (about 5 PM-8 PM). For Spain, this peak is not as pronounced as for other countries. The probability curve is rather flat, showing that dishwashers in Spain are operated all over the day with roughly the same probability.

If the general pattern of a power demand curve of a current average dishwasher (cf. Figure 24) is aggregated with the average probability of start time (cf. Figure 26) and an appliance-specific usage factor, which takes into account the average number of cycles per year, the general pattern of a daily load curve depicted in Figure 27 can be derived. It has to be noted that this daily load curve is based on data representing the user behaviour of only ten European countries, which are named in Figure 26. As the countries investigated cover a major part of the population of EU-28 and the user behaviour appears to be similar in these countries, it seems to be reasonable to assume that the consumer behaviour and this general pattern of a daily load curve is also valid for all EU-28 countries. If the total energy consumption of dishwashers will further decrease as expected for the next years, the power demand curve will change, which will have an impact on the daily load curve.

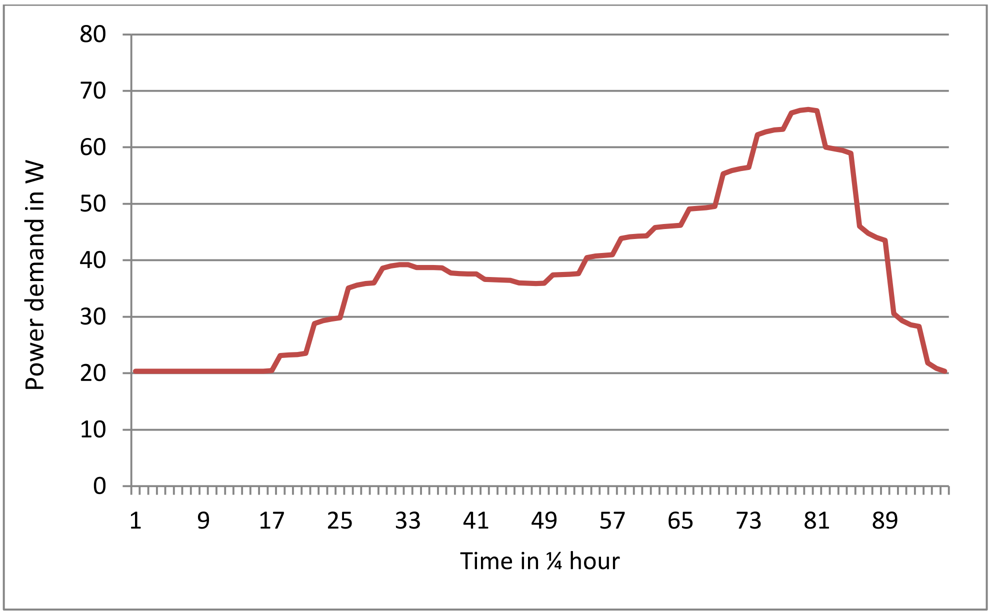

Figure 27: General pattern of a daily load curve of a current dishwasher (source: modified according to Stamminger et al., 2009[170])

Washing machines

In Europe, a trend towards decreasing household sizes and increasing capacity of washing machines from an average capacity of 4.8 kg in 1997 to 6.0 kg in 2008 can be observed (VHK, 2014159). In 2011, an average number of 3.8 cycles per household and week was determined by Schmitz and Stamminger (2014)[165], corresponding to 198 cycles per year. The International Association for Soaps, Detergents and Maintenance Products (A.I.S.E) reported an average wash frequency of 3.2 per household and week (166 cycles per year) across Europe in 2011 (A.I.S.E., 2013[166]).

In view of the energy consumption per household per year, large differences between the countries could be registered, which can be explained by different washing temperatures and frequencies (Figure 28).

[165] Schmitz and Stamminger (2014): Usage behaviour and related energy consumption of European consumers for washing and drying. Energy Efficiency, 7, 937-954.

[166] A.I.S.E. (2013). The case for the “A.I.S.E. low temperature washing” Initiative.

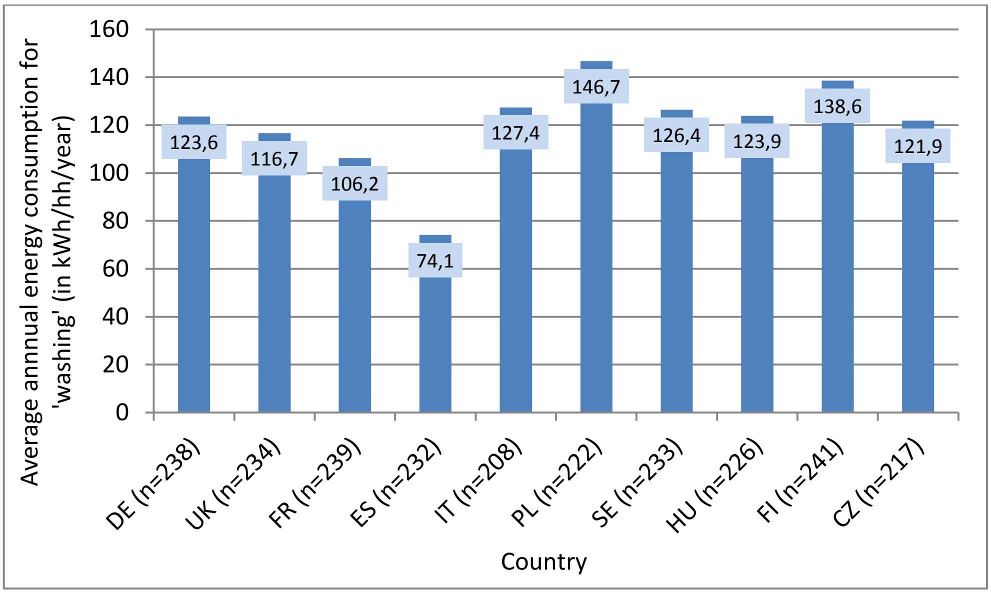

Figure 28: Average energy consumption for 10 European countries in 2011 (Source: Schmitz and Stamminger, 2014165)

Assuming a normal cotton programme and an energy consumption of 0.89 kWh per cycle, the power demand curve of a current average washing machine follows the pattern shown in Figure 29.

As the power demand is dependent on the washing temperature and also the amount of water needed for the washing process, this pattern may change according to the programme chosen and the capacity of the machine.

Due to the Energy Label and other political measures, the total energy consumption of washing machines in Europe is expected to further decrease within the next years. Assuming lower washing temperatures, the power demand curve of an average washing machine in 2025 may change towards a lower power demand in the heating phase and increased cycle times.

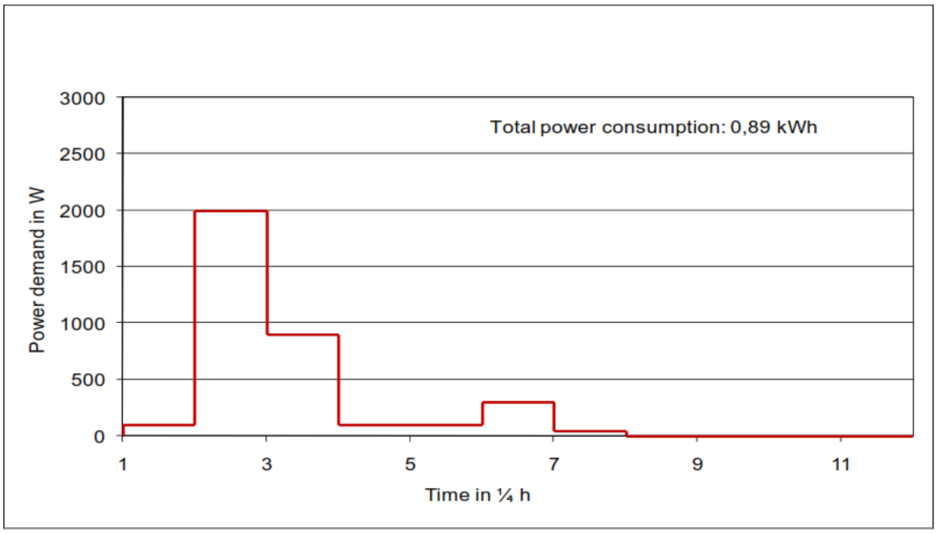

Figure 29: Typical pattern of a power demand curve of an average washing machine operating in a normal cotton programme (source: Stamminger et al., 2009[170])

It is assumed that use patterns of washing machines vary on a daily, but not on a seasonal basis. In 2007, about 2500 consumers from ten European countries were asked about the time of the day they usually use their washing machines (EUP LOT 14163). When looking at the results showing the frequency of operation of washing machines during the day (Figure 30), two preferred time slots can be identified, one in the morning and the second in the afternoon/ evening.

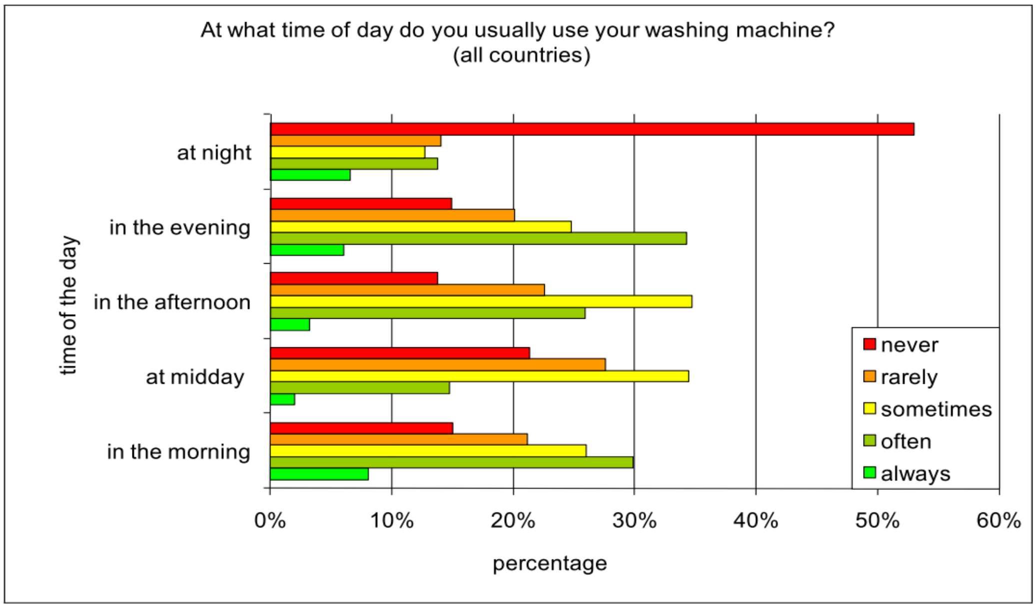

Figure 30: Frequency of operation of washing machines during the day (Source: EUP LOT 14163)

Within the framework of the Smart-A project (Stamminger et al., 2009170), this information was used to deduce the probability of start time of the washing machine operation for the ten European countries investigated (Figure 31). Two major time periods can be identified for the initiation of the washing machine operation, one in the morning between 7 AM and 9 AM and one in the late afternoon/ evening period (about 4 PM-8 PM). The daily use pattern is similar for all countries investigated with the exception of Spain, where the morning peak is more pronounced, as well as Sweden and Finland, where machines are predominately operated in the afternoon/ evening hours. At present, there is no reason per se to expect that the daily use pattern of washing machines will change in the near and mid-term future.

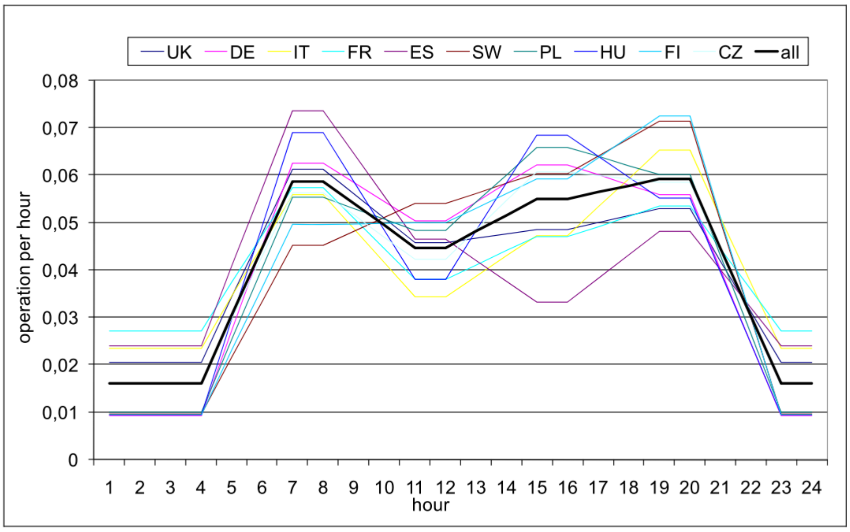

Figure 31: Probability of start time of the washing machine operation for the ten European countries investigated (source: Stamminger et al., 2009170)

If the general pattern of a power demand curve of a current average washing machine (cf. Figure 29) is aggregated with the average probability of start time (cf. Figure 31) and an appliance-specific usage factor, which takes into account the average number of cycles per year, a general pattern of a daily load curve can be derived (Figure 32). It has to be noted that this daily load curve is based on data representing the user behaviour of only ten European countries, which are named in Figure 31. As the countries investigated cover a major part of the population of EU-28 and the user behaviour appears to be similar in these countries, it seems to be reasonable to assume that the consumer behaviour and this general pattern of a daily load curve is also valid for all EU-28 countries. If the total energy consumption of washing machines will further decrease as expected for the next years, the power demand curve will change, which will have an impact on the daily load curve as well.

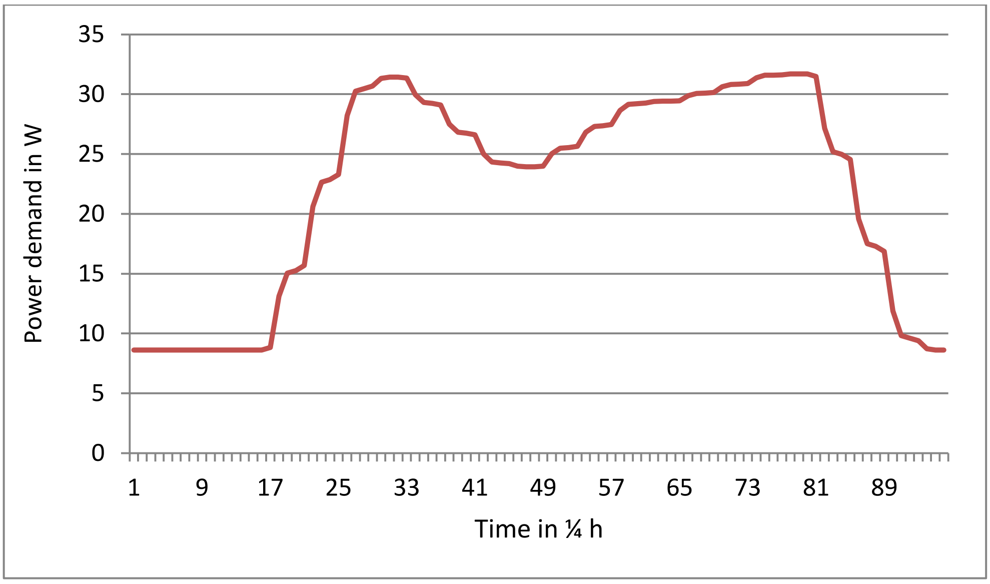

Figure 32: General pattern of a daily load curve of a current washing machine (source: modified according to Stamminger et al., 2009170)

Tumble dryers

The usage of tumble dryers is highly dependent on the season. According to a survey conducted within the framework of the EUP LOT 16 study (Lefèvre, 2009162), 50 % of consumers owning a tumble dryer use it always or often during the winter season. For the summer period, less than a quarter of the consumers (24 %) gave this statement. In the same study, an average frequency of 3.6 cycles per household and week (1.1 cycles/ person/ week) was calculated for the winter and 2.3 cycles per household and week (0.7 cycles/ person/ week) for the summer season. Assuming a duration of 26 weeks per season, this corresponds to an average of 153 cycles per household per year.

A study conducted in ten European countries by Schmitz and Stamminger (2014)[165] indicates that a share of about 16 % of all drying cycles of all households are done using a tumble dryer in winter. During summer, this share is about 9 %.

Based on data published by the European Commission (2003)[167], Stamminger et al. (2009)170 calculated an average electricity consumption of 2.46 kWh/ cycle (251 kWh per household per year). For this calculation, an annual average of 102 drying cycles per household owing a tumble dryer was assumed.

Considering a normal cotton programme and an energy consumption of 2.46 kWh per cycle, the power demand curve of a current average conventional tumble dryer (without heat pump technology) follows the pattern shown in Figure 33.

As the power demand is dependent on the process temperature and also on the amount and type of load, this pattern may vary between machines and according to the programme chosen.

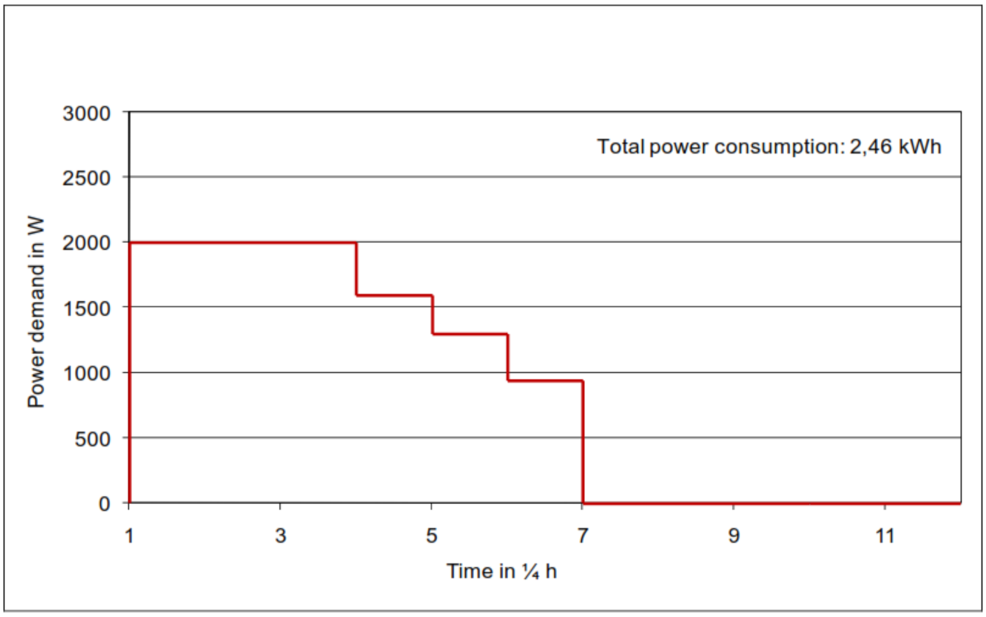

Figure 33: Typical pattern of a power demand curve of an average conventional tumble dryer operating in a normal cotton programme (source: Stamminger et al., 2009[170])

Due to the Energy Label, other political measures and the increasing availability of more efficient technologies (heat pump dryer), the total energy consumption of tumble dryers in Europe is expected to further decrease within the next years. This may result in a lower power demand during the whole cycle. At present, energy efficient tumble driers (class A and better) already account for

[167] European Commission (2005): Green Paper on Energy Efficiency or Doing More with Less. COM (2005) 265 final.

42 % of total sales in EU (Michel et al., 2015[168]). Figure 34 shows the power demand curve of a current average heat pump dryer.

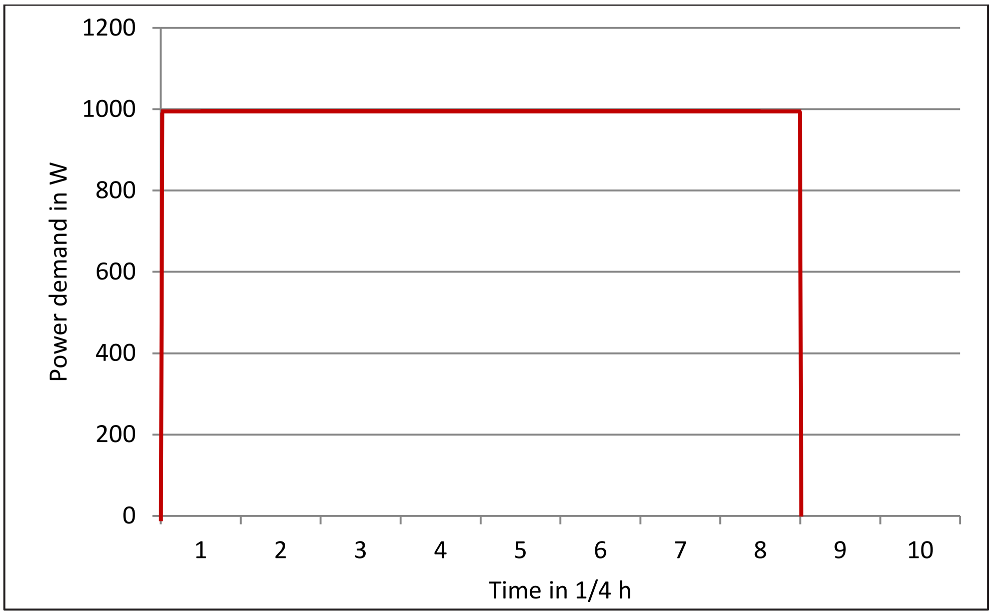

Figure 34: Typical pattern of a power demand curve of an average heat pump tumble dryer operating in a normal cotton programme (source: own illustration)

Use patterns of tumble dryers vary both, on a daily and on a seasonal basis. According to Stamminger et al. (2009)170, the probability of the start time of the tumble dryer operation can be derived from the respective information about washing machines (Figure 31) by simply adding two hours to the time the washing cycle is started. Normally, the washing and drying process are done consecutively. The offset of two hours is seen as an average time span between the start of these two devices. Against the background of increasing cycle times of washing machines, this offset is expected to become larger in the near and mid-term future.

If the general pattern of a power demand curve of a current average conventional tumble dryer (cf. Figure 33) is aggregated with the average probability of start time (cf. Figure 31) and an appliance-specific usage factor, which takes into account the average number of cycles per season, a general pattern of a daily load curve can be derived (Figure 35). For heat pump tumble dryers, the general pattern of a daily load curve is shown in Figure 36. It has to be noted that this daily load curve is based on data representing the user behaviour of only ten European countries, which are named in Figure 31. As the countries investigated cover a major part of the population of EU-28 and the user behaviour appears to be similar in these countries, it seems to be reasonable to assume that the consumer behaviour and this general pattern of a daily load curve is also valid for all EU-28 countries. If the total energy consumption of tumble dryers will further decrease as expected for the next years, the power demand curve will change, which will have an impact on the daily load curve as well.

[168] Michel, Attali and Bush (2015): Energy efficiency of White Goods in Europe: monitoring the market with sales data. Changes and trends regarding energy efficiency, energy consumption, size and price in the markets of refrigerators, washing machines and tumble driers in the EU, France and Portugal, 2004 to 2014. Available online: http://www.topten.eu/uploads/File/WhiteGoods_in_Europe_June15.pdf.

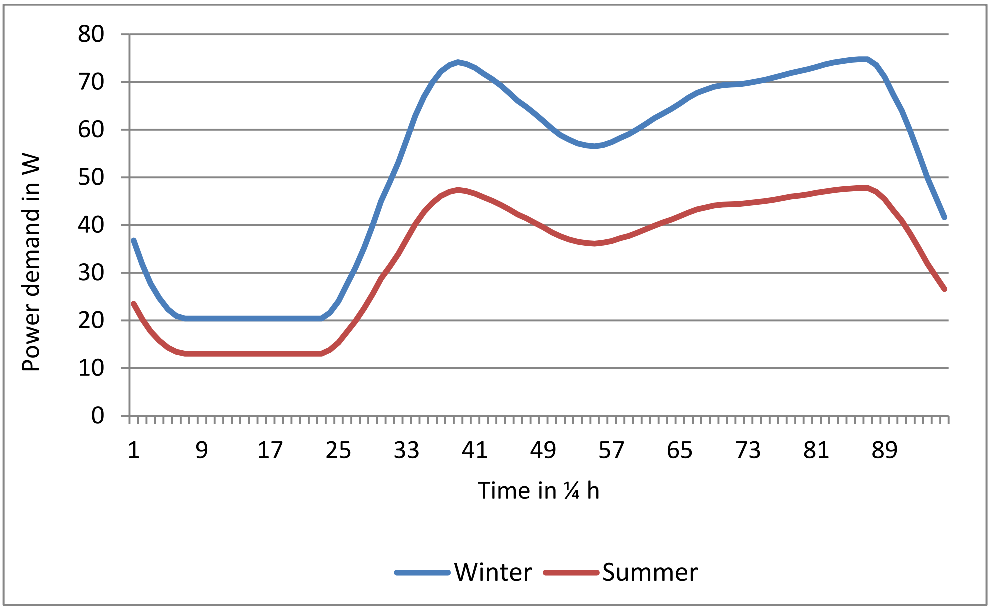

Figure 35: General pattern of a daily load curve of a current conventional tumble dryer for winter and summer season (source: modified according to Stamminger et al., 2009170)

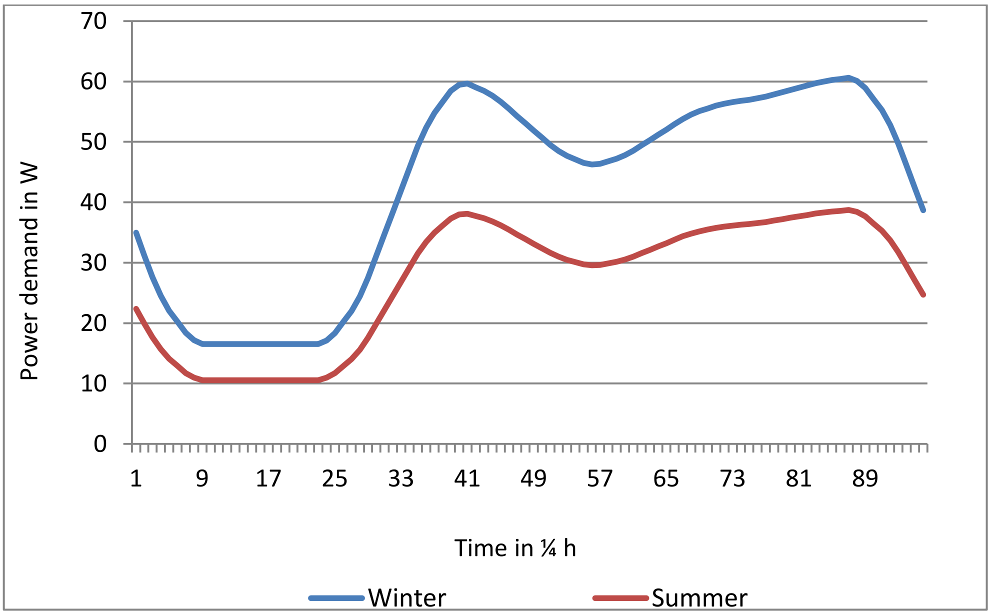

Figure 36: General pattern of a daily load curve of a current heat pump tumble dryer for winter and summer season (source: own illustration)

Washer-dryers

According to a study by Schmitz and Stamminger (2014)165 conducted in ten European countries, the average number of washing cycles per week and household is 4.3. This corresponds to an annual number of 224 cycles. The aforementioned study also revealed that washer-dryers are mainly used for washing purposes. The integrated drying function is only used in 29 % of all wash cycles. This means an average frequency of 1.3 times a week. Even though the majority of appliances in this study were equipped with a 'wash and dry in a row' function (no consumer interaction is needed between the washing and the drying cycle as far as the load capacities for washing and drying are respected), this function is only chosen for 24 % of all wash cycles (corresponding to 1.1 cycles per

week). This might be explained by the fact that the capacity for drying is often smaller than for washing, which means that either consumer interaction would be needed to remove wet clothes partly before drying or alternatively the washing capacity cannot be used to the full extent. Another reason is the fact that not all fabrics and items are suitable for tumble drying and therefore have to be removed after the washing process.
The energy consumption of washer-dryers currently available on the market varies between 3.7 kWh and more than 6 kWh (http://www.topten.eu) for a washing and drying cycle. This wide range can be explained by the fact that only the efficient appliances are equipped with a heat pump, while the inefficient once are lacking this technology.
It is assumed that use patterns of washer-dryers vary both, on a daily and on a seasonal basis. The study by Schmitz and Stamminger (2014)165 has shown that in summer, owners of washer-dryers predominately prefer to dry their laundry outside. About 60 % of participants in this study stated to use the drying function of the washer-dryer rarely or never during the summer season. For the winter season, only about half of the households gave this statement. Even though no data are available, it might be assumed that the probability of start time of the washer-dryer operation is equivalent to the probability pattern of washing machines (cf. Figure 31).

3.2.1.3. LIFESPAN

The average life span of periodical appliances may vary depending on the manufacturer, the model, the equipment, the use conditions and the maintenance. However, calculations and estimations from GfK and experts from industry suggest an average life span of 10 to 15 years for appliances of this category. Information that is more detailed is given in Table 18.

Table 18: Average life span of periodical appliances (Source: [a] VHK, 2014159; [b] EUP LOT 14163; [c] Lefèvre, 2009162)

Type of appliance	Average life span
Dishwashers:	13 years[a]
Washing machines:	14 years[b]
Tumble dryers:	13 years[c]
Washer-dryers:	n.a.

3.2.1.4. Possibilities for consumers to engage in smart periodical appliances

In view of periodical appliances, two different possibilities to shift energy or modulate power could be identified.

1. Remote activation: the user selected program is remotely activated before the user deadline is reached.
2. Altered electricity consumption pattern: while the appliance is activated, the consumption patterns changed through pausing the operation, changing the temperatures, etc.

In the first case, the machines are remotely started, e.g., when a surplus of (renewable) energy is available on the grid. For this case, user's involvement is limited to the activation of the respective mode and the definition of a desired deadline. As the operation of a single appliance is only shifted in time, the sequence of the programme and with this, the power demand curve of a cycle, remain unchanged. In the case of washing machines or washer-dryers, the drum should be reversed after the end of the cycle until switching the machine off to avoid the laundry going mouldy or sticking together (additional energy is needed for this function, in average 10 W[169]). Appliances in this category offer a high energy shifting capacity. Studies indicate that around 30 % of the configurations of washing machines and tumble dryers can be operated with remote activation. For dishwashers this is 56 %. The average length of the time window for remote activation varies from 3 to 8 h (Mert et al. 2008147).

In the second case, machines may change their operation if they are triggered by an external signal, e.g., showing a shortage of energy available on the grid. Possible changes include short-term interruptions, changes in temperatures or spinning speed or shifts of single programme phases (e.g. heating or spinning phases). This may change the power demand curve of a single appliance and the overall duration of a cycle. For periodical appliances, short-term interruptions might be critical if they occur during the heating phase. Depending on their duration and the actual process temperature, heat energy may be lost to the surroundings and additional energy is needed to recover the process temperature. Investigations by Stamminger et al. (2009)170 recommend interruptions not exceeding a time of 10 minutes in order to avoid significant losses in heat energy. A further aspect, which has to be taken into account in view of short-term interruptions, is the performance. If the operation of washing machines or tumble dryers is interrupted, for instance, the laundry may go mouldy or stick together or fading of colours may occur. In order to avoid such textile damages, the drum should be moved in regular intervals during interruptions longer than 5 minutes.

The complexity of technical adjustments and redesign needed is higher for the second than for the first option.

Flexibility is typically situated in the afternoon and especially in the evening. The evening flexibility peak is most pronounced for the dishwashers. There is more flexibility in the weekends than in during weekdays. As described before, there are almost no seasonal effects for dishwashers and washing machines. However, tumble dryers are predominately used in winter season.

3.2.1.5. Comfort constraints and consumer objections

Several studies (e.g. Kobus et al., 2015140, Saele and Grande, 2011141, Mert et al., 2009142, Paetz et al., 2011148, D'hulst et al., 2015186, Vanthournout et al., 2015188) have shown that the willingness of consumers to shift loads to off-peak hours is rather high for washing machines and for dishwashers. Pilot studies, however, revealed significant inter-personal differences.

In view of washing machines, concerns expressed include safety aspects (e.g. fear of flooding or fire if appliances are operated unattended or during the night). Additionally, consumers are afraid of noise during operation at night. Although the willingness to postpone wash cycles is generally high (77 % of consumers asked in the framework of the Smart-A Study would accept shifts of at least 3 hours), the fear of textile damages (e.g. getting mouldy) is becoming a critical factor for shifting operation (Mert et al., 2008147). Also short term power interruptions may cause textile damages like colour fading or getting mouldy and should therefore not exceed 5 minutes without tumbling (Stamminger et al., 2009170).

For dishwashers, consumers' acceptance of shifting loads or short term interruptions is markedly high. According to findings of the Smart-A project (Mert et al., 2008147), the majority of consumers would be willing to shift their operation at least for 3 hours. Since many consumers already use their dishwasher during night or absence from home, only a few of them are afraid of unattended operation, flooding, fire or noise.

In view of tumble dryers, consumer's acceptance of load shifts demand might be lower than for other periodical appliances. Normally, their operation immediately follows the washing process. If the start is postponed, consumers are afraid of textile damages and wrinkles. In the case of washer-dryers, the level of acceptance is assumed to be higher than for separate tumble dryers as no additional

[169] Based on measurements of University of Bonn, not published

consumer interaction is required if the load capacity of the washing and drying function is respected. (Mert et al., 2008147)
In a pilot study in the framework of the LINEAR project focussing on the flexibility potential of washing machines, dishwashers and tumble dryers and other wet appliances, significant shares of the flexible electricity consumption were shifted to lower price periods, whereas the dishwasher outperformed the other wet appliances in flexibility. User fatigue couldn't be observed during the project. The participants of this pilot study reported on a small impact in view of the comfort, which is not further specified. (Vanthournout et al., 2015188)

3.2.2. CONTINUOUS APPLIANCES

3.2.2.1. USAGE BEHAVIOUR

Continuous appliances are appliances that provide a capacity to store thermal energy in a form ready to be delivered to the user without any further transformation. These appliances require no interaction with the user after initial set up, although user actions can impact the appliance's operation. In this category we need to distinct between the following appliances destined for private use:

- Refrigerators
- Freezers
- Electric storage water heaters

Moreover, commercial refrigeration appliances fall in the category of continuous appliances.

Residential refrigerators and freezers are mostly based on a closed vapour-compression system. Besides a compressor, they consist of three main components, an evaporator, a condenser and an expansion valve. A fluid refrigerant circulates inside a closed piping system. By absorbing the heat inside the refrigerator or freezer and cooling down the air, the refrigerant evaporates to a gas and flows to the compressor, where it is compressed. The compression causes the temperature and the pressure of the refrigerant to rise. After that, the refrigerant passes the condenser, where it releases heat (equivalent to the heat absorbed inside the refrigerator/ freezer and the thermal equivalent of compressor's work) to the surroundings and becomes liquid. The expansion valve is used to expand the refrigerant and control its flow back to the evaporator. In this process, electrical energy is mainly needed to operate the compressor. Additional energy may be required for the internal light, fans, displays and automatic defrosters.
In the case of electric storage water heaters (hot water buffers), cold water is heated up by one or two direct immersion heating elements, which are located near the bottom and in the upper part of an insulated storage tank. The tank is connected to a cold water supply and has an outgoing insulated pipe for hot water, which normally supplies different taps. Wattage and voltage of electric storage water heaters vary depending on their storage capacity and the temperature range. Whereas the usual residential voltage current (230 V, 16 A) is sufficient for devices with a small storage capacity up to 30 litres, water heaters with larger tanks are frequently connected to high voltage current (~ 400 V). Besides the energy needed for heating up the water, electric storage water heaters may consume stand-by energy to maintain the desired water temperature (about 1.8-2.6 kWh per day; Stamminger et al., 2009[170]). However, water heaters and hot water storage tanks are now subject to Ecodesign requirements (COMMISSION REGULATION (EU) No 814/2013 of 2 August 2013), which

[170] Stamminger (2009): Synergy potential of smart domestic appliances in renewable energy systems. Shaker Verlag, Aachen.

regulate a decrease of standing losses. Consequently, the stand-by energy consumption to maintain a desired water temperature will reduce within the next years.
The rated power of the aforementioned appliances is shown in Table 19.

Table 19: Rated power of devices (source: Stamminger, 2009[18])

Appliance	Rated power of devices
Refrigerators/ freezers	50-300 W
Electric storage water heaters	2000-6000 W

For residential refrigerating appliances, the market penetration is extremely high reaching 1.4 appliances per EU households in 2015. This corresponds to a total of 303 million appliances in stock. (VHK and Armines, 2015[171]) During the last years, refrigerator-freezer-combinations account for the highest share of refrigerating appliances (60 % in EU-15, about 80 % in New Member States; Bertoldi et al., 2012[172])
According to estimates by JRC, the installed stock of electric storage water heaters in EU-27 in 2007 was 90 million units. Electric storage water heaters with a capacity of more than 30 litres represent 27 % of the installed base of primary water heaters. (Bertoldi and Anatasiu, 2009[173])
For more information on stock data, refer to Task 2.
Given the high power consumption of electric water heaters and the large installed base volumes of refrigerating appliances, the potential of this category for smart applications is assessed to be high. Therefore, these appliances are described more in detail in this chapter.

3.2.2.2. User behaviour concerning continuous appliances

Daily and annual use pattern

Refrigerators

In view of refrigerators energy consumption, only limited data are available. According to VHK (2014[161]), an average annual energy consumption of 270 kWh per refrigeration appliance in stock in 2015 was calculated. This corresponds to a total energy consumption of about 82 TWh/a (303 million appliances in stock in 2015[161]). During the last years, energy efficiency improvements have overcompensated the trend towards an increase in size[174] and it can be assumed that refrigeration appliances will become even more efficient in the future. According to latest data from Topten.eu (2015)[175], the average declared energy consumption for refrigerators sold in 2014 was 231 kWh.
Besides technical factors, the user behaviour and environmental factors determine the energy consumption of refrigerators (Geppert and Stamminger, 2013[176]).

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[171] VHK and Armines (2015): Ecodesign & Labelling Review Household Refrigeration. Preparatory/review study Commission Regulation (EC) No. 643/2009 and Commission (Delegated) Regulation (EU) 1060/2010. Interim report

[172] Bertoldi, Hirl, Labanca (2012): Energy Efficiency Status Report 2012, Electricity Consumption and Efficiency Trends in the EU-27.

[173] Bertoldi, Atanasiu (2009). Electricity Consumption and Efficiency Trends in European Union – Status Report 2009, European Commission DG Joint Research Centre

[174] Herzog (2015): THE MDA (Major domestic appliances) EU ENERGY LABEL REACHING ITS LIMIT? A DISCUSSION. Available online: http://iet.jrc.ec.europa.eu/energyefficiency/sites/energyefficiency/files/events/EEDAL15/S7_Policies7/eedal15_submission_49.pdf

[175] Topten.eu (2015): Energy efficiency of white goods in Europe: monitoring the market with sales data. Available online: http://www.topten.eu/uploads/File/WhiteGoods_in_Europe_June15.pdf (latest 10-03-2015)

[176] Geppert and Stamminger (2013): Analysis of effecting factors on domestic refrigerators' energy consumption in use Energy Conversion and Management, Volume 76, December 2013, Pages 794-800.

These factors include:

- Ambient temperature and humidity
- Exposure to external heat sources (direct sunlight, ovens, dishwashers, washing machines)
- Capacity
- Temperature setting
- Insertion of warm load
- Frequency and duration of door openings
- Installation (freestanding or built-in)

Previous studies have shown that the user behaviour (e.g. temperature settings, insertion of load) as well as environmental factors like ambient conditions vary largely in European countries, making it difficult to predict the energy consumption of refrigerators in real life (EUP LOT 13[177]), Geppert and Stamminger, 2010[178]).

Depending on their capacity, the actual power demand of refrigerators is between 50 and 300 W, whereas Stamminger et al. (2009)170 calculated an average of 138.2 W. Although the efficiency of compressors is still increasing, it can be assumed that this average power demand remains constant over the next years due to a trend towards higher capacities (average net volume in 2015[161]: 278 l; growth rate 1.2 % per year[159]). Under normal conditions, the compressor is working intermittently with a total operation time of about 1/3. However, this operation time may increase up to 100 % under extreme conditions (extremely high ambient temperatures, large amount of hot load).
Figure 37 shows a typical pattern of a power demand curve of a refrigerator.

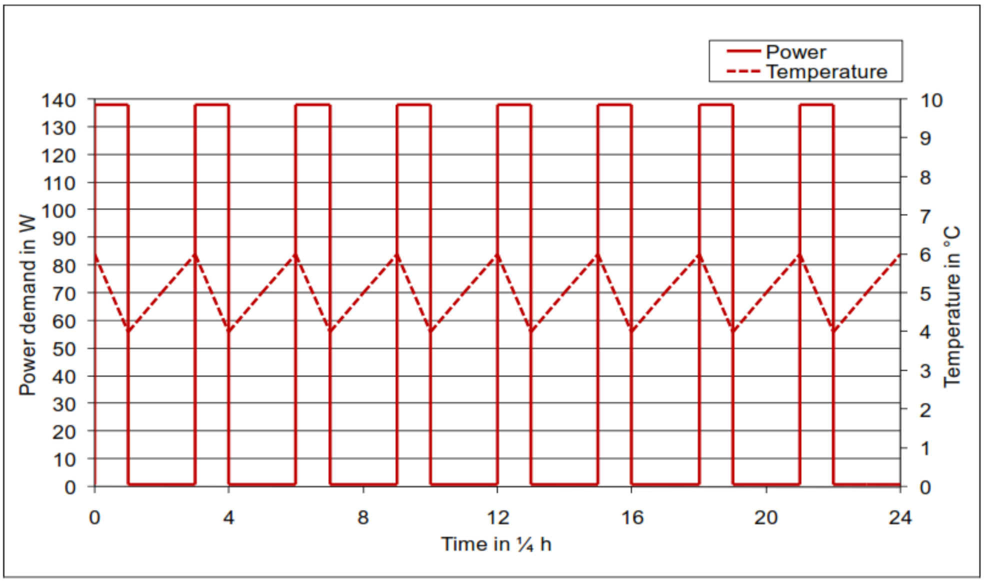

Figure 37: Typical pattern of a power demand curve of a refrigerator (Source: Stamminger et al., 2009170)

It is assumed that use patterns of refrigerators mainly vary on a daily basis. Seasonal variations due to differences in ambient temperatures are only weak and may be neglected as refrigerators are normally located inside closed rooms where the temperature is nearly constant all over the year. In

[177] Preparatory Studies for Ecodesign Requirements of EuPs. LOT 13: Domestic Refrigerators & Freezers. Final Report

[178] Geppert and Stamminger (2010): Do Consumers Act in a Sustainable Way Using Their Refrigerator? The Influence of Consumer Real Life Behaviour on the Energy Consumption of Cooling Appliances International Journal of Consumer Studies, 34(2), 219-27

view of daily variations, results of a study in different European households by Thomas (2007)[179] suggest an increased use in the afternoon/ evening period (Figure 38). It seems reasonable to assume that this usage pattern will not change within the next decade.

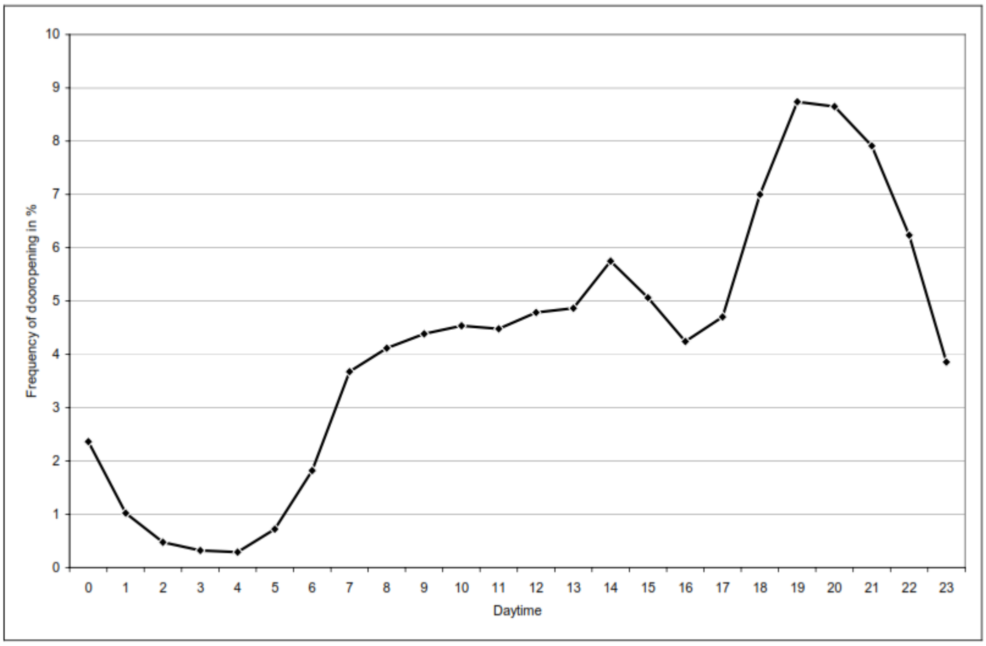

Figure 38: Frequency of door openings during the day (source: Thomas, 2007179)

If the typical pattern of a power demand curve of a refrigerator (shown in Figure 37) as well as the daily usage pattern (cf. Figure 38) are taken into account and it is assumed that 25 % of the total energy consumption is caused by this usage (e.g. door opening, placing of warm food), a typical daily load curve of an average refrigerator in Europe will follow the pattern shown in Figure 39. (Stamminger et al., 2009170)

[179] Thomas S. (2007): Erhebung des Verbraucherverhaltens bei der Lagerung verderblicher Lebensmittel in Europa. Shaker Verlag, Aachen.

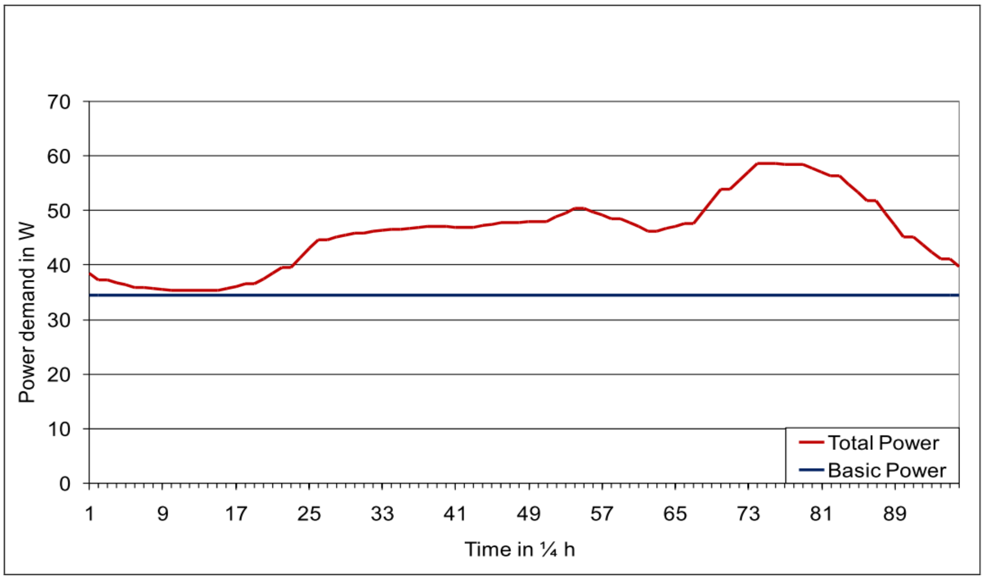

Figure 39: General pattern of a daily load curve of an average refrigerator (source: Stamminger et al., 2009170)

Freezers

In view of freezers energy consumption, only limited data are available. In most cases, no distinction is made between refrigerators and freezers. In the preparatory study in 2005, a total energy consumption of 40 TWh/ year for freezers (54,292 million appliances in 2005) was calculated (EUP LOT 13177). This is corresponding to an annual consumption of about 737 kWh per appliance. In the meantime, freezers have become substantially more efficient.

As described for refrigerators, user behaviour and environmental factors determine the energy consumption of freezers (Geppert and Stamminger, 2013[42]). These factors include:

- Ambient temperature and humidity
- Exposure to external heat sources (direct sunlight, ovens, dishwashers, washing machines)
- Chest vs. upright freezers
- Capacity
- Insertion of frozen load
- Insertion of load to freeze
- Frequency and duration of door openings
- Installation (freestanding or built-in)
- Activation of “super frost” function

Previous studies have shown that the user behaviour (e.g. temperature settings, insertion of load) as well as environmental factors like ambient conditions vary largely in European countries, making it difficult to predict energy consumption of freezers in use (EUP LOT 13177, Geppert and Stamminger, 2010[42,178]).

Depending on their capacity, the actual power demand of freezers is between 50 and 200 W, whereas Stamminger et al. (2009)170 calculated an average of 105.5 W. Under normal conditions, the compressor is working intermittently with a total operation time of about 1/3. However, this operation time may increase up to 100 % under extreme conditions (extremely high ambient temperatures, large amount of unfrozen load). The typical pattern of a power demand curve of a freezer without any consumer interaction is similar to that of refrigerators shown in Figure 37.

It is assumed that use patterns of freezers vary on a daily and on a seasonal basis. Ambient temperatures are often higher during the summer (EUP LOT 13177), resulting in an increased operation time of compressors. The most common temperature setting is -18 °C and this setting remains unchanged in the majority of households (EUP LOT 13177). On a daily basis, consumer's interaction with freezers is normally very limited. According to estimations by Stamminger et al. (2009)170, consumers open their freezers about one to two times per day to take out frozen food (mostly in the afternoon/ evening period) and one to three times per week to place unfrozen food. Opening the freezer's door once and taking out frozen food doesn't have a significant impact on the energy consumption. However, the operation time of the compressor and consequently the energy consumption will increase if new goods have to be cooled down and frozen. To avoid excessive rises in temperature and defrosting of frozen food after storing new goods, consumers can activate a "super frost" function in preparation. This function forces the freezer to cool down to a lower than the normal temperature. Nevertheless, the temperature inside the freezer will increase as soon as unfrozen food is placed, and the compressor operates non-stop until the heat is removed. After switching off the "super-frost" function, the temperature raises back to the initial one, accompanied by a pause in compressor's operation. These changes in power demand curve are illustrated in Figure 40.

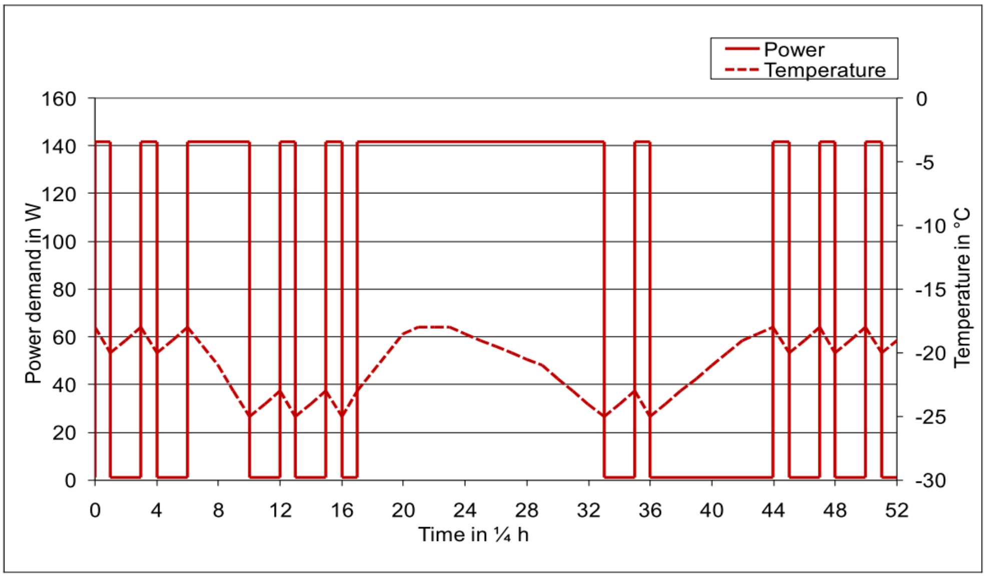

Figure 40: Typical pattern of a power demand curve of a freezer during storage of new goods to be frozen (source: Stamminger et al., 2009170)

If the consumer behaviour is taken into account and it is assumed that 10 % of the total energy consumption is caused by this consumer behaviour (e.g. placing unfrozen food), a typical daily load curve of an average freezer in Europe will follow the pattern shown in Figure 41. (Stamminger et al., 2009170)

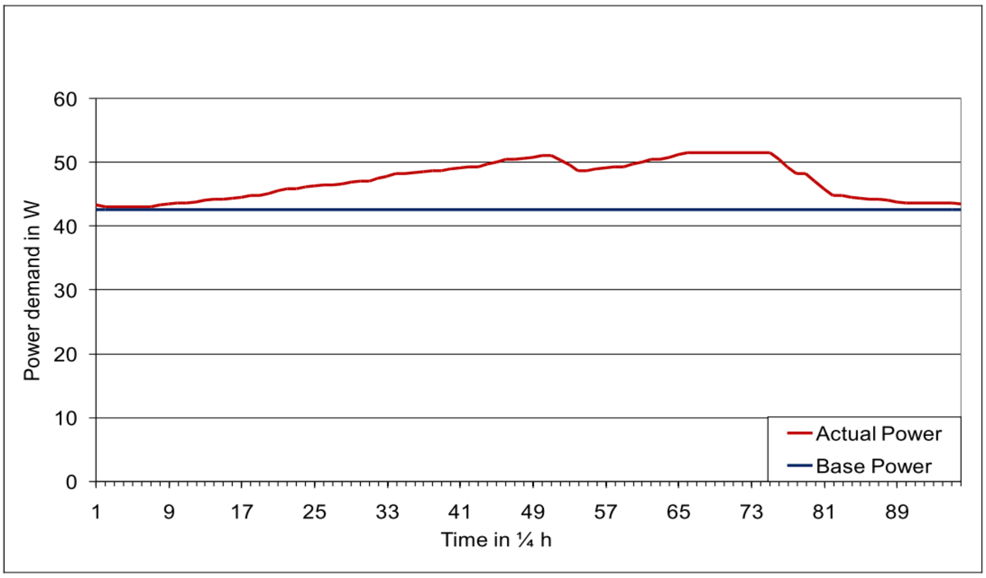

Figure 41: General pattern of a daily load curve of an average freezer (Source: Stamminger et al., 2009170)

Commercial refrigeration appliances

In close cooperation with industry, specifics of the consumption from commercial refrigeration, and its flexibility potential were estimated. Firstly, general daily patterns for consumption of commercial refrigeration appliances are developed. Secondly, the timeframe for maximum average load shifting time for these processes is given in the paper.

In (Funder-Kristensen et al., 2015), a methodology to calculate aggregated total consumption of a group of different types of supermarkets is developed. In the cited paper, two relevant flexible processes are identified related to commercial refrigeration: cooling process by compressors, and defrosting process. Flexibility in commercial refrigeration related to the compressor process can be best described as load shedding or load shifting, whereas the flexibility from the defrosting process can be utilized as load shifting.

The method relies on the number and area of different types of supermarkets in the considered area. In (Funder-Kristensen et al., 2015), a simple way to convert all the supermarket types into a single generic supermarket class is utilized. For the purposes of this study, the same method is applied. The converted area of all the supermarket types into this generic class per EU-28 Member State is presented in Table 20. The numbers for 2014 and 2020 are obtained from industry, and they are based on Planet Retail data.

For 2030 data in Table 20, a compound annual growth rate of 2% in the period from 2020 to 2030 for the retail market is assumed. Moreover, it is assumed that basic flexibility per m^2 will increase. This is not covered by increase in yearly average consumption per m^2, but in the increased number of supermarket area [m^2].

Table 20 Area of supermarkets expressed in converted m^2 per EU-28 Member State (source: calculation disclosed by correspondence by Danfoss).

Converted area [m^2]	2014	2020	2030
Austria	2.622.887	2.795.862	3.408.140
Belgium	2.759.579	2.991.654	3.646.810
Bulgaria	506.870	693.879	845.835
Cyprus	90.513	150.011	182.863
Czech Republic	1.782.830	1.888.133	2.301.623
Germany	22.149.284	24.004.219	29.261.009
Denmark	1.607.371	1.625.977	1.982.057
Estonia	538.496	701.350	854.942
Spain	7.838.926	9.302.877	11.340.155
Finland	2.013.210	2.418.153	2.947.715
France	22.066.766	23.334.136	28.444.182
United Kingdom	11.342.746	12.405.664	15.122.435
Greece	1.409.347	1.568.836	1.912.403
Croatia	873.687	1.123.874	1.369.996
Hungary	3.317.630	3.415.686	4.163.702
Ireland	981.409	1.022.173	1.246.023
Italy	7.085.567	7.451.524	9.083.366
Lithuania	573.585	637.757	777.422
Luxembourg	174.537	196.275	239.258
Latvia	241.197	282.752	344.674
Malta	30.171	50.004	60.954
Netherlands	3.395.744	3.806.681	4.640.323
Poland	3.720.754	4.548.618	5.544.740
Portugal	1.672.448	2.139.876	2.608.497
Romania	911.194	1.188.816	1.449.160
Sweden	3.539.269	3.817.954	4.654.064
Slovenia	485.984	542.125	660.847
Slovakia	757.481	909.795	1.109.035

The consumption of the commercial refrigeration is determined separately for the two identified flexible processes. The consumption of the defrost process is treated as a constant not depending on the time of the year and the climatic zone. The estimated consumption of the defrosting process is 13 [kW/m^2], and it can be shifted for maximally 90 minutes, see (Funder-Kristensen et al., 2015).

The yearly consumption of the compressor is correlated with the outside temperature, and follows seasonal and daily patterns. The variations in consumption by commercial refrigeration due to the climate differences between EU-28 Member States are taken into account by division of EU-28 into three climatic zones. These zones are defined as follows.

Climatic zones:

- A: Denmark, Sweden, Finland, Estonia, Latvia, Lithuania, the Netherlands, United Kingdom, and Ireland
- B: Germany, Belgium, Luxembourg, Poland, Czech Republic, Austria, Slovakia, Slovenia, Croatia, Hungary, Bulgaria and Romania
- C: Portugal, France, Greece, Italy, Spain, Cyprus, and Malta.

The consumption for each of the climatic zones is based on the calculations for a particular city from the zone. For zone A, this is Copenhagen, for zone B, Berlin, and for zone C, Madrid. Detailed calculations are conducted as presented for different cities in (Mikhailov et Matthiesen, 2013), where "Pack Calculation II" tool is developed and valorised.

Table 21 (source: private correspondence with Danfoss)

Climatic zone	yearly average [kW/m^2]	Daily variation [% of daily average]	Seasonal variation [% of yearly average]
A	40	40	40
B	43	50	45
C	46	55	50

The consumption is different depending on the climatic zone, and is defined as presented in Table 21.

The yearly consumption of the compressor follows a sinus curve with the highest amplitude in summer and lowest amplitude in winter. The yearly average is used to shift the sinus curve so that the correct consumption is obtained. The consumption also follows a sinus curve each day (each 24 hours). This sinus curve is centered around the daily average with a daily amplitude. The peak of the daily sinus curve corresponds to the hottest time of the day, which is at 2-3 pm according to the climate report for the … The coldest part of the day then corresponds to the time before the dawn in the middle of night before sunset, around 4-5am.
As for the yearly consumptions oscillations, end of January is the coldest (30 January), end of July hottest (30 July), so the consumption of commercial refrigeration is also the coldest on at the end of January, and hottest at the end of July. Similar assumption is also used in (Mikhailov et Matthiesen, 2013). The developed profiles can be validated against the profiles presented in (Fredslund, 2013).

It is assumed that this consumption can be shifted for 15 minutes on average, (Funder-Kristensen et al., 2015).

Lastly, not all the commercial refrigeration appliances will be able or willing to participate in the demand response schemes. Therefore, an estimation of share of smart enabled commercial refrigeration appliances in the total share of commercial refrigeration appliances is presented in

Table 22. As there are currently only pilots starting around provision of such flexibility, for 2014 and 2014, it is assumed there are no smart enabled commercial refrigeration appliances in EU-28 area. In the coming years, according to the educated guess from industry, the share of flexible commercial refrigeration actually providing flexibility is expected to increase to 50% and surpass the share of smart enabled residential refrigeration.

Table 22 Share of smart enabled commercial refrigeration appliances in the total share of commercial refrigeration appliances (source: correspondence with Danfoss).

Year	2014	2020	2030
Smart enabled appliances [%]	0	10	50

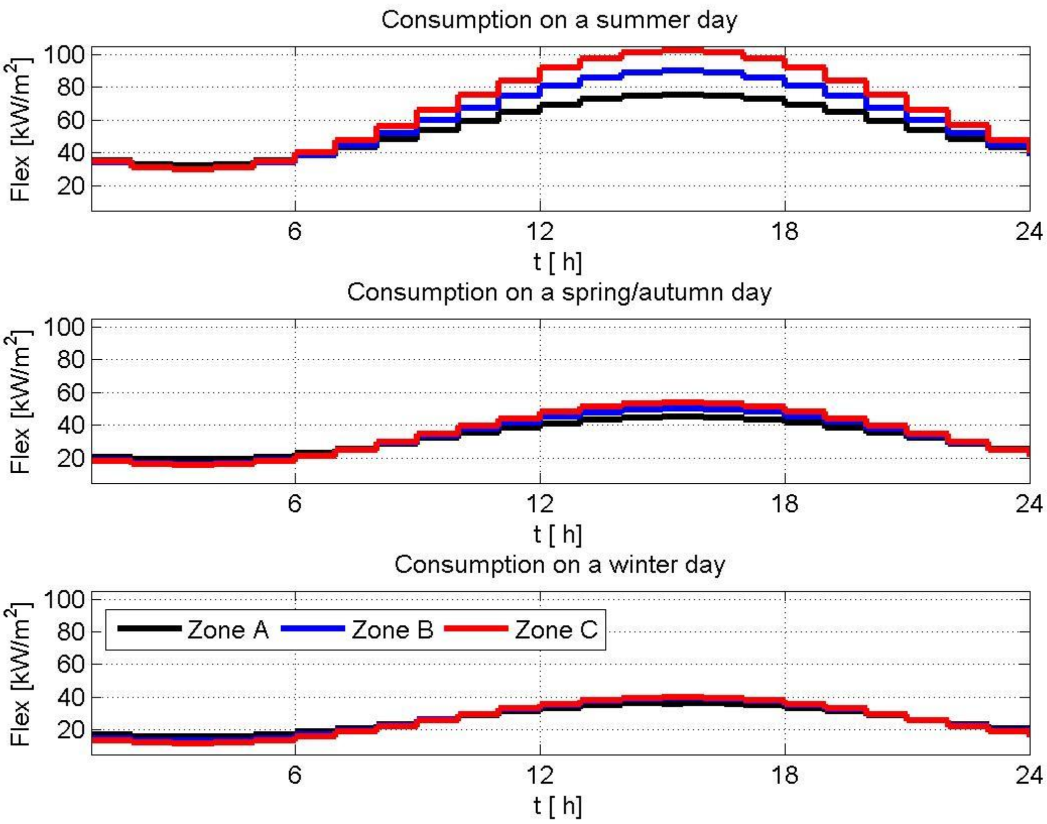

Figure 42 Daily consumption patterns of compressors in commercial refrigeration appliances, expressed in [kW/m^2], and given in dependence on the climatic zone and season in the year.

Electric water heaters

According to Bertoldi et al. (2012)173, electric water heaters consumed 8.7 % of total residential electricity consumption in 2007, corresponding to 73.0 TWh/ year. Taking into account the installed stock of in total 73 million devices[180] (about 20 million of night storage water heaters[180]), an average annual consumption of about 1000 kWh per appliance can be calculated.

As described for refrigerators and freezers, the energy consumption of electric water heaters is also significantly affected by user's behaviour and environmental factors:

- Number of people per household
- Frequency, duration and timing of showers or baths per person
- Number and usage of appliances connected to hot water supply (e.g. dishwashers, washing machines)
- Manual dishwashing habits
- Use of hot water for cooking

[180] VHK, 2007 + industry estimations from Ariston Thermo Group (personal communication). Includes electrical storage and heat pump water heaters

- Presence at or absence from home
- Temperature of hot water
- Temperature of incoming cold water

In 2007, the preparatory study on water heaters (EUP LOT 2[181]) calculated an average hot water consumption of 24 litres per person per day for EU-25, corresponding to an average of 59 litres per household per day. However, there are considerable differences between different Member States as shown in Figure 43.

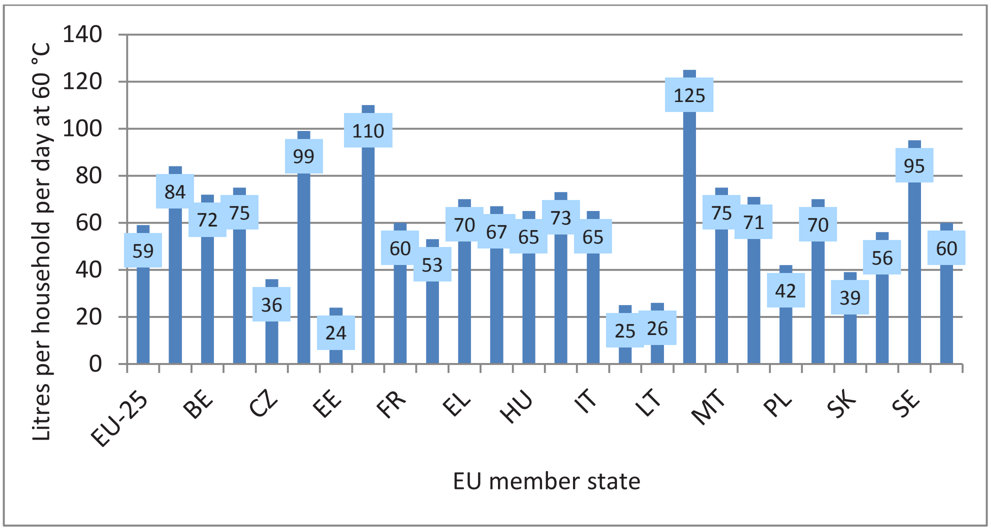

Figure 43: Hot water consumption per household per day for EU-25 (source: own illustration based on EUP LOT 2181)

Due to changes in consumer behaviour and variations in temperature of the incoming (cold) water, seasonal variations in use pattern of electric water heaters can be assumed. In-home measurements of water temperature and water consumption in 20 multi-family houses in Switzerland in 1993 have shown that the hot water temperature remained unchanged at about 60 °C all year. This study also suggests that the daily hot water consumption varies on a seasonal basis and that it is dependent on weekdays/ weekend (Figure 44). Defra (2008)[182] reported on similar seasonal effects observed in UK with highest volumetric hot water consumption in winter and lowest consumption in summer. The same study also analysed the annual pattern of incoming cold water temperatures. Regarding to this, considerable differences (about 10 K between the coldest and warmest temperature) have been found with highest temperatures occurring in summer. European data on seasonal variations of both, volumetric hot water consumption and cold water inlet temperatures, are lacking so far.

[181] Preparatory Study on Ecodesign of Water Heaters. Final report.

[182] Defra, 2008: Measurement of Domestic Hot Water Consumption in Dwellings. URL: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48188/3147-measure-domestic-hot-water-consump.pdf.

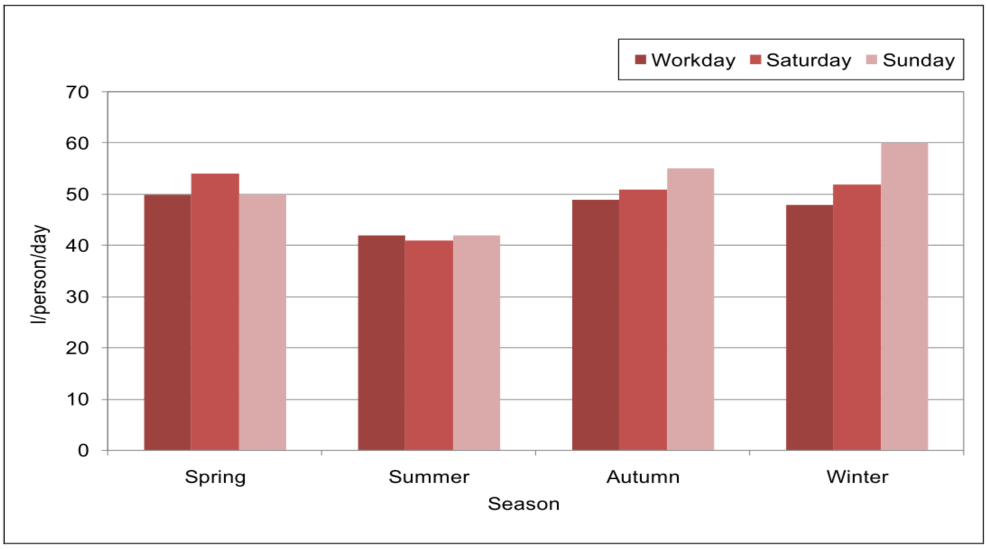

Figure 44: Daily hot water consumption by season and weekday (source: BfK, 1993; taken from Stamminger et al., 2009170)

Besides seasonal variations, use pattern of electric water heaters also varies on a daily basis.

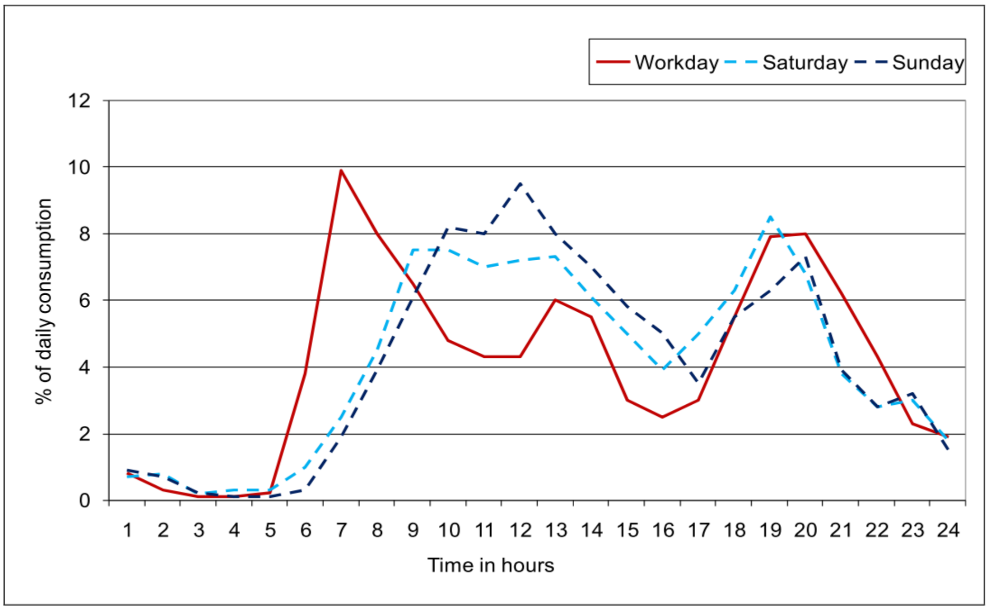

Figure 45: Profile of daily hot water consumption in Switzerland (source: BfK, 1993[183]; taken from Stamminger et al., 2009170)

[183] Bundesamt für Konjunkturfragen, 1993: Blatter, Borel, Hediger, Simmler: Materialien zu RAVEL. Warmwasserbedarfszahlen und Verbrauchscharakteristik. Bern.

On working days, two peaks can be observed, one in the morning between 6 a.m. and 9 a.m. and one in the evening period between 7 p.m. and 10 p.m. (Figure 45). Whereas the morning peak is postponed by about 4 hours (between 10 a.m. and 2 p.m.) during the weekend, the evening peak almost remains unchanged. More recently, Defra (2008)182 published similar information on hot water consumption pattern in UK, from which the following daily profile has been deduced (Figure 46). For this reason, it seems to be reasonable to assume that the daily profile shown in Figure 45 is still valid today and similar for all European countries.

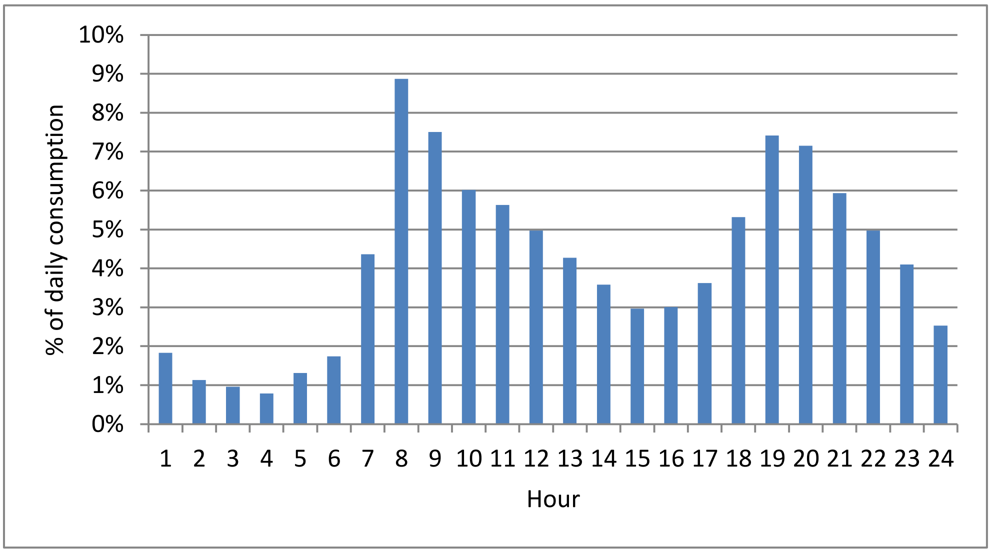

Figure 46: Profile of daily hot water consumption in UK (own illustration deduced from Defra, 2008[182])

In view of power demand curves of storage water heaters, it has to be distinguished between two main types: storage heaters, which heat during the night only (NSWH) and maintain the water temperature during the day and continuous water heaters, which reheat the stock of water to the predefined temperature after each tapping event (hot water buffers; CSWH). In general, the storage capacity of NSWH is higher (usually between 100 and 300 l, average 200 l) compared to CSWH (average 80 l). Regarding NSWH, power varies between 1500 and 3000 W dependent on capacity with an average power of 2500 W. In the case of CSWH, the power is lower (average 1500 W). (ATG, 2016[184])

Information about the distribution of these two types of storage water heaters is scarce. According to estimations by a manufacturer, water heaters heating during the night are the prevailing type in France and Germany (about 20 million appliances in stock in 2015[184]), whereas continuous storage water heaters (about 53 million appliances in stock in 2015[184]) are predominately used in Spain, Italy, Hungary, Czech Republic and Poland. In UK, both types are common. Data on the distribution in other European Countries are currently not available. (Stamminger et al., 2009[170])

General pattern of power demand curve for NSWH is exemplarily shown in Figure 47, whereas a storage capacity of 200 l, a temperature difference of 45 K, a rated power of 2.5 kW and an efficiency of 80 % (representative for the actual stock[184]) was assumed. Actual power demand curves may differ from the pattern given here. In general, the power demand curve needs to fit the respective total energy consumption, which is dependent, amongst others, on the amount of water to be heated, the

[184] ATG, 2016: Artiston Thermo Group, personal communication.

temperature of the incoming cold water and the target temperature. At present, NSWH usually start loading around 10-11 pm and stop heating when respective target temperature is reached (ATG, 2016[184]). An estimated distribution of energy consumption of NSWH over 24 hours of a day is given in Figure 48.

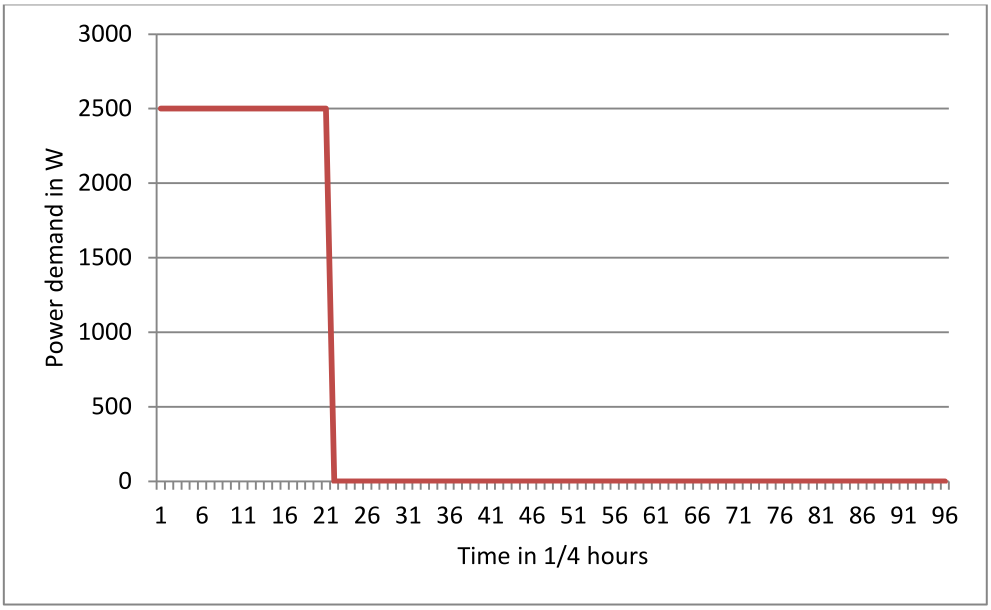

Figure 47: General pattern of a power demand curve of NSWH (source: own illustration)

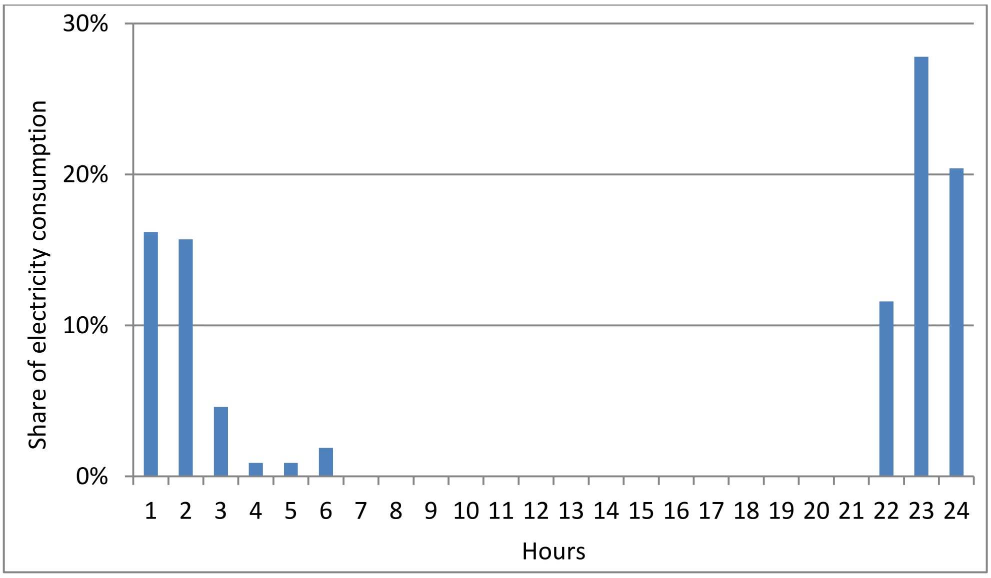

Figure 48: Estimated distribution of electricity consumption of NSWH over 24 hours of a day (source: own illustration deduced from ATG, 2016[184])

Load curve of CSWH directly corresponds to the daily tapping pattern (Figure 46). If the profile of daily hot water consumption (cf. Figure 8) is combined with the general pattern of a power demand curve of a 1.5 kW CSWH heating up 59 l (Δ T= 45 K), a typical pattern of a daily load curve () can be derived. It has to be noted that this daily load curve is just an example. As the pattern is dependent on the total amount of water to be heated, the temperature difference and the rated power, it is only valid under the conditions specified before. Due to huge variations in conditions between different countries and even between households in the same country, it is impossible to give a general pattern of a daily load curve of storage water heaters.

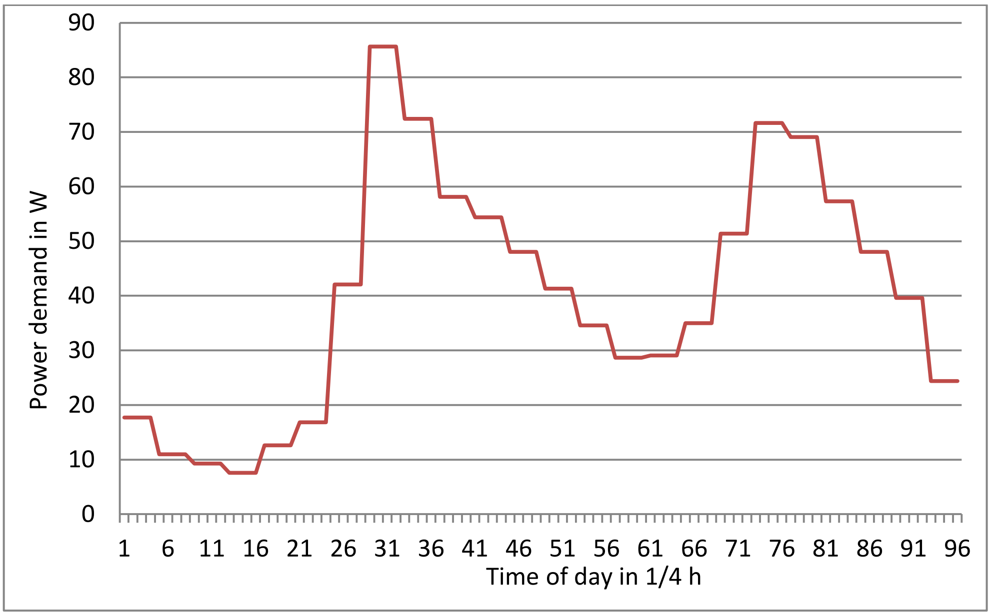

Figure 49: Typical pattern of a daily load curve of a 1.5 kW CSWH (source: own illustration)

3.2.2.3. Lifespan

The average life span of continuous appliances may vary depending on the manufacturer, the model, the equipment, the use conditions and the maintenance. Average data are given in Table 2.

Table 23: Average life span of continuous appliances (Source: [a] VHK and Armines, 2015[171]; [b] CECED, 2006[185]; [b] EUP LOT 2181)

Type of appliance	Average life span
Refrigerators:	12-13 years (+ 3-4 years secondary use)[a]
Freezers:	17 years[b]
Storage water heaters:	15 years[c]

3.2.2.4. Possibilities for consumers to engage in smart continuous appliances

In view of continuous residential appliances, two different possibilities to shift energy or modulate power could be identified.

1. Power line triggered operation (e.g. frequency control): changes in frequency are detected by appliances and transferred into action (activation or delay of cooling or heating).
2. Altered electricity consumption pattern: changes in the operational parameters of the appliance (motor speed, temperature settings, etc.) allow modification of the consumption pattern.

In the first case, the appliances are activated when a surplus of energy/ renewable energy is available on the grid, communicated e.g. via power line frequency or other control signals. In the following, the procedure is explained taking the example of frequency control.

[185] CECED, 2006: Energy Efficiency, A shortcut to Kyoto Targets. The Vision of European Home Appliance Manufacturers.

Both, surplus and shortage of energy have an impact on the total load on the grid and thus the frequency. These changes in frequency can be detected by appliances of this category and transferred into a respective action.

If power shortage is for example indicated during the operation of a refrigerator's compressor, the compressor will stop its operation even if the temperature, at which the thermostat normally switches off, is not reached. On the other hand, if there is a surplus of energy available on the grid, the compressor will start to operate even if the maximum temperature, at which the thermostat normally switches on, is not reached yet. In this way, the upper and lower temperature limits will not be exceeded. The hysteresis rather gets smaller and as a consequence, the food quality will not be compromised. For freezers, the same scenario is applicable. In the case of storage water heaters, a surplus of energy may prepone the start of the heating process and a power shortage may interrupt it for a short period of time. In the case of frequency control, appliances operate fully automatic so that no consumer interaction is required. In response to the load on the grid, frequency control may change the on-off cycle of refrigerators and freezers and may prepone or delay start of electric storage heaters or interrupt their operation by seconds or minutes.

In the second case, the appliances are remotely controlled and may change their operation. For refrigerators and freezers, possible changes include pre- or postponed start of the compressor, changes in temperature hysteresis or motor speed/ power level. In view of water heaters, the following changes are possible: delay in start or interruption of heating phase, preponing operations for storing energy in anticipation of future use in the coming hours, reducing or increasing water temperature desired. In order to enable remote control of appliances, a bidirectional communication is needed. This may change the power demand curve of a single appliance (e.g. shift in operation by seconds or minutes or changes in motor power) and the overall duration of a cycle.

The complexity of technical adjustments and redesign needed is higher for the second than for the first option.

For appliances in this category, flexibility depends on the thermal storage capacity. Flexibility is mainly situated in the afternoon (refrigerators and freezers) and in the early morning (electric water heaters). The flexibility of hot water buffers remains to a great extent stable during the day (D'hulst et al., 2015[186]). Whereas for refrigerators and freezers, seasonal effects are only weak, water heater loads are seasonal with highest potential occurring in winter.

In view of commercial refrigeration appliances, flexibility is limited for appliances containing perishable goods (e.g. supermarket cabinets), as a predefined maximum temperature always has to be maintained for reasons of food safety. However, flexibility may be provided by changing cooling power or turning off the light (e.g. at night). As far as beverage coolers, which do not contain any perishable goods, are concerned, the flexibility goes far beyond what is possible for supermarket cabinets. A growing number of beverage coolers are equipped with electronic control components (so called "energy management devices") steering energy consuming components/ functions of the appliance. Besides changing speed or power of compressors or fans or turning off the light, working temperatures may be increased during off-peak hours (e.g. during night or during the weekend). (JRC, 2014[187])

In general, it has to be mentioned that DSF should promote and not compromise food safety, thermal performance and energy efficiency of refrigerating appliances.

[186] D'hulst, Labeeuw, Beusen, Claessens, Deconinck, Vanthournout (2015): Demand response flexibility and flexibility potential of residential smart appliances: Experiences from large pilot test in Belgium. Applied Energy 155: 79-90.

[187] JRC (2014): JRC Technical Reports - Ecodesign for Commercial Refrigeration. Preparatory study update Final report.

3.2.2.5. Comfort constraints and consumer objections

In order to prevent microbial growth and quality losses of food, the temperature inside the compartment of refrigerators has to be kept constant within narrow ranges. As a result, delays in start time, short term interruptions and changes in temperature hysteresis are only feasible to a limited extent. Whereas it is possible to store energy by cooling to lower than normal storage temperatures in the case of freezers, this possibility is limited in the case of refrigerators because of the risk of freezing sensitive food and loosing food quality.
Although the acceptance for smart operation of refrigerators and freezers is generally high (96-98 % of consumers asked in the framework of the Smart-A Study would accept shifts), the fear of food spoilage or deterioration is becoming a critical factor (Mert et al., 2008147). Additionally, consumers raised doubts concerning a safe operation of the technology. To provide failure –resistant technologies and the possibility to monitor easily the storage temperatures might help to overcome these concerns (Mert et al., 2008147).
In view of electric storage water heaters, it is essential for a high consumer acceptance to always ensure a sufficient amount of hot water. Consequently, shifts in operation are limited, especially for water heaters with small storage capacities. In terms of devices with large storage capacities, operation shifts are possible without comfort or user impact. Operation of water heaters may also be adapted to shortages of power on the grid by reducing the desired water temperature (at present about 60 °C). However, this scenario might be critical from a hygienic point of view as the growth of microorganisms such as *Legionella* can only be reliably prevented at higher water temperatures of about 60 °C. In the framework of the LINEAR project, user acceptance with smart domestic hot water buffers was examined (Vanthournout et al., 2015[188]; Linear[189]). In order to avoid losses in comfort, some measures were used in the aforementioned study. So, a minimum state of charge was defined determining that the state of charge may not be less than 30 %. If it comes below this value, the buffer is automatically recharged until reaching a value higher than 30 %. These measures proved effective during the study as none of the participants complained about comfort losses. Due to the fact that no further consumer interaction is required once the comfort settings are done, consumer's acceptance for smart operation of domestic hot water buffers was high. Also in the study by Mert et al., 2008147, participants predominately stated to accept smart operation of water heaters as long as there is no loss of comfort.

3.2.3. Behavioural appliances

3.2.3.1. Usage Behaviour

Behavioural appliances are appliances where the operation is linked to its functionality and whose operations require the active involvement of consumers. In this category there are the following appliances destined for private use:

- Electrical hobs
- Electric ovens
- Range hoods
- Vacuum cleaners
- Instantaneous water heaters

[188] Vanthournout, Dupont, Foubert, Stuckens, Claessens (2015): An automated residential demand response pilot experiment, based on day-ahead dynamic pricing. Applied Energy 155: 195-203.
[189] Linear (local intelligent networks and energy active regions): www.linear-smartgrid.be

Regarding **electric hobs,** three main types may be distinguished: sealed hobs using solid plates made of cast iron, ceramic hobs heated with a halogen heating element and induction hobs. In the case of sealed hobs, heat is transferred via thermal conduction. In view of ceramic hobs, a halogen heating element is producing the heat, which is transferred to the cooking ware by radiation and conduction. Induction hobs create heat energy inside the cookware itself by inducing turbulent electric flow in its bottom. In all three cases, electrical energy is mainly needed for heating processes. Additional energy may be required for displays.

In the case of **electric ovens**, a variety of heating methods can be used including top and bottom heat, fan heat, grill and combinations of them. The heat is mainly transferred via radiation and, to a minor degree, by convection. Normally, temperatures can be set between 50 and 300 °C. Besides the energy needed for heating processes, electric ovens may consume stand-by energy (e.g. display, clock, and programme). Additional to single ovens, combinations of hobs and ovens (called cookers) are available and very common in the European market. (Stamminger et al., 2009170)

In view of electric **range hoods**, a variety of types and sizes are available on the market, including wall-chimney-hoods, island hoods, under-cabinet hoods or downdraft hoods. Their main function is to remove airborne grease, combustion products, smoke, fumes and odours coming from cooking processes. Range hoods can either be vented or ductless. Vented hood exhaust the air to the outside of the house by using a fan. On its way to the outside, the air passes one or more grease filters. Ductless hoods use several filters (e.g. activated charcoal) to clean the air and recirculate it back to the kitchen. Energy is mainly consumed by the fan. Additional energy may be required for lighting, displays and for stand-by losses.

Vacuum cleaners are appliances that suck up dust and particles from the floor and other surfaces by creating a partial vacuum. The main components are a fan, which is driven by a motor, different filters and nozzles. There are many different designs and technologies available on the market, e.g. canister, drum, upright, hand-held, robotic, cyclonic, bag less, bagged, wet-and-dry vacuum cleaners. Energy is mainly needed to operate the motor/ to create the partial vacuum.

In view of **instantaneous water heaters**, water is instantly heated up by passing the device. Heater rods of bare wire are often preferred for these devices. Due to their high wattage, instantaneous water heaters need to be connected to high voltage current (~ 400 V). In contrast to electric storage heaters, hot water is not stored and consequently no stand-by energy is required to maintain water at a desired temperature.

The rated power of the aforementioned appliances is shown in Table 24.

Table 24: Rated power of devices in stock (source: [a]Schätzke[190], 1997; [b]HEA[191]; [c]EUP LOT 17[192], [d]Stamminger et al., 2009170)

Appliance	Rated power of devices
Electric hobs	100-2,000 W (per plate)[a]
Electric ovens	Up to 3,500 W
Electric cookers	8,000-13,000 W[b]
Range hoods	120-1,000 W[b]
Vacuum cleaners	1,000-2,700 W[c]
Instantaneous water heaters	2,400-27,000 W[d]

[190] Kutsch, Piorkowsky, Schätzke (1997): Einführung in die Haushaltswissenschaft. Haushaltsökonomie, Haushaltssoziologie, Haushaltstechnik. Stuttgart 1997

[191] HEA (2015): Fachwissen Elektroherde. Available online: http://www.hea.de/service/fachwissen/elektroherde/

[192] Work on Preparatory Studies for Ecodesign Requirements of EuPs (II). Lot 17 Vacuum Cleaners. Final report

Since September 2014, vacuum cleaners are subject to Ecodesign requirements, which regulate a progressive decrease of rated input power (European Commission, 2013[193]). Consequently, the average rated power will reduce within the next years.

According to the EUP LOT 23[194] report, 145.7 million electric hobs (solid plates, radiant and induction hobs, mixed hobs, electric cooker tops) were in stock in 2007, corresponding to a penetration rate of 71 % (assumption: 205 million households). The overall trend shows that the share of electric hobs (especially induction hobs) will increase during the next years with slightly decreasing shares of gas fuelled hobs. However, there are variations between the Member States with some favouring electric (e.g. Germany and Sweden) and some gas fuelled hobs (e.g. Italy).

The penetration rate (EU-15) for electric fuelled ovens in 1998 was 61 % (Kasanen, 2000[195]). Sales figures from 2006 (96 % of all build-in units were electric ovens) admittedly show a trend towards an increasing share of electric ovens (EUP LOT 22[196]). There are differences across the Member States with some preferring electric ovens (e.g. Scandinavian countries) and some preferring gas fuelled appliances (e.g. Spain and Ireland).
In view of range hoods, the EUP LOT 10[197] report on ventilation indicates about 36 million hoods in stock in 2005 and about 39 million in 2010. Consequently, the penetration rate is about 19 % but is estimated to increase within the next years.

According to the EUP LOT 17 report192, the European market for vacuum cleaners is already oversaturated meaning that on average, every household has such an appliance and some households even have more than one.

According to estimates by JRC, the installed stock of instantaneous water heaters in EU-27 in 2007 was 29 million units. Instantaneous water heaters (> 12 kW) represent a share of 6.6 % of the installed base of primary water heaters. In view of secondary installations, instantaneous water heaters have a share of 7 %. (Bertoldi and Anatasiu, 2009173)

For more information on stock data please refer to Task 2.

As all behavioural appliances require an active involvement of consumers during operation and cooking and cleaning activities are time-bound in the majority of households, the acceptance of consumers for shifts in operation are presumably low. In view of instantaneous water heaters, smart operation would lower consumer's comfort significantly and is therefore considered as improbable. Concerning hobs and ovens, however, the potential of short term interruptions can be assessed as rather high as far as the cooking or baking results are not compromised. In contrast, short term interruptions are improbable for range hoods and vacuum cleaners as their power demand remains also constant during operation and interruptions in power supply would interrupt their operation. A reduction of their power would decrease their performance (lower air change rate, a loss of suction

[193] European Commission (2013): COMMISSION REGULATION (EU) No 666/2013 of 8 July 2013 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for vacuum cleaners
[194] Preparatory Studies for Ecodesign Requirements of EuPs (III) Lot 23 Domestic and commercial hobs and grills, included when incorporated in cookers. Final report
[195] Kasanen, P. (2000): Save II study, efficient domestic ovens, Final report, TTS Institute
[196] Preparatory Studies for Ecodesign Requirements of EuPs (III) Lot 22 Domestic and commercial ovens (electric, gas, microwave), including when incorporated in cookers. Final report
[197] Preparatory study on the environmental performance of residential room conditioning appliances (airco and ventilation). Study on residential ventilation - Final report

power or a reduction of heating power, respectively), and will presumably not be accepted by consumers.
Because of the reasons mentioned before, the focus is on electric hobs, ovens and cookers in the remainder of this chapter.

3.2.3.2. User behaviour concerning behavioural appliances

DAILY AND ANNUAL USE PATTERN

Electric hobs and ovens
Data on energy consumption of electric hobs, cookers and ovens are limited and often only available for one of the aforementioned appliances. Bertoldi et al. (2012)173 reported on a total consumption of 63.1 TWh for electric hobs and ovens together (40.1 TWh for hobs, 23.0 TWh for ovens). Considering stock data as shown above, an average energy consumption of about 206 kWh per appliance and year can be calculated for hobs (including mixed hobs and cooker tops). According to the SAVE II final report on efficient domestic ovens (Kasanen, 2000[195]), the average energy consumption per electric oven per year in Europe is 138 kWh with large variations between different Member States.
Besides technical factors, the user behaviour and environmental factors determine the energy consumption of hobs. These factors include:

- Choice of cooking utensils (pots and pans)
- Use of lids
- Type of hob (solid plate, radiant, induction)
- Temperature setting
- Duration of the cooking or baking process
- Use of synergistic effects
- Frequency of cooking or baking
- Frequency and duration of door openings (ovens)
- Heating mode of the oven (top or bottom heat, convection, grill, combinations)
- Use of pyrolytic function (ovens)

In a study by Sidler (1999)[198], the operation time for different hobs varied between 26 and 58 minutes per day. Data by Sidler (2009)[199] suggest seasonal effects of cooking showing that more energy is consumed in winter than in the summer period.
In view of electric ovens, Kasanen (2000)[195] reported on an average use frequency of 110 times per year, whereas the frequency is higher in Scandinavian countries and France and much lower in Italy and the Netherlands. The average operation time is 55 minutes per cycle (EUP LOT 22196).
Sidler (1999)[198] has published daily power demand curves of hobs and ovens, which are given in Figure 50 and Figure 51, respectively.

[198] Sidler et al. (1999): An experimental investigation of cooking, refrigeration and drying in 100 households. Programme SAVE, Project ECUEL.
[199] Sidler, O (2009): ENERTECH. “Notes techniques: Connaissance et maîtrise des usages spécifiques de l’électricité dans le secteur résidentiel”

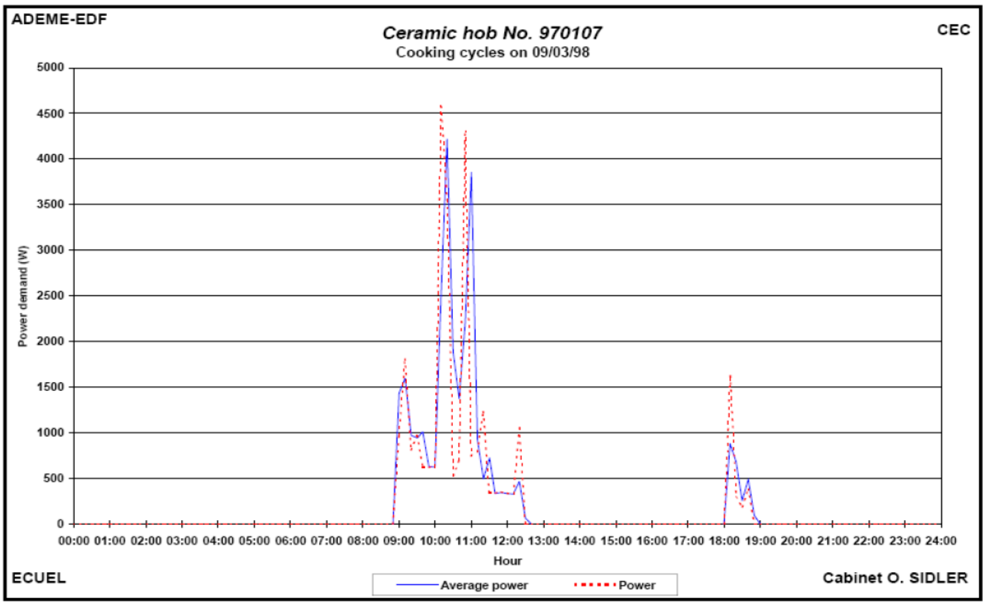

Figure 50: Daily power demand curve of an electric hob (source: Sidler, 1999[198])

In view of daily variations of electric hobs, the results suggest an increased use late in the morning (between 9 a.m. and 11 a.m.) and in the evening period (between 6 p.m. and 7 p.m.).
For electric ovens, only one main use period was found in the morning (between 8.30 a.m. and 11 a.m.)

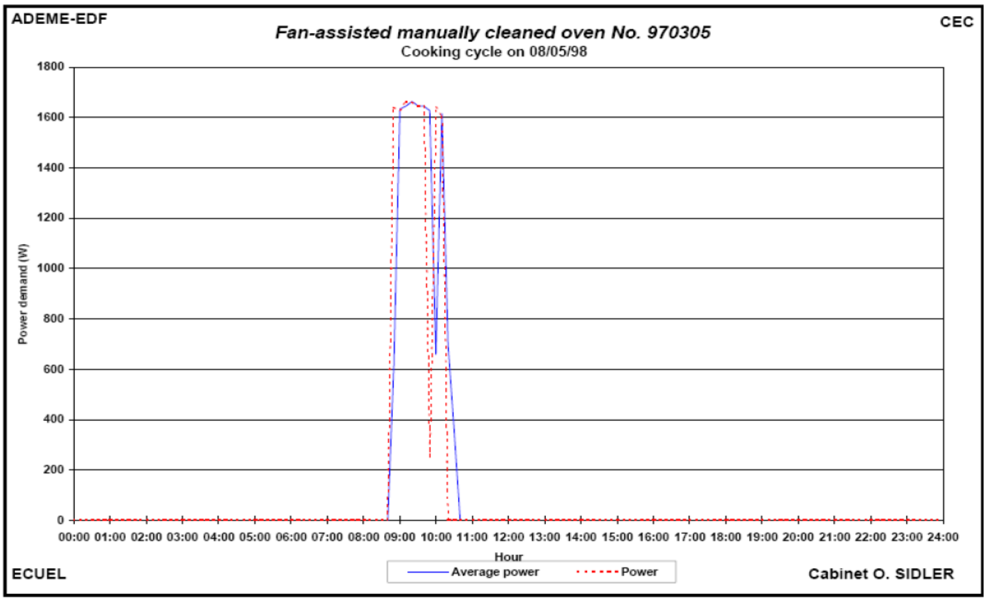

Figure 51: Daily power demand curve of an electric oven (source: Sidler, 1999[198])

Depending on the type of hob, the size of the plate and the temperature chosen, the actual power demand of hobs will vary between about 100 and 2,000 W. During operation of a hob, a typical pattern of power demand can be identified, independent on the actual power. This typical pattern is given in Figure 52. In the starting phase, the hob normally uses its full power to heat itself up. After that, the heating element of the hob is working intermittently, whereas the phases in power on mode are much shorter than the first (heating up) phase.

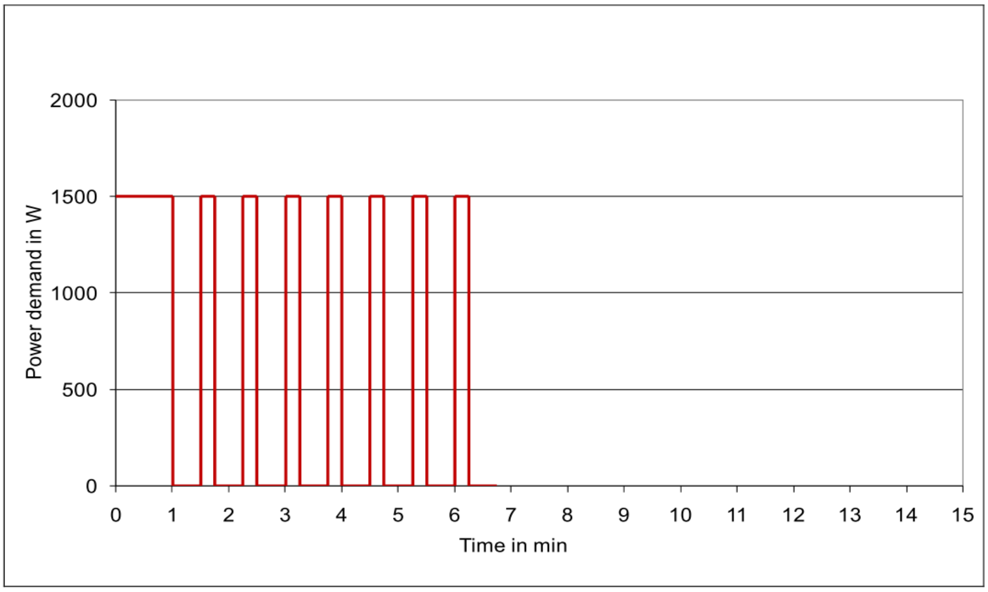

Figure 52: Typical pattern of a power demand curve of an electric hob (Source: Stamminger et al., 2009170)

A typical power demand curve of an electric oven (Figure 53) looks similar to that of a hob. However, the heating up phase is much longer than for hobs. Electric ovens are also working intermittently, whereas the total operation time of the heating element depends on the heating method as well as on the temperature setting.

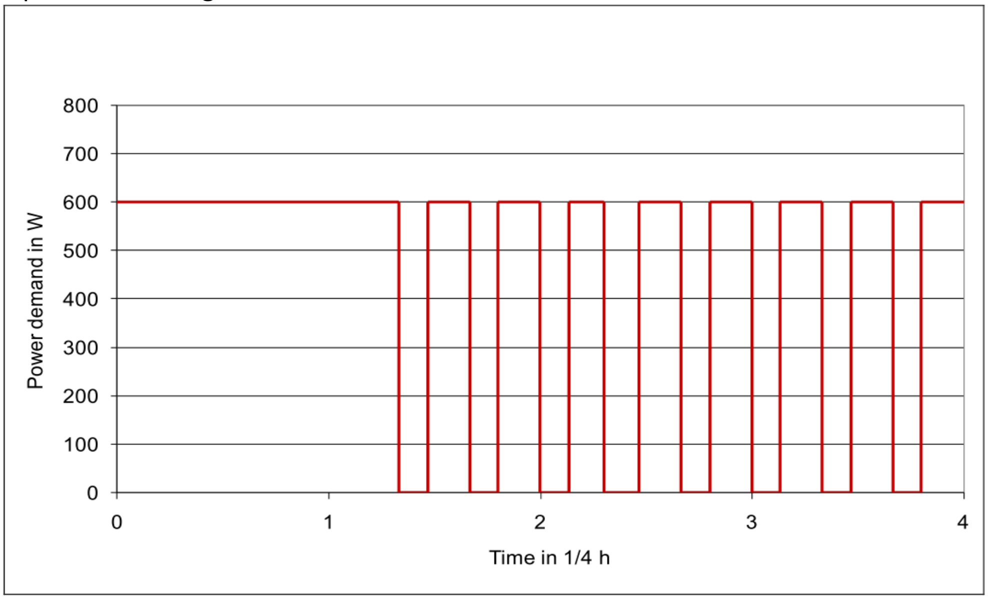

Figure 53: Typical pattern of a power demand curve of an electric oven (Source: Stamminger et al., 2009170)

If the daily cooking behaviour is taken into account, a typical daily load curve of an electric oven in an average European household will follow the pattern shown in Figure 54. (Stamminger et al., 2009170)

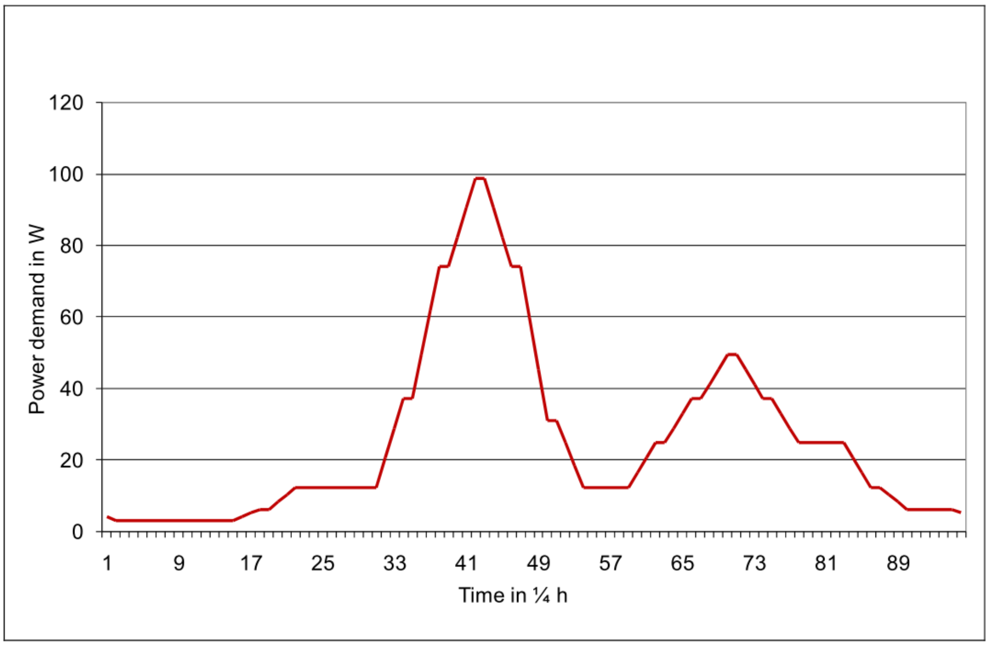

Figure 54: General pattern of a daily load curve of an electric oven in an average European household (source: Stamminger et al., 2009170)

3.2.3.3. Lifespan

The average life span of behavioural appliances may vary depending on the manufacturer, the model, the equipment, the use conditions and the maintenance. Average data are given in Table 25.

Table 25: Average life span of behavioural appliances (Source: [a] EUP LOT 23194; [b] EUP LOT 22[196])

Type of appliance	Average life span
Electric hobs (except induction):	19 years[a]
Electric hobs (induction):	15 years[a]
Electric ovens:	19 years[b]

3.2.3.4. Possibilities for consumers to engage in smart behavioural appliances

In view of hobs and ovens, one possibility to shift energy or modulate power could be identified.

3. Altered electricity consumption pattern: pause between heating cycles, interrupt the heating phase, etc.

In this case, appliances may change its operation if they are triggered by an external signal showing a shortage of energy available on the grid. Possible changes include prolongation of intervals between two heating phases, interruption of a heating phase or changes in heating power. The external signal should include information on the shortage of energy and how long it will last and the appliance will answer with an appropriate action. Power demand curve of a single appliance can be changed in different ways, e.g. shift in operation or reduction of power by seconds or minutes. As such changes must not compromise the performance of the cooking process, it has to be ensured that they are limited in time (up to a few seconds) and don't take place during the first heating phase. (Stamminger et al., 2009170)

Flexibility is typically situated especially in the late morning and, to less extent, in the evening. As described before, there are week seasonal effects of cooking resulting in maximum energy consumption during winter and minimum consumption during the summer period.

3.2.3.5. COMFORT CONSTRAINTS AND CONSUMER OBJECTIONS

As described above, the operation of behavioural appliances requires an active involvement of the consumer and thus is time-bound in narrow ranges. For this reason, the acceptance of consumers for shifts in operation is presumable low. However, short term interruptions for a few seconds or postponed heating phases will hardly be recognised by the users so that these scenarios will rather be accepted. In order to prevent losses in the performance of the cooking process, interruptions or shifts in heating phases have to be strictly limited in time. Data on the maximum tolerable duration of interruptions are lacking so far. If the cooking process is compromised in any way, consumers will not accept the aforementioned changes in operation. (Stamminger et al., 2009170)

3.2.4. HVAC

The following section contemplates to incorporate HVAC equipment through DSF technology to the basic balancing mechanisms/ancillary services of the electrical grid. In order to do so, the main grid-stabilizing mechanisms used in most European deregulated markets will be taken into account: e.g. frequency containment, automatic frequency restoration, manual frequency restoration.
Concerning HVAC technologies (heating, ventilation and air conditioning), use patterns must match the timing of the balancing grid mechanisms (instantaneous, short term, long term, …) so that the incorporation of a DSF technology may allow the grid operator to adjust their operations without interrupting a defined cycle or jeopardizing occupants' comfort.

3.2.4.1. USER BEHAVIOUR CONCERNING HVAC APPLIANCES

HVAC appliances are installed to ensure thermal comfort and air quality to buildings' occupants. The main constraint regarding energy shifting HVAC appliances are the consequences on thermal comfort, humidity, CO_2 and other pollutants that these actions may cause. The points to be covered in this section are: comfort constraints, seasonal periods, occupation schedules, lifespan of HVAC appliances.

3.2.4.2. COMFORT CONSTRAINTS

- Heating: During the winter, the inside temperature for occupation periods (which could be specified by end-users) should not fall below 18 °C (19 °C for tertiary buildings). As well as the variation of temperature should not be higher than 2°C/h according to the standard EN 15251.
- Cooling: During summer, the inside temperature for occupation periods (which could be specified by end-users), shall not exceed 27°C according to EN 15251. As well as the variation of temperature should not be higher than 2°C/h according to EN 15251 standard.
- Air treatment: Ventilation assures air quality for building occupants; the standard EN 15251 gives guidance regarding standard air flow rates by person and admissible pollutant concentration in buildings.

SEASONAL PERIODS

Europe can be divided into three main climate types: oceanic, continental and Mediterranean. These different climates will modulate the potential for demand side flexibility by HVAC appliances within the continent. The used base is heating-degree-days/hours and cooling-degree-days, which take into account the amount of time that the heating/cooling is on and how far is the external temperature from the inside temperature set point. The seasonal periods are the heating period and the cooling period.

Heating season

Table 26: Heating season for EU27 (Bio Intelligence Service, 2012[200]) (values are weighted by dwelling stock)

EU Country	Heating Season (months)	Heating-degree-days
Finland	10,8	323
Sweden	10,2	306
Estonia	8,8	265
Latvia	8,6	257
Lithuania	8,3	250
Poland	7,7	231
Austria	7,6	229
Czech Republic	7,6	229
Denmark	7,5	226
Slovakia	7,5	224
Croatia	6,7	208
Germany	7,2	215
Luxembourg	7	214
Romania	7	211
United Kingdom	6,9	210
Slovenia	6,7	208
Hungary	6,7	202
Ireland	6,7	202
Netherlands	6,7	201
Belgium	6,7	200
Bulgaria	6,4	193
France	6,1	184
Italy	5,4	163
Spain	5,3	158

[200] BIO Intelligence Service (2012) Preparatory Studies for Ecodesign Requirements of EuPs (III), ENER Lot 20 – Local Room Heating Products - Task 3: Consumer behavior and local infrastructure. Prepared for the European Commission, DG ENER.

EU Country	Heating Season (months)	Heating-degree-days
Greece	5	151
Portugal	4,5	135
Cyprus	3,8	114
Malta	3,5	105
EU28 mean	**6,9**	**209**

Regarding the cooling season, the following Table 27 shows the different potentials within the European Union (EU27).

Cooling season

Table 27: Cooling season for EU27 (VHK, 2014159)

Member State	Cooling-degree-days	Total (population correction)	Population Share
Ireland	5	0,035	0,70%
Denmark	57	0,684	1,20%
Netherlands	75	2,7	3,60%
Estonia	78	0,234	0,30%
Sweden	81	1,701	2,10%
Belgium	84	1,764	2,10%
United Kingdom	94	12,408	13,20%
Finland	97	1,164	1,20%
Latvia	102	0,408	0,40%
Luxembourg	103	0,103	0,10%
Lithuania	105	0,63	0,60%
Czech Republic	116	2,204	1,90%
France	138	18,354	13,30%
Germany	168	30,912	18,40%
Slovenia	187	0,561	0,30%
Austria	213	3,408	1,60%
Poland	216	14,904	6,90%
Slovakia	260	3,38	1,30%
Bulgaria	275	3,85	1,40%
Croatia	277	1,939	0,70%
Hungary	282	5,64	2,00%
Portugal	324	5,832	1,80%
Romania	379	12,886	3,40%
Italy	420	52,08	12,40%
Spain	652	45,64	7,00%
Malta	714	0,714	0,10%

Member State	Cooling-degree-days	Total (population correction)	Population Share
Greece	893	16,967	1,90%
Cyprus	972	0,972	0,10%
EU 28 Mean	**263**	**n/a**	**100%**

Table 26 and 27 summarize the total seasonal demand for HVAC appliances (EU 27) using the base indicator of heating-degree-days and cooling-degree-days. The number of heating-degree-days is on average ten times more important than the cooling-degree-days and it has a more homogenous behavior within the Member States. On the contrary, for the cooling season the total potential (weighted by population of each Member States) has an uneven distribution, being the cooling demand for Mediterranean and continental climates (Spain, Italy, Greece, Romania, France, Germany, Slovakia) much more important than oceanic and northern countries (see Figure 55).

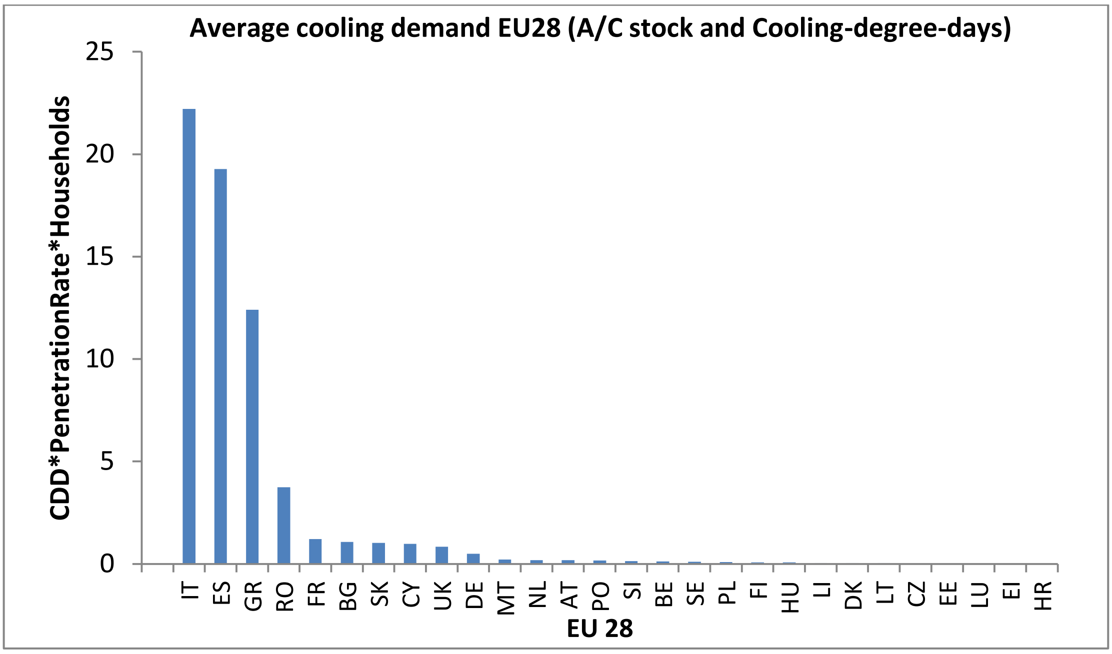

Figure 55: Average cooling demand EU28 (A/C stock and Cooling-degree-days)

Nevertheless, given that Europe has 3 different time zones, user behavior among the continent is not homogeneous and therefore, the heating/cooling demand is shifted in time. A different approach is therefore proposed: Europe is divided in representative climates, respecting the different countries' time zones. The following map of Europe (Figure 56) shows the climatic division that has been made in order to simulate the heating and cooling demand for Europe.

Figure 56: EU28 Climate division for HVAC profiles case studies

Climatic zones:

- Portugal (GMT 0)
- United Kingdom, Ireland (GMT 0)
- France (GMT +1)
- Germany (GMT +1)
- Italy, Slovenia, Croatia (GMT +1)
- Belgium, Netherlands and Luxembourg (GMT +1)
- Denmark, Sweden (GMT +1)
- Poland, Czech Republic, Austria, Slovakia and Hungary (GMT +1)
- Greece (GMT +2)
- Bulgaria and Romania (GMT +2)

3.2.4.3. Occupation Schedules

Many different occupation schedules are possible, for the residential sector as for the tertiary sector. User behavior in the residential sector is influenced by the dwelling's occupants (age, type of work, profession, unemployed, …). The following data was used in order to build the different occupation schedules for the residential and the tertiary sector:

Residential occupation periods

- A French study (INSEE, 2015) resulting from different inquiries regarding 10,000 representative French dwellings. The following information was collected: Number of people per dwelling, occupation schedules, profession, and age of the inhabitants. This data will be used to simulate every European country; under the hypothesis that people's schedule and behavior is the same among EU28.

Tertiary occupation periods

- For the tertiary sector the occupation schedules are much more homogeneous, among the different service sectors: Office buildings, hotels, retail stores, hospitals, supermarkets, sport facilities, retirement homes and schools. The occupation schedules for each building are given below, as well as for different occupation areas within the building:
  - Hotel:
    - Kitchen : 7h-9h , 10h-14h and 18h-23h from Monday to Sunday
    - Restaurant and Lobby: 8h-22h from Monday to Sunday
    - Rooms: 18h-9h from Monday to Sunday
  - Supermarket:
    - Main sales' area: 9h-21h from Monday to Sunday
    - Offices: 9h-20h from Monday to Saturday
  - Office Building:
    - Offices: 7h-20h from Monday to Friday
    - Conference rooms: 7h-20h from Monday to Saturday
  - School: Idem as for office buildings
  - Retirement Home:
    - Common areas: 9h-20h from Monday to Sunday
    - Nursing rooms: 7h-20h from Monday to Sunday
    - Cafeteria: 8h-9h,13h-14h and 19h-20h from Monday to Sunday
    - Rooms: 0h-24h from Monday to Sunday
  - Hospital:
    - Offices: 7h-20h from Monday to Sunday
    - Restaurant and Laboratories: 7h-20h from Monday to Sunday
    - Operating rooms: 7h-20h from Monday to Sunday
    - Rooms: 0h-24h from Monday to Sunday
  - Sport Facilities: 9h-21h from Monday to Sunday
  - Retail stores:
    - Main shopping area: 9h-21h from Monday to Saturday
    - Cinema: 13h-2h from Monday to Sunday

LIFESPAN OF HVAC APPLIANCES

The lifespan of HVAC products may vary according to the equipment, but a good estimation is around from 10 to 15 years for boilers, air conditioners and heat pumps. More detailed information is given in the following Table:

Table 28: (Bio Intelligent Service, 2012) *Source: (Ecodesign Boilers, 2007)

<table>
<tr><th>Main Category</th><th>Type of heating appliance</th><th>Average lifespan</th></tr>
<tr><td rowspan="8">Fixed heaters</td><td>Convector panel heaters</td><td>12</td></tr>
<tr><td>Radiators</td><td>20</td></tr>
<tr><td>Fan heaters</td><td>12</td></tr>
<tr><td>Ceramic heaters</td><td>12</td></tr>
<tr><td>Radiant heaters</td><td>12</td></tr>
<tr><td>Storage heaters (static)</td><td>20</td></tr>
<tr><td>Storage heaters (dynamic)</td><td>20</td></tr>
<tr><td>Under-floor heating</td><td>40</td></tr>
<tr><td rowspan="5">Portable electric heaters</td><td>Convector panel heaters</td><td>12</td></tr>
<tr><td>Radiators</td><td>12</td></tr>
<tr><td>Fan heaters</td><td>12</td></tr>
<tr><td>Radiant heaters</td><td>12</td></tr>
<tr><td>Ceramic heaters</td><td>12</td></tr>
<tr><td rowspan="2">Boilers</td><td>Gas Fired</td><td>12*</td></tr>
<tr><td>Oil Fired</td><td>12*</td></tr>
</table>

Energy consumption and shifting potential per appliance per day / per season (refer to task 1 for more information) for 28 EU Member States.

Heating:

- Peak power: up to about 95 GW (2010)
- Energy consumption: about 280 TWh/a
- Potential energy to be shifted: about 30 TWh/a, about 100 GWh/day in the coldest winter months (heating off for one hour)

Cooling:

- Peak power: 160 GW
- Energy consumption: 80 TWh (2010)
- Potential energy to be shifted: 65 GWh/day (this corresponds a the mean demand over the summer for an off-period of one hour)

Air treatment:

- Energy consumption: 59 TWh (2010)

- Peak power: 10 GWh
- Potential energy to be shifted: 10 GWh/day (air treatment off for one hour)

CASE STUDIES (POSSIBILITIES FOR CONSUMERS TO ENGAGE IN SMART APPLIANCES)

Residential sector

- Heating and cooling needs: Thermal simulations at a national scale for each country of EU28, using the platform Smart-E (Berthou et al., 2015)[201]. This platform focuses on the thermal and electrical energy consumption in residential dwellings and service buildings. It has a library of algorithms that has been designed to simulate real or hypothetical cities using a techno-explicit bottom up approach fed with public databases and specific users' data.
- Cooling efficiency: For residential air conditioners and heat pumps, only the split type was considered ; seasonal performances in heating and cooling modes were estimated based on Ecodesign preparatory studies and regulations[202],[203]. For efficiency projections, it is supposed the rate of improvement due to the Ecodesign directive will be maintained till 2030 thanks to revised and more ambitious regulations. Average efficiencies are then used to derive a standard performance model of appliances so as to deduce the electricity consumption from hourly thermal loads. Average SEER (cooling mode seasonal efficiency) and SCOP (Seasonal heating coefficient of performance) are given in the table below for the whole installed base of appliances (not just for new products) for a given year.

Residential AC (split)	SEER stock	SCOPstock
2014	3,8	3,2
2020	4,9	3,7
2030	7	4,2

- Weather data: Dry bulb temperatures and radiation data were obtained for each of the following cities: Paris, Madrid, Lisbon, London, Frankfurt, Brussels, Prague, Bucharest, Athens, Rome, Stockholm and Helsinki. Each of this cities represents a country (or several countries of the climatic zone) (www.noaa.org and "Blanc et al, HelioClim Project")

[201] T. Berthou, B. Duplessis, P. Riviere, P. Stabat, D. Casetta, D. Marchio, "Smart-e: A tool for energy demand simulation and optimization at the city scale" - 14th International Conference of the IBPSA, Hyderabad, India, 7-9 December 2015

[202] (Rivière, 2009) P. Rivière, et al., Preparatory Study on the Environmental Performance of Residential Room Conditioning Appliances (Airco and Ventilation) - ENER lot 10, Final report. Brusels (2009)

[203] COMMISSION REGULATION (EU) No 206/2012 of 6 March 2012 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for air conditioners and comfort fans.

- Building diversity: Orientation, size of the building, glazed surfaces, year of construction, insulation were taken from the study (INSEE, 2015) for a representative sample of 10000 buildings in France. For the other EU countries the building distribution was considered the same.

- Insulation values: Insulation ratio values were obtained from (VHK, 2007) for each country of Europe.

- Penetration of electric heating: After obtaining a demand curve for each climatic zone, this curve is weighted according to the number of square meters and the penetration electric heating technologies (radiators, electric boilers, radiators…) in each country. Data comes from the following studies: "Policy development for improving RES-H/C penetration in European Member States (RES-H Policy), 2009", www.episcope.eu, www.tabula.org.

  Penetration of air conditioning in Europe: Data for each country in Europe was obtained from Rivière et al., 2009[202]

Tertiary sector

- Heating and cooling needs were obtained from 8 different service sector buildings, using the software Climhybu (CSTB, 2010)[204]. Then these curves are weighted with the heated and cooled surface per country.

- Cooling efficiency: the same approach as for residential equipment is adopted; only two products are considered, air conditioners (Splits, Variable Refrigerant Flow systems and rooftops) and chillers. References used for projection are Ecodesign studies and regulations (or planned regulations).[205], [206], [207], [208]

Tertiary AC (split)	SEER stock	SCOPstock
2014	3,8	2,7
2020	4,5	3
2030	6	3,6

Tertiary AC (chiller)	SEER stock	SCOPstock
2014	3,4	2,7
2020	3,6	2,9
2030	4,5	3,3

[204] CSTB (2010). Projet CLIMatisation HYbride des immeubles de BUreaux, Une boite à outils d'aide à la décision pour la conception et la réhabilitation basse consommation des immeubles de bureaux, Rapport final, Coordination : CSTB, 2010.
[205] VHK (2007). Preparatory Studies for Ecodesign Requirements of EuPs (I), ENER Lot 1 – Boilers, DG ENER
[206] Commission Regulation (EU) No 813/2013 of 2 August 2013 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for space heaters and combination heaters
[207] P. Rivière, et al., Sustainable industrial policy – building on the ecodesign directive – energy-using product group analysis/2, ENTR Lot 6: air-conditioning systems, Final report. Brusels (2012)
[208] European Commission, Project of regulation with regard to ecodesign requirements for air heating products, cooling products, high temperature process chillers and fan coil units

- Characteristic tertiary buildings for the following service sector were considered: Hospitals, Hotels, Schools, Retirement Homes, Offices (three type of sizes), Retail shops, supermarkets and sport facilities.

- Weather data: Dry bulb temperature and radiation data for the year 2014 were obtained from www.noaa.org for temperatures and Blanc et al., 2011 for radiation to the climatic zones described above.

- Distribution of the tertiary sector building (by square meters) was obtained from the following source: www.buildingsdata.eu

- Penetration of the heating technologies: Entranze Project 2013 and www.episcope.eu

- Penetration of air conditioning: Source distribution by sector: Preparatory study, Lot 6 Air conditioning (task 2)[205] and (Werner, 2010)[209].

POSSIBILITY OF ADAPTATION TO GRID CONTROL MECHANISMS:

HVAC systems can be shut down and turned on without any built-in machine constraints (unlike Washing machines for example), as well as their capacity can be adjusted (change the speed of the compressor - which would more efficient than turning the units off-, the temperature set point or the fan speed). Therefore, there is an important potential for all "grid balancing mechanisms" in order to shift the energy consumed by HVAC in different times of the day.

Australian case for example: the Demand-Response project began in 2005 due to the fact of the increasing energy demand caused by the growing penetration rate of AC (air conditioning is a peak coincident load in Australia). It is projected that the proportion of Australian households that would be equipped with an AC unit will increase from 56% in 2010 to 70% in 2020. In order to avoid peak demands, the regulation AS4755 mandates to incorporate Demand Response mechanisms to AC units, so a third party actuator can modulate the load. Encouragements include a low price of the DR platform (10AUS$, around 1% of the retail cost for a residential unit), and Payments of $250 are offered to customers who buy an AS/NZS 4755 compliant air conditioner and have it activated on installation, and to customers who have their existing air conditioner connected to the Energex communications system (Wilkenfeld, 2011[210]).

END CONSUMER COST

PURCHASE COST

Surplus purchase cost of the appliance due to the DSF functionality. According to one stakeholder, enabling demand side flexibility in HVAC appliances would increase the retail price. This price would vary if a centralized control unit enables to operate several DSF HVAC appliances. Price estimation for one household having three air conditioners can be seen in the figure below:

[209] Sven Werner, European space cooling demands, Energy, Available online 13 December 2015, ISSN 0360-5442, http://dx.doi.org/10.1016/j.energy.2015.11.028

[210] Wilkenfeld (2011): Smart appliances for smart grids: flexibility in the face of uncertainty 2011

Item	Number	Unit price	Initial
CEM & installation	1	2,000€	2,000€
Adaptor	3	100€	300€
Set up	1	100€	100€
Total			2,400€

Another scenario, is whether the customer completely relies on an aggregator to control directly the HVAC appliance (the air conditioner for instance). This would only add up the set up and the adaptor price, increasing only around 150€.

For tertiary buildings (commercial), prices are considerably higher. Considering a VRV (variable refrigerant flow unit air conditioning unit), enabling demand side flexibility according to one stakeholder is as follows (all prices in Euros):

Item	Number	Unit price	Initial	Running (per year)
Controller (I/F& S/W)	1	8000	8000	0
Mobile router	1	500	500	120
Install &setup	1	10500	10500	0
Total			19000	120

In addition, these prices include the following investments from the industry side:

- Development costs
  - Hardware and software modifications
  - Certification (radio frequency regulation if Wifi is used, safety regulations)
  - License and membership fees (Wifi alliance, Bluetooth…)
- Compatibility test costs
  - Adaptability to different smart-phones (smart-phones will be mainly used as an operation terminal)
  - Annual update and bug fixes of the application software
- Operating costs
  - The communication between the household and the grid/aggregator requires an IP address resolution

EXPERIENCE WITH DSF MECHANISMS IN HVAC EQUIPMENTS

- Daikin has implemented DSF control in many countries over the world, allowing them to control remotely HVAC equipment. More precisely, they have participated in **Open ADR** trial by Japanese government, university and companies, in order to carry out cooperative operation with smart cities and aggregators in wide areas. Mainly speaking, the control consisted in a "Power Measurement Unit" which sends only information about the difference of total demand and target current. HVAC equipment (air conditioners, heat pumps) power down automatically depending on established difference and pre-settled priority.

- The EcoGrid project carried out by Sintef Energy Research and other partners in Bornholm (Denmark), evaluated the potential of demand side flexibility appliances (mainly heat pumps and electric heating) based on a real-time market approach. This demand response program lets distributed energy resources and flexible electricity demand, receive and respond to variable electricity prices. Different control systems and interfaces were used along the project: Ecohome (present in 60% of the studied homes, remote control of the heating system), Greenwave Reality (electric radiators and heat pump control), Siemens Synco Living (consists of a central unit/control panel that is connected to the internet, the control of the electric heating and/or domestic hot water boiler is done via contactors installed in the fuse box of the participants and thermometer probe in the boiler). The final conclusions of this project are not yet available, but preliminary results regarding the tests and adjustments done in 2013/2014 winter show that: For the IBM Greenwave reality solutions a maximum of 90 minutes of heating off-time is now guaranteed, with no single off time period longer than 60 minutes and with a few hours in between off periods. In addition some recommendations and preliminary conclusions for further analyses and deployment of demand side flexibility mechanisms are: Low data quality -the system must receive reliable temperature readings to ensure that heating is regulated in accordance with the comfort preferences of the customer-, internet connection must be stable, the nature of the individual heat pumps' own optimization system limits regulation possibilities, comfort setting of the households gives little room for "down or up" regulation for consumption. (http://www.eu-ecogrid.net/)

3.2.5. BATTERY OPERATED RECHARGEABLE APPLIANCES

3.2.5.1. USAGE BEHAVIOUR

This category comprises the following segments:

- Multimedia :
  - Smartphones
  - Tablets
  - Laptops
  - (Video) cameras
  - Personal navigation
  - etc.

- Household appliances
    - Electric toothbrushes
    - Fans
    - Vacuum cleaners
    - Clocks
    - Shaving products
    - etc.
- Power tools
    - Drill machines
    - Screwdriver
    - Garden trimmers, mowers & edgers
    - etc.

Given the low power consumption in the charging process, only appliances with large installed base volumes and frequent charging patterns will have enough potential for load shifting.
Household appliances have smaller installed base volumes than smartphones and tablets and it is presumed that they have a lower and less predictable charging frequency. On top of that many have such low consumption that the charging energy is too small to be relevant, even in large numbers.
For power tools, the charging power is higher compared to multimedia devices, but the charging frequency is usually lower and these appliances have a 'charging when going to be used' pattern, making it hard to provide flexibility. Also the amount of 'active' appliances is much lower.
Personal navigation devices and digital cameras have smaller installed base volumes than smartphones and tablets and it is presumed that they have a lower and less predictable charging frequency.
Smartphones and tablets have low charging power consumption, but have a very large volume (and still growing) installed base.
Laptops have also a smaller installed base then smartphones and almost similar to tablets but a higher charging power consumption.
Therefore only laptops, smartphones and tablets appliances will be taken into account in the remainder of this chapter.

3.2.5.2. User behaviour concerning charging

It is clear that if the devices are smartly charged, it is essential for a good user acceptation, to always guarantee sufficient State of Charge (SOC).

3.2.5.3. Comfort constraints

From studies by the J.D. Power and Associates 2012[211] it is shown that satisfaction with battery performance is becoming a critical factor in overall satisfaction as well as brand loyalty. It is clear that if the devices are smartly charged, it is essential for a good user acceptation, to always guarantee

[211] J.D. Power and Associates Reports. Denzil Ferreira, Anind K. Dey, Vassilis Kostakos. Understanding Human-Smartphone Concerns: A Study of Battery Life. Has Become a Significant Drain on Customer Satisfaction and Loyalty. March 2012. Pervasive Computing. June 2011.

sufficient State of Charge (SoC). This puts a constraint on the smart charging to be able to predict very accurately and reliably the next usage of the multimedia device in order to guarantee the expected comfort on next usage. [212]

3.2.5.4. Occupation Schedules

A 4-week study[213] with more than 4000 attendees, which assessed their smartphone charging habits, was performed by Ferreira et al.. From this, an insight on charging behaviour could be retrieved. It has been observed that many charging instances happen overnight, with connection to power supply units typically for periods > 14 hours (See Figure 57). They also noticed that the majority of charging events during the day are for short periods (< 3 h).

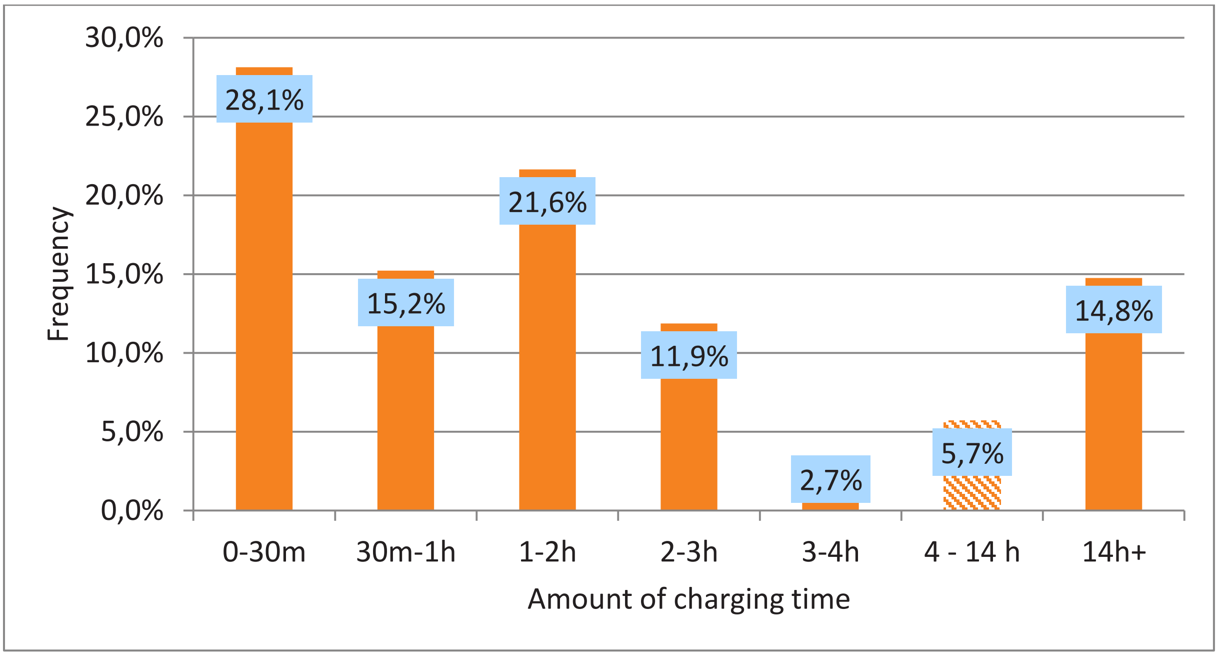

Figure 57 : Time plugged in

When looking at the time slots, it is seen that 2 major scheduling periods can be identified for the initiation of the charging, one between 6 PM and 8 PM and another between 1AM and 2 AM.

3.2.5.5. Lifespan

The lifespan of approximately 5 years for smartphones and tablets is rather short compared to other consumer electronics (Figure 58).

[212] Sasu Tarkoma, Matti Siekkinen, Eemil Lagerspetz, Yu Xiao, Aalto University, Finland. Smartphone Energy Consumption - Modeling and Optimization. August 2014.
[213] Denzil Ferreira, Anind K. Dey, Vassilis Kostakos. Understanding Human-Smartphone Concerns: A Study of Battery Life. Pervasive Computing. June 2011.

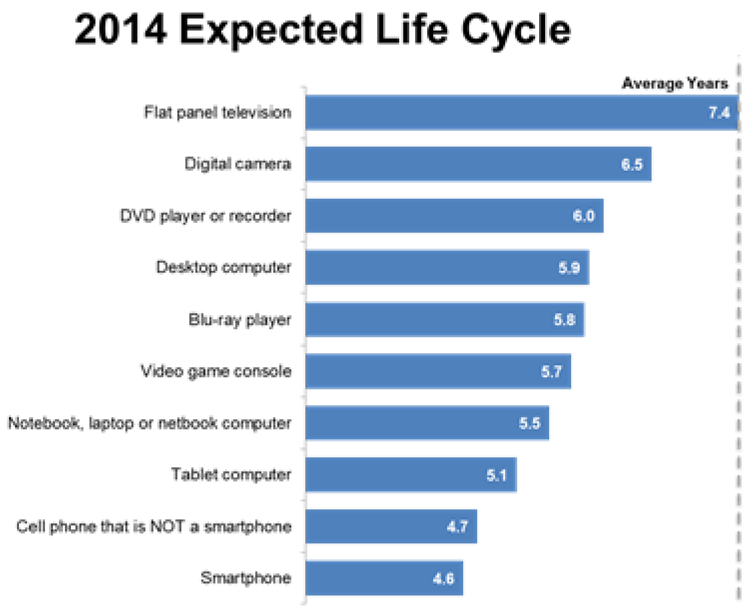

Figure 58: Source: Consumer Electronics Association (CEA), 2014 CE Product Life Cycle. Base: U.S. Adults (n=1,013)

Energy consumption and shifting potential per appliance per day/ per season for 28 EU Member States.

As stated in Task 1, the potential per appliance and day is very low. The main benefit needs to come from the large volume of appliances:
For smartphones only, the sales figures (IDC[214] and Gartner[215]) worldwide have gone from 300 million in 2010 to more than 650 million in 2012 and grew to above 1 billion in 2014. The situation is similar for tablets worldwide, with sales growing from 200 million in 2013 to an expected 260 million in 2016 (Gartner, January 2015)[216]. Estimates of laptop sales vary between 200 and 180 million.
For Europe (EU28), the sales of all mobile phones (smartphones and regular mobile phones) range from 227 million in 2009 to 213 million in 2013.

Table 29: Mobile subscriptions in Europe

	2014	2020
Mobile subscriptions (million)	1,135	1,280
Smartphone subscriptions (million)	475	815

The figures for Europe*[217] on the installed base show almost half a billion of smartphone subscriptions in 2014 and an expectation of more than 800 million subscriptions by 2020.

[214] IDC Press Release : Worldwide Smartphone Growth Expected to Slow to 10.4% in 2015, Down From 27.5% Growth in 2014, According to IDC, August 2015, http://www.idc.com/getdoc.jsp?containerId=prUS25860315
[215] Gartner Press Release : Gartner Says Smartphone Sales Surpassed One Billion Units in 2014, March 2015, http://www.gartner.com/newsroom/id/2996817
[216] Gartner, Press Release : Gartner Says Tablet Sales Continue to Be Slow in 2015, January 2015, http://www.gartner.com/newsroom/id/2954317
[217] Ericsson, Europe Ericsson Mobility Report Appendix, November 2014

When looking at the total energy consumption of these appliances of

- Smartphone: 3 to 5 kWh/year
- Tablet: 12 kWh/year
- Laptop: between 150 and 300 kWh/year.

it can be concluded that a flexibility capacity would derive from the large number of appliances, rather than from the individual power consumption.

A first calculation of the authors is based on the assumption that in 14.8% of the charging session appliances are plugged in long enough to provide flexibility (as stated in Figure 57). Taking into account the values for smartphones this could lead to 14.8% * 4 kWh (average) * 475 million = 281 GWh per year or 0.77 GWh/day and for tablets 14.8% * 15kWh * 200 million: 444 GWh shifting potential per year or 1.2 GWh/day, but here the assumption is made that the 14.8% of sessions also corresponds to the same amount of charging power. It's however clear that for correct calculations, there is still a general lack of available and reliable studies on this. For laptops the calculations were not done, since no info is found on the charging (duration) patterns for these devices. These charging patterns will probably be different to that of the smartphones by the nature of the usage pattern and the fact that laptops are often connected to mains power supply while being used.

Important note:

It has to be taken into account that the energy (demand) shifting potential is a balance between flexibility and energy saving.

From a flexibility point of view, the longer the charger is connected, the more shifting potential is (theoretically) available. However from an energy saving point it is important to disconnect the charger ASAP after the battery is fully charged since it also consumes (little, but present) power when devices are connected.

Given the evolution and regulation on the requirements for standby, off mode electric power consumption of electrical and electronic household and office equipment[218], the issue will become less important.

[*] From the report it is not clear which countries are included, but since also Russia is mentioned it will be broader than EU28.

[218] COMMISSION REGULATION (EU) No 801/2013. Amending Regulation (EC) No 1275/2008 with regard to ecodesign requirements for standby, off mode electric power consumption of electrical and electronic household and office equipment, and amending Regulation (EC) No 642/2009 with regard to ecodesign requirements for televisions. 22 August 2013.

3.2.6. RESIDENTIAL ENERGY STORAGE SYSTEM

3.2.6.1. USAGE BEHAVIOUR

Differentiation

Grid-connected battery-based electric energy storage systems are a recent development for dwellings. Two different set-ups exist:

- back-up power
- electric energy storage

The first one is similar to uninterrupted power supply systems that are used in industry, data centers and hospitals. For households they can be an alternative for noisy generators and can take over the power supply in a household immediately if necessary. In countries with a questionable electricity grid or where fear exists that a power outage can happen, there are several companies who sell such 'home battery backup systems'. These batteries have to always be fully charged until a power outage happens, so they cannot be used as a smart appliance in the context of this study.

The second set-up is the fast growing market: storing cheaper (renewable) electric energy to avoid buying expensive electricity at a later period. The stored electricity is often generated by a PV installation. For this new product category, there is no unique and universal definition so far. Therefore, the following terms are used (amongst others):

- storage battery for home use
- residential energy storage system
- solar-energy storage unit
- solar battery
- home battery

In off-grid dwellings batteries are already common practice, often powering a DC-grid. This is however out of scope of this document.

Basic use of a home battery

A home battery is usually used together with a PV installation. It avoids that more expensive electricity has to be bought back in the evening whereas own solar electricity flows into the distribution grid in the daytime. Storage is a way to increase the self-consumption of solar energy and therefore a residential energy storage system is a DSF capable smart appliance, relieving the distribution grid. The proof of attractiveness and the premises to be so are described in[219,220]. In Germany 25,000 home batteries have been installed up to 2015[221]. Some home battery sellers state explicitly that their storage systems can also be connected to small wind turbines and cogeneration units. Although buying electricity at the night tariff and to use it in the daytime would sound like another possibility, the spread between these tariffs is mostly small.

[219] Grietus Mulder, Daan Six, Bert Claessens, Thijs Broes , Noshin Omar, Joeri Van Mierlo. The dimensioning of PV-battery systems depending on the incentive and selling price conditions. Applied Energy. April 2013.

[220] Michael Fuhs, Shamsiah Ali-Oettinger. Storage has landed. PV Magazine. November 2012.

[221] „Die Sonne speichern", Presse, 8 January 2015. [Online]. Web address: http://die-sonne-speichern.de/pressemeldungen/. [Latest: 4 May 2015].

Distinction between different implementations

1. Residential energy storage systems combined with a separate PV installation. The installation consists of a battery storage system and additional convertors to connect the storage system to the house grid.
2. Fully integrated residential energy storage systems with PV (e.g. SMA Sunny Island). In these systems the battery storage is part of the PV installation and a single integrated controller takes care of the balancing between PV, grid and storage
3. Setup 2 combined with smart control of appliances, e.g. via controlled power plugs.
4. Standalone residential energy storage systems. The purpose here is, e.g., to use the electricity price differences (business case -> difference in prices) – communication tariffs or to provide, e.g., ancillary services with volume as a control signal.
5. Electric Vehicle (EV) To Home. In this setup, electric vehicles will be used as a (mobile) Battery Storage Systems, to store and extract electric energy. The setup is currently in use in Japan, but not yet popular in the EU.

3.2.6.2. USER BEHAVIOUR CONCERNING CHARGING

The main goal for setup 1, 2 and 3 is maximisation of self-consumption, in order to minimise the economic disadvantage due to feed in tariffs that are lower than the buying price.
Setup 4 focusses more on the difference in pricing in time. This can be due to Day/Night, Peak/Off peak pricing or in the future, variable pricing blocks during the day. Or to receive reservation and activation fees for other services.
Setup 5 (EV's) is out of scope of the study.
The systems taken into account for this chapter are focussed on residential usage and range between 2 to 10 kWh.
The biggest market for Battery Storage Systems in Europe is Germany with an installed base of 25,000 installed systems today221. For other European countries figures are very low and some only have some projects with experiment setups. No exact figures were found for these countries.

3.2.6.3. COMFORT CONSTRAINTS

The modern residential energy storage systems operate fully automated. The systems can make use of advanced algorithms taking into account price variations, solar predictions based on regional weather information, self-learning techniques to predict expected consumption, etc. These algorithms need minimal or no user interaction. The capacity needed is dependent on consumption patterns and installed appliances (E.g. heat pump or not) and installed PV capacity.
An additional advantage, but certainly not the main goal, is that the residential energy storage system can provide in backup power when the grid is not available. The household can go in Island Mode, but first needs to disconnect physically from the grid. This might require extra hardware such as a grid feeding monitoring.

3.2.6.4. Occupation Schedules

The usage and dimensioning is dependent on the targeted DSF business case. More details on the different business cases are described in T2.3.

3.2.6.5. Lifespan

Most system manufacturers estimate the lifespan at 15 to 20 years. For modern Li-Ion batteries this is feasible if they operate within their designated operations conditions (Temperature, Charging and Depth of discharge limits). For Lead-Acid the maximum discharge depth is around 50 % while for Li-Ion this can vary between 50 and 100 % of nominal capacity, depending on the type. For some battery types, 100% is not possible, but we can state that the majority has a higher Depth of Discharge level then Lead-Acid [222].
The capacity of the batteries degrade over time dependent on type of battery, the number of cycles, depth of discharge and temperature as shown below (see Table 30 and Table 31).

Table 30: Cycle life as a function of depth of discharge (source: http://batteryuniversity.com/learn/article/how_to_prolong_lithium_based_batteries)

Depth of discharge	Discharge cycles	
100% DoD	300 – 500	A partial discharge reduces stress and prolongs battery life. Elevated temperature and high currents also affect cycle life.
50% DoD	1,200 – 1,500	
25% DoD	2,000 – 2,500	
10% DoD	3,750 – 4,700	

Table 31: Estimated recoverable capacity when storing Li-ion for one year at various temperatures

Temperature	40% charge	100% charge	
0°C	98%	94%	Elevated temperature hastens permanent capacity loss. Not all Li-ion systems behave the same.
25°C	96%	80%	
40°C	85%	65%	
60°C	75%	60% (after 3 months)	

For more technical details on the lifespan and constraints of batteries refer to Task 4.

[222] Jeff Dahn and Grant M. Ehrlich. Lithium-Ion Batteries. Linden's handbook of batteries. 2011.

3.2.6.6. Energy consumption and shifting potential per appliance per day / per season (refer to Task 1 for more information) for 27 EU Member States.

Shifting potential

For the purpose of this report, a distinction is made between the overall shifting capacities independent of a business case and the “battery with PV” business case, since that is currently the most used and we have more detailed information on this.

The overall shifting capacity is dependent on the operating range of the installations. Parameters like maximal depth of discharge, maximal charge and discharge currents determine how much of the total capacity can be actually used for flexibility. The parameters differ for the used battery technologies (Lead-acid, Li-Ion, etc.).

For the battery with PV installations, the shifting potential will vary strongly in the different seasons as well as with geographical location (Figure 59). Below it is estimated what this would mean on a European level.

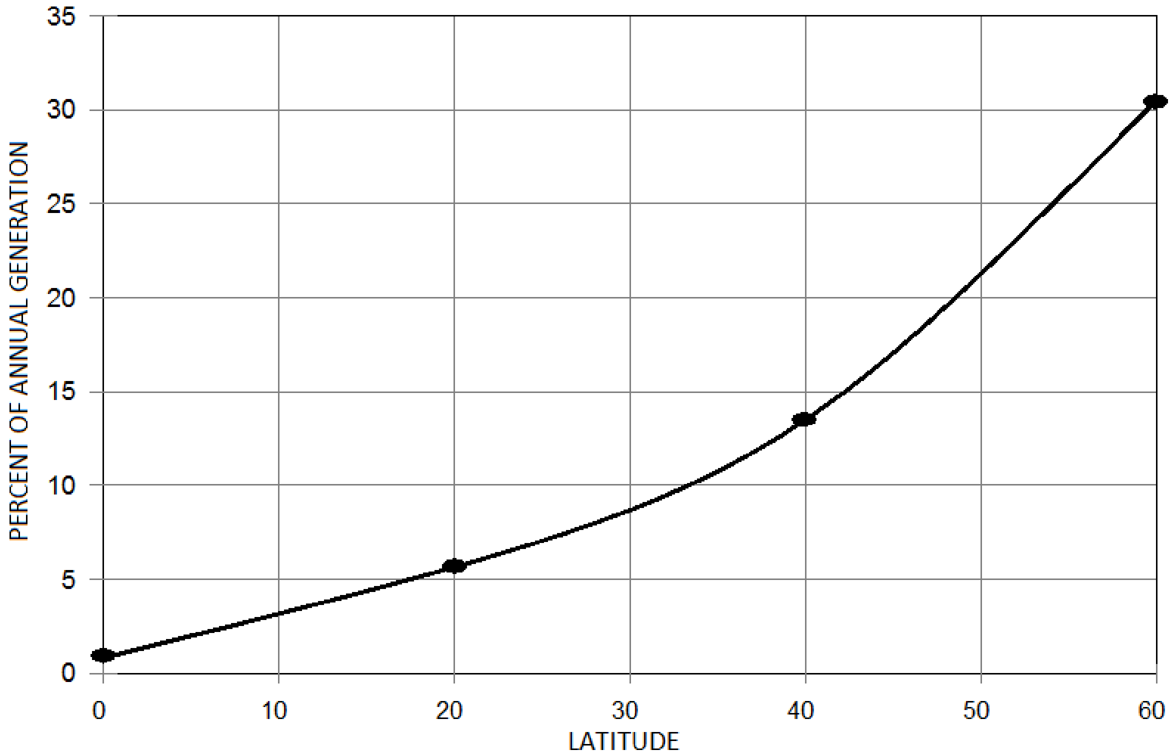

Figure 59: Battery storage requirements versus latitude. (http://euanmearns.com/how-much-battery-storage-does-a-solar-pv-system-need/)

By the end of 2013, in total 81 GW of PV was installed and in 2014 an additional 10 GW was installed77. IEA-RETD76 indicates that 20% of the installed PV capacity is situated in the residential sector, which results in a total of 18 GW of installed residential PV capacity in Europe.

The average capacity of residential installations is 4 kW[223], so translated to the number of installations 4.5 million existing installations can be assumed.
For each installation a self-consumption share without storage of 40% is estimated, when storage is integrated this is expected to be 70% with an average storage of 4 kWh (based on a conservative estimate which is a bit higher than the smallest installations (~2 kWh) but below the average (6 kWh) of the range of the residential installations (2 to 10 kWh).

- The average production of an installation would be 4 kW * 1,000 full load hours /year = 4,000 kWh.
- 40% self-consumption equals to 1,600kWh/year220.
- The assumed 30% extra gained from the storage for later consumption, accounts for 1200 kWh.
- For the average consumption of a household, figures from Germany were used[52]: 3,500 kWh/year. All together this applies that a household would need to retrieve 3,500 kWh – 1,600 kWh (PV) – 1,200 kWh (storage) = 700 kWh from the grid and 1,200 kWh (30%) of the PV production is sent back to the grid (feed-in).
- The total shifting potential can now be calculated twofold :
  - Shifting for self-consumption: 1,200 kWh * 4.5 million installations = 5.4 TWh
  - Additional shifting by using the remaining full load cycles. Since the objective is to store and extract from the residential energy storage on daily basis, 365 full load cycles per year can be assumed. The used 1,200 kWh used for self-consumption accounts for 300 full load cycles of 4 kWh, leaving additional storage capacity for 65 days resulting in 260 kWh/year. Based on the 4.5 million installations this provides a shifting potential of around 1.17 TWh.

All together this results in a shifting potential of about 5.5 TWh, which is 0.18% of the total electricity consumption (3,101.3 TWh) in EU28 in 2013[224].

3.2.7. LIGHTING

3.2.7.1. USAGE BEHAVIOUR

This category comprises lighting in residential and commercial indoor areas and public street lighting by use of the following types of light sources:

- LFL: Linear fluorescent lamp
- CFL: Compact fluorescent light
- Tungsten
- GLS: General lighting service ('incandescent')
- HID: High intensity discharge lamp
- LED: Light emitting diode

[223] Australian Energy Market Operator (AEMO). Ltd Rooftop PV Information Paper - National Electricity Forecasting. 2012
[224] Net electricity generation, 1990–2013. Eurostat online.

The general usage is that the light is switched on when it is needed and switched off again after use. In offices and other commercial indoor areas, there is a high degree of automatic systems, either on/off or variable according to the incoming daylight.

There are the following possibilities to modulate capacities:

- For advanced LED light bulbs: There are already LED light bulbs on the market, which can be controlled by a smart phone over Wi-Fi – in some cases combined with a special hub for the bulbs. This can be further developed into a DSF enabled system controlled by signals from the power supply system. For LED systems there will be no technical problems in dimming and switching off the light.
- For CFLs: It is also possible to build in DSF enabling, but in a less extent dimming compared to LEDs.
- Generally, for all light bulbs (LED, CFL, Tungsten, GLS) it is technical possible to mount an extra DSF module for switching on and off the bulbs.
- For luminaires and lighting systems in commercial areas (mainly LFL): There are already advanced systems on the market, which can be controlled by local conditions in the lighted area through presence sensors and solar radiation sensors combined with the time of day. This can be further developed into a system controlled by signals from the power supply system.
- Public street lighting: Street lighting systems are already highly controlled from outside and it is possible to combine this with a DSF module.
- Many light technologies can be dimmed (tungsten, halogen, fluorescent, LED etc.) resulting in reduction in power load and energy consumption. Lighting including street lighting is naturally mostly switched on in periods with no solar radiation apart from indoor areas with no or few windows such as basements, commercial centres etc. meaning that the energy consumption is higher in evenings and during nights, though also depending on time of year and geographical location within EU. For offices and some other commercial area, the energy consumption is reduced during weekends. The energy consumption is higher during these periods, which would be a basis for the flexibility potential.

3.2.7.2. COMFORT CONSTRAINTS

The negative comfort impact by DSF enabled lighting is naturally a serious constraint. Light is used when there is a need for light and only too little awareness or not correctly adjusted control systems will result in a potential for reducing light intensity or switching off without comfort impacts.

The comfort impacts will be large especially in the homes and commercial areas, which may include safety issues. Only very short periods of dimmed or switched off time would be accepted; we assume 5 minutes per day.

For public street lighting the comfort impact may be more limited, at least for shorter periods of time. On average, we assume half an hour per day.

3.2.7.3. Lifespan

Lifespan is measured in hours of light. The life varies from about 1000 hours for tungsten lighting sources up to around 50000 hours for LED lighting.

Energy consumption and shifting potential per appliance per day/ per season for 28 EU Member States.
The estimated stock year 2013 based on the Ecodesign Preparatory Study on Light Sources (ENER Lot 8/9/19[225]:

- LFL: Linear fluorescent lamp: 2209 million units
- CFL: Compact fluorescent light: 4406 million units
- Tungsten: 2569 million units
- GLS: General lighting service ('incandescent'): 561 million units
- HID: High intensity discharge lamp: 84 million units
- LED: Light emitting diode: 144 million units

Separately, the estimated number of street lighting luminaires in EU-25 is about 60 million (2004 figures)[226].

Total calculated energy consumption year 2013 calculated on the basis of (Kemna, 2014):

- LFL: Linear fluorescent lamps: 126 TWh/year
- CFL: Compact fluorescent light: 33 TWh/year
- Tungsten: 57 TWh/year
- GLS: General lighting service ('incandescent'): 13 TWh/year
- HID: High intensity discharge lamp: 48 TWh/year
- LED: Light emitting diode: 1 TWh/year
- Total: 279 TWh/year

Total energy consumption (2020) of street lighting is 35 TWh/year (VITO, 2007).

Data on shifting or capacity modulating potential per appliance in a smart grid perspective are scarce. Instead, we have assessed the potential from available data on stock, lumen output, operating hours, and efficiency[227] combined with more details on street lighting.

Based on average data on lumen/unit and lumen/watt, the average wattage for each unit is:

- LFL: Linear fluorescent lamps: 29 watt
- CFL: Compact fluorescent light: 11 watt
- Tungsten: 50 watt
- GLS: General lighting service ('incandescent'): 51 watt
- HID: High intensity discharge lamp: 144 watt
- LED: Light emitting diode: 5 watt

[225] VITO. Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements ('Lot 8/9/19'). Draft Interim Report, Task 2 (revision 1)
[226] VITO. Preparatory Studies for Ecodesign Requirements of EuPs. Final Report. Lot 9: Public street lighting. 2007.
[227] René Kemna (VHK). ECODESIGN IMPACT ACCOUNTING Part 1 – Status Nov. 2013. May 2014.

- Tungsten stock: 36 watt

The technical potential for load shifting for each light bulb is of the same size assuming switching off. Modulating i.e. dimming potential is much less but naturally depends on the dimming level.

Based on data on the total amount of lumen for EU27 and the lighting efficiency, we have calculated the total power draw for each type of lighting technology assuming full simultaneous power draw:

- LFL: Linear fluorescent lamps: 56 GW
- CFL: Compact fluorescent light: 36 GW
- Tungsten: 49 GW
- GLS: General lighting service ('incandescent'): 8 GW
- HID: High intensity discharge lamp: 7 GW
- LED: Light emitting diode: 29 GW
- Total: 185 GW

This figure needs to be reduced with a simultaneity factor i.e. taking into account that all lighting devices are not switched on all the time. As a rough estimate, we assume a 30 % simultaneity factor and a 50 % comfort factor i.e. only 50 % would be possible to switch off without losing unacceptable comfort losses. The total shifting potential is therefore about 28 GW.

Of this total shifting potential, street lighting is estimated at about 5 GW (based on VITO, 2007) and residential and commercial indoor lighting is 23 GW.

If assumed maximum 5 minutes and 30 minutes of acceptable off time per day for residential and commercial indoor lighting and street lighting, respectively, then the switching potential would be about 4 GWh/day.

Functionalities supporting energy efficiency

For lighting in homes and commercial areas, information feedback on the level of consumption; when the consumption takes places in relation to the needs and efficiency and possibilities of impacting the consumption by behaviour changes and change of bulbs and lighting systems may provide substantial energy savings.

Street lighting is typically highly controlled and professional procured, and only few savings would be possible to achieve with more information feedback.

3.2.8. CONCLUSIONS

Periodical appliances

Periodical appliances are characterised by relatively long average lifespans (about 13 to 14 years) and relatively high power consumption. The numbers of installed base are high for washing machines reaching almost 200 million appliances. For dishwashers, tumble dryers and washer-dryers, these numbers are markedly lower with lowest ownership rates occurring in Eastern European countries. By trend, the penetration rates of these appliances are increasing in all the Member States.

Periodical appliances offer a high flexibility, whereas the dishwasher outperforms the other periodical appliances in flexibility. Delay in start time as well as short term interruptions of operation or modulations in power consumption pattern (e.g. postponing single phases) are assumed to be accepted by consumers if the performance is not compromised. User's concerns mainly focus on safety aspects (e.g. flooding or fire during unattended operation). These concerns could be addressed by improving safety features and by offering relevant insurances.

Continuous appliances

Cooling appliances like refrigerators and freezers are characterised by high numbers of installed base in all the Member States and relatively low power consumption. Load shifting would be possible (e.g. changes of compressor on and off cycles, short term interruptions of compressor's operation) but strictly limited in time for reasons of food safety and quality (seconds to a few minutes). Flexibility could also be provided by modulating power consumption (e.g. changes in motor speed). As cooling appliances operate fully automatic, there is no impact on user's comfort. If food safety and quality is not compromised and the system is working reliably, consumers will rather accept smart operation.

Electric storage water heaters are available in relatively large numbers in the Member States with numbers of installed base ranging in about 90 million units. In comparison to other residential appliances, they are characterised by extremely high power consumption. However, electric storage water heaters represent a heterogeneous category with comprising appliances with different storage capacities and modes of operation. Whereas water heaters heating during the night are the prevailing type in France and Germany, continuous storage water heaters are predominately used in Spain, Italy, Hungary, Czech Republic and Poland. In UK, both types are common. Data on the distribution in other European Countries are currently not available. Load shifting potential of electric storage water heaters highly depends on their storage capacity. As far as consumer's comfort is not compromised, delay in start of operation or interruptions would be possible. The same applies for modulation of power consumption (e.g. changes in temperature settings or power).
The average lifespan of continuous appliances is within the range 13-17 years.

Behavioural appliances

Despite large numbers of installed base in all Member States and a high level of rated power, the flexibility of all behavioural appliances is low. This can be explained by the fact that their operation requires an active involvement of the consumer and thus is time-bound in narrow ranges. In most cases, the consumer wants the service being available directly upon request and load shifts would have serious impacts on consumer's comfort. For this reason, users will presumably not accept shifts in operation. For hobs and ovens, short-term interruptions or postponed heating phases for a few seconds will rather be accepted, if the cooking process is not compromised in any way. However, there is a lack of available studies on this topic.

HVAC

HVAC appliances have a great potential to become communication-enabled or DSF enabled, given that they represent the main energy consumption in dwellings in the EU (heating accounts for 53% and cooling for 7%) (Waide et al., 2014). The main constraint regarding the communicating- or external action on HVAC systems is thermal comfort. The main disadvantage would be the possibility to jeopardize occupant's thermal acceptance (normally inside temperature) when demand-response acts on their HVAC appliances (on/off on peak hours, reducing the inverter current, load of the heat pump) during some time. These appliances are present among the whole EU28, with a penetration ratio for heating around 90% (EcoheatCool,2005) and for cooling around 15% (Ecodesign Lot 10, 2008). Heating presents a more homogeneous stock, due to Europe's temperate climate, being the opposite for air conditioners, where the stock is heterogeneous within the Member States. It is negligible in 20 of the Member States (less than 6%), and more important in Mediterranean and Eastern Europe (Italy, Spain, Greece, Romania, Slovakia, Southern France, Portugal). According to (BIOIS, 2011) heating is used approximately 7 months in EU28 (with demand largely varying between countries) and air conditioning 4 months for the countries/regions mentioned before (June to September). Taking into account that the heating market in Europe is saturated, existing heating technologies will decrease in sales, except for those that are more energy efficient and will be replaced (or be installed in new constructions) such as heat pumps i.e. (see also Task 1, Annex 1). As for air conditioners, for a penetration rate of 15% (more saturated markets on Member States mentioned above), future trends (Rivière, 2007) estimate a sales growth, mainly on split reversible A/C systems.

Battery operated rechargeable appliances

Due to the relatively low power consumption, Battery Operated Rechargeable Appliances need to be available in large numbers to be able to provide sufficient flexibility.

In this category we selected smartphones, tablets and laptops as possible candidates. These appliances today are largely available in all the Member States. Numbers of installed base range in hundreds of millions, all together.

Furthermore they already have sufficient control logic and communications features available, so that the implementation will be mainly limited to software. A quick calculation shows that sufficient flexibility (hundreds of GWh per year) can be gained without any change in user behaviour. But it is also clear that for correct calculations, there is still a general lack of available and reliable studies on this subject.

If the flexibility would need to be increased, the devices should be connected to their charging stations (wired or wireless) for longer periods, limiting the mobility that usually is the key feature of these appliances. On top of that, it has to be taken into account that the energy (demand) shifting potential is a balance between flexibility and energy saving, where longer connection leads to more shifting potential, but also to more energy consumption due to power losses (little, but present) when devices are connected. The lifespan of the devices is rather short, 4-5 years.

Residential energy storage system

From their nature, Residential Energy Storage Systems are ideal appliances for providing flexibility in the electric grid. Today we mainly see implementations of these systems in combination with PV installations. In this case maximum self-consumption of the PV generated energy is the goal. These systems can operate fully automatic and have no impact on the users comfort. Apart from this business case, the storage systems can also be used for different other business cases like dynamic pricing, peak shaving from and to the grid and aggregator services.

Although it's not their prime target, they can also provide additional comfort in cases of power downs. If we look at the current installations, we see that these systems are still very small in numbers and only common in Germany (25.000). The individual flexibility however is large. The lifespan of installations is expected to be between 15 and 20 years, but is strongly dependent on its usage (Temperature, Charging and Depth of discharge limits) and the quality of the battery. A quick calculation on the PV case shows a shifting potential of about 5.5 TWh per year.

Lighting

Due to energy labelling and ecodesign measures, there is a high focus on energy efficient lighting, both regarding efficient lighting devices and regarding efficient control (presence sensors, automatic dimming according to actual needs, etc.). When lighting is an energy service, which needs to be produced simultaneous as the needs occur, all lighting load shifting would have serious user impacts including safety issues.

Therefore, even though the technical potential is large, the flexibility is low, especially for homes and commercial areas, and the real potential will mainly exist for short periods of emergency load shifting.

3.3. DATA PROTECTION, DATA SECURITY AND CONSUMER RIGHTS

For some (but not all) DSF applications, high-resolution data on energy consumption are required. However, frequent measurement of power consumption may have serious implications on data privacy and the security of consumers as various information on the consumer can be deduced from these data (Siddiqui et al., 2012[228], Molina-Markham et al., 2010[229]). This information include the number of people living in a household or present at home at a certain point of time, type and brand of appliances available in a household, use patterns of devices, use mode, daily routines (e.g. sleeping, eating, showering, watching TV, etc.). In principle it can be said that the higher the frequency of readings, the more precise information can be deduced (Karwe and Strüker, 2014[230]). Related to data privacy, potential questions and concerns raised by consumers are manifold. They include, but are not limited to the following (Siddiqui et al., 2012228):

- Who is collecting and storing the data?
- For how long will the data be stored?
- Frequency of data readings
- Encryption of data
- How will the data be safeguarded?
- Who else has access to the data?

[228] Siddiqui, Zeadally, Alcaraz, Galvao (2012): Smart Grid Privacy: Issues and Solutions. Computer Communications and Networks (ICCCN), 2012.

[229] Molina-Markham, Shenoy, Fu, Cecchet, Irwin (2010): Private Memoirs of a Smart Meter. BuildSys '10 Proceedings of the 2nd ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Building, pp. 61-66.

[230] Karwe and Strüker (2014): A Survey on Privacy in Residential Demand Side Management Applications. In: Cuellar (Ed.): Smart Grid Security. Second International Workshop, SmartGridSec 2014, Munich, Germany, February 26, 2014. Revised Selected Papers. Springer

- Will the data be used for other purposes besides electricity delivering and billing?
- Can the data be used for or against a consumer?
- Liability in case of data abuse
- Access to control the appliances

Unless it is ensured that data protection and privacy of individuals are respected, consumers will not accept any DR programmes.
As conditions differ widely in different Member States (e.g. penetration rate of smart meters, responsible entities for installation of smart meters, involvement of Data Protection Authorities, data paths, etc.), it is hard to define specific rules and recommendations in view of data processing and data protection. Nevertheless, the Task Force Smart Grid Expert Group 2[231,232]and the Article 29 Data protection working party[233] made general recommendations for data handling and safety as well as consumer protection:

"**Privacy by design and default**" is recommended for the design of technologies and services involved in processing private data. Privacy by Design means that privacy is embedded into design and architecture of the whole system. It should ensure data reduction and data economy as readings should take place only in intervals necessary for the respective system and service. The same applies for the transmission of readings. In general, processing and transmitting of data should be reduced to a minimum. Data should remain on the consumer's side to the highest possible extent (for some DSF applications, it is possible to retain data locally and communicate it only in case of an imminent DR action). Entities, given the proper authorisation, should only have access to personal data necessary to fulfil their respective role.

The **retention of data** should be related to the purpose. Different retention periods may apply for different purposes (e.g. billing, taxation, billing complaints, optimisation of energy consumption). The Smart Grid Task Force made some recommendations on the scope and length of data retention, which are summarised in Table 32.

[231] Task Force Smart Grids Expert Group 2 (2011): Essential Regulatory Requirements and Recommendations for Data Handling, Data Safety, and Consumer Protection. Recommendation to the European Commission
[232] Task Force Smart Grids Expert Group 2 (2011): Regulatory recommendations for data safety, data handling and data protection report
[233] Article 29 Data Protection Working Party: Opinion 12/2011 on smart metering

Table 32: Recommendation for scope and length of data retention (Smart Grids Task Force, 2011231)

Purpose	Scope	Length	Kept by
Network maintenance	Personal/anonymised/aggregated	strictly necessary / national law	Utility
Billing and payments	summed up usage	around 12-13 months / national law	Utility and energy market supplier
Billing complaints	detailed personal data	national law	consumer
Taxation – tax records	summed up usage	national law	utility
Taxation – tax breaks	detailed personal data		consumer
Value added services	upon consent	upon consent	any interested
Policy making	anonymised/aggregated	unlimited	public authorities

Data should be retained in an **aggregated and anonymised form** to the highest possible extent. For billing purposes, aggregation of several readings of one individual meter is conceivable, for load management the aggregation of data from several meters. It has to be ensured that the actions of individual households and patterns of single appliances cannot be recognised. Another possibility is to retain the information locally until their communication is triggered in case of imminent DR actions.

Pseudonymisation has to be named as a further security measure hampering the possibility to link consumption data and identity information. Notwithstanding the above, it has to be mentioned that none of the aforementioned security measures are impregnable.

In order to ensure privacy, **safeguards** should be available comprising the whole system (elements of the network at home, the transmission of data, the storage of the data and any processing). These safeguards should be updated on a regular basis.

Any **disclosure of private data to or processing of data** by third parties should require the knowledge and consent of the respective consumer. This should include the right to withdraw any consent given earlier.

If any **Value Added Services** apart from energy supply (e.g. optimisation of energy consumption) are offered by the energy provider or a third party, it has to be an optional service and the customer needs to explicitly opt-in to provide its data for this purpose.

In the case of **mobility** (e.g. customers changing their providers, their locations, etc.), it should be ensured that the data stay linked to the respective customer or will be deleted completely. Regarding a change of the provider, this includes a secure transmission of the data.

Additionally, it has to be mentioned that Directive 95/46/EC on the protection of individuals with regard to the processing of personal data and on the free movement of such data and national laws implementing this Directive also apply to data processing in the framework of smart appliances and smart meters. In some respect, the aforementioned Directive is outdated as it does not take adequate account of new technological developments and Internet Services as for instance Cloud computing. For this reason and in order to harmonise data protection in Europe, a new General Data Protection Regulation is planned for the near future replacing Directive 95/46/EC.

Besides privacy concerns, consumers and experts also raise security concerns in view of smart applications. On the level of individual consumers, hacker attacks may imply a loss of control of single appliances or the introduction of malicious software (e.g. for spying purposes or profiling). On a grid level, attacks and introduction of malware might have enormous consequences. They can initiate an instantaneous increase or drop in demand, both destabilising the grid and resulting in severe problems or even damages of distribution, transmission and generation facilities. (Yan et al., 2012[234])

According to Stakeholders' opinion, the risk of an attack on the infrastructure is considerably higher than the risk of an attack on an individual appliance. Even though, some measures are recommended to decrease the risk of an individual attack. For instance, a manual "connection on/ off" switch should be provided that allows the consumer setting back the appliance to a local control. Additionally, an update capability should be available in the communication interface to tackle known threats and future security needs. Moreover, it has to be ensured that settings can only be changed within proper limits. If these limits are going to be exceeded, a safety shutdown of the respective appliance is recommended.
According to the National Institute of Standards and Technology[235] (NIST), deliberate attacks are not the only threats in view of the security of smart applications. Also potential accidents, e.g. due to equipment failures, user error or natural catastrophes should be taken into account.

A more in-depth analysis of security aspects is given in Annex of this Task 3 report. This analysis describes potential threats to Smart Appliances and ideal and basic approaches to mitigate the former, by using the principles of *defense-in-depth*, *security by design* and *security by default.* As the concept of Smart Appliances includes the processing of potentially sensitive user data, also privacy concerns are a major subject of this analysis, particularly in respect with the European Data Protection Regulation. The according recommendations therefore suggest anonymization and pseudonymization techniques (such as *k-anonymity* and its enhancements) and giving as less information away from end customers as possible (according to the *need-to-now principle*). They further suggest using a neutral party to enforcing this principle or using aggregation to enhance privacy. Further, user data could be marked in order to allow prosecuting data protection violations. The insights gained should serve as a basis for further research in Smart Appliance Security. Particular needs are reference architectures and norms, elaboration of privacy models, certification models and, after adoption of this technology on a broader basis, practical security surveys.

Besides data protection and security, protection of vulnerable costumers, who may be disadvantaged because of remuneration schemes, is of major importance. In view of DSF applications, vulnerability may be defined in terms of the access and understanding of new technologies and the possibility to make use of these technologies for energy managing and cost saving purposes (NEA, 2014[236]).

[234] Yan, Qian, Sharif, Tipper (2012): A Survey on Cyber Security for Smart Grid Communications. IEEE Communications surveys & Tutorials, 14, 4.
[235] NIST Special Publication 1108R2 (2012): NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0. Available online: http://www.nist.gov/smartgrid/upload/NIST_Framework_Release_2-0_corr.pdf
[236] NEA (2014): Developing an Extra Help Scheme for vulnerable smart meter customers. Available online: https://www.citizensadvice.org.uk/global/migrated_documents/corporate/smart-meter-extra-help-scheme-full-report-final1.pdf

Elements that potentially contribute towards consumer vulnerability include but are not limited to disability, age, (mental) health problems, hearing or visual impairment, low literacy, language or numeracy skills, tenure and low income. In order to avoid disadvantages of vulnerable costumers and ensure that all consumers can access the benefits resulting from DSF applications, adequate (political) measures have to be taken to provide support for vulnerable costumers and their specific problems.

3.4. Recommendations on refined product scope

In order to refine the product scope from the perspective of consumer behaviour, all appliances are categorised according to their load shifting potential (Table 33). The categorisation has been done on the basis of the information and assessments mentioned before.

Table 33: Categorisation of appliances according to their load shifting potentials (categorisation in terms of energy or number of products/ applicability of demand shift)

High potential	Medium potential	Low/ no potential
Washing machines	Refrigerators/ freezers	Electric water heater (instantaneous)
Dishwasher	Battery operated rechargeable appliances (smart phones and tablets)	Vacuum cleaners
Tumble dryer		Range hoods
Washer-dryer		Battery operated rechargeable appliances (others)
Electric water heater (storage)		Lighting
HVAC		Hobs
Battery storage systems		Ovens

The „high potential“-category consists of appliances, which have high numbers of installed products and/ or a high level of rated power/ high energy consumption. The consumer acceptance of load shifts or short interruptions is good for these appliances and it seems feasible to handle their comfort constraints.

Although **refrigerators and freezers** have high numbers of appliances in stock and it is assumed that smart operation (e.g. frequency control) would be accepted by consumers, these devices are categorised as “medium potential” due to their low level of rated power. The same applies for chargers of **smart phones and tablets**.

The potential of **hobs and ovens** is assessed to be low despite the large installed base in the EU and a high level of rated power. The assessment can be explained by the fact that their operation requires an active involvement of the consumer and thus is time-bound in narrow ranges. For this reason, the acceptance of consumers for shifts in operation is presumable low and only short-term interruptions for a few seconds or postponed heating phases will rather be accepted, if the cooking process is not compromised in any way.

Instantaneous electric water heaters are categorised as a low/ no potential appliance. To reach a high level of consumer acceptance, it is essential to always ensure a sufficient amount of hot water. This is only possible in the case of storage water heaters. In view of instantaneous water heaters, short-term interruptions in power supply would cause losses in comfort, which will not be accepted by consumers.

In view of **vacuum cleaners** and **range hoods**, shifts in operation and short-term interruptions are also improbable. Their power demand remains constant during operation and interruptions in power supply would consequently interrupt their operation. A further reduction of their power would decrease their performance (lower air change rate or a loss of suction power, respectively), and will presumably not be accepted by consumers.

Battery operated rechargeable appliances others than smart phones and tablets are categorized as low/ no potential appliances. This is due to the fact that they either have a smaller installed base or a lower and less predictable charging frequency (e.g. household appliances, power tools, navigation systems).

In the case of **lighting**, load shifts or short term interruptions would decrease the comfort for consumers and will presumable not be accepted.

Onset on barriers and opportunities for Ecodesign

During the last years, the share of appliances offered on the European market, which can be connected to the Internet for safety or convenience reasons, has continuously been growing. It can be expected that this trend will further grow. This might be seen as an opportunity for DSF. As far as it is possible to use the same software, there would be (almost) no extra costs for consumers to operate their existing appliances in a smart mode in order to shift loads. This would result in a very short payback time, which was identified as a key success factor.

From the consumers' point of view, data protection and consumer rights have to be seen as the major barrier. To overcome this barrier, it is essential to harmonise standards at European level and develop technical solutions for appliances, communication and billing systems that ensure the highest security standards when dealing with personal data.

3.5. DEMAND SIDE FLEXIBILITY USE CASES – SYSTEM PERSPECTIVE

The use of DSF in the energy system can serve multiple objectives. First, it can be used to optimize the day-ahead scheduling of electricity production and consumption. Second, it allows in real-time to match supply and demand in case of deviations in scheduling. These use cases are explained in detail below and the role of smart appliances as provider of flexibility is discussed.

In Task 5, for these use cases a model will be developed allowing the environmental product assessment and definition of the base cases. Section 3.5.2 gives an overview of the European market context and in section 3.5.3 the main data assumptions used in the model are listed.

Note that the modelling of the use cases makes abstraction of any specific energy market structure. For there is varying support for DR in the deregulated EU Member States' energy markets. In some countries no DR mechanisms are available, in others DR is already extensively used in the large industry. The way the energy market is organized will determine the extent and distribution of the return from the DR business cases. The following factors vary significantly between Member States, making an overall assessment of the impact of DR on all market players case-specific (non-exhaustive list of factors):

- The ownership of the smart meter is not identical for all EU Member States (e.g. owner can be the DSO or the retailer).
- The access to ancillary services of the TSO for DSF sources varies and depends on the ancillary service products of the respective TSO's.
- Various versions of variable tariffs are available throughout Europe and not all countries support variable tariffs.
- The role, obligations and rights of DR aggregators is not yet clear in many Member States.
- The rights and methods of the DSO to interact with DSF for the purpose of safeguarding the distribution grids from this extra source of variability is not yet clear in many Member States.
- In only few Member States, mechanisms exist to alter the perimeter of the BRPs with the effect of residential DSF.

3.5.1. DEFINITION OF USE CASES

Two distinct use cases can be defined, based on two important time blocks in the market: day-ahead versus real-time.

Day-ahead use case

In day-ahead, the schedule of electricity production and consumption is determined. In order to match supply and demand, balance responsible parties have several possibilities. First, they can adapt their production volume by optimizing own generation units or by participating to the various European Power Exchanges that enable them to trade volumes in the short term (day-ahead). The prices on the power exchange are determined on an hourly basis and are published in a transparent way. The prices on the day-ahead market reflect the marginal cost of the last unit that is needed to produce these volumes.

DSF could directly participate in the day-ahead market platform. The Balancing Responsible Parties (BRPs) have also the possibility to modify the load in order to match supply and demand. Load reduction or load shifting can avoid costs of additional production during hours with high prices. In this case, the DSF is directly integrated in the portfolio of the BRP. Independent how DSF by the use of smart appliances is offered in day-ahead, it will support the matching of supply and demand at a lower cost. In case of high estimated production of RES during certain hours, load could be shifted or increased during these hours. In case of high estimated load, a decrease or shift in load will have a downward effect on prices.

The day-ahead scheduling of production and consumption is done at national level. However, in recent years, an evolution towards more integrated markets on European level can be observed. Several day-ahead markets within the EU are coupled today, resulting in a unified day-ahead price in case of no congestion of transmission lines.

The harmonisation of day-ahead markets is part of the larger goal of European harmonisation as discussed in 3.5.1. In 2015, a total of 20 EU power markets are coupled through the Multi-Regional Coupling[237].

Imbalance use case

In real-time, deviations are observed between supply and demand. Different reasons can explain these deviations. Changing weather conditions are the primary source of these deviations. The realised production of renewable energy sources (wind and solar) is highly dependent on the weather. The demand or load is also affected by weather conditions such as temperature and cloud cover. In addition, non-weather related causes such as sudden outages of generation units or human errors e.g. in load forecasts can also explain why there is an imbalance between supply and demand in real-time.

The TSO is responsible for the stability of the grid and security of supply at the lowest cost in real-time or in near real-time. It will monitor in real-time the deviations of the grid and activate the necessary ancillary services in order to balance the system. Ancillary services can be provided by both, generation and load management, dependent on the type of ancillary service product. Dependent on the country, ancillary services are contracted by the TSO via yearly, monthly or weekly tenders. Today, the three categories of ancillary services are FRC[238], FRRa[239] and FRRm[240]. The relevant ancillary services for DSF today are FCR and FRRm. FRC is used by the TSO to ensure that the grid frequency stays within a certain range within the interconnected high-voltage European system. FRRm is used by the TSO to cope with major imbalance and congestion issues.

The cost of the activation of ancillary services (FRRa and FRRm) is reflected in the imbalance price published afterwards. As each BRP is responsible for the balance of its own portfolio, their individual imbalances will be invoiced based on the imbalance prices.

[237] The Multi-Regional Coupling (MRC) is a cooperation between the Power Exchanges APX, Belpex, EPEX SPOT, Nord Pool Spot and OMIE, and the Transmission System Operators 50Hertz, Amprion, Creos, Elia, Energinet.dk, Fingrid, National Grid, REE, REN, RTE, Statnett, Svenska Kraftnät, TenneT TSO B.V. (Netherlands), TenneT TSO GmbH (Germany) and TransnetBW.

[238] FRC = frequency containment reserves or currently called primary reserves. FCR are continually activated and have a fast response time (15 sec).

[239] FRRa = automated frequency restauration reserves or currently called secondary reserve. FRRa is activated on automated basis.

[240] FRRm = manual frequency restauration reserves of currently called tertiary reserves.

Similar to the day-ahead use case, DSF can be part of the imbalance use case in different ways. First, DSF can participate directly in the market of ancillary reserves (FCR and FRRm). An example of DSF participating to the market of FRRm is the product R3DP in Belgium (see later). The response time for FRRm is on average 15 minutes, which is sufficient for DSF to participate. In general, it is more difficult for DSF to participate in the market of FCR due to the fast response time that is required (15 seconds). However, applications based on batteries could participate to this market.

Alternatively, DSF can be used by the BRPs in order to optimize the balancing of their portfolio which results in a decrease of their imbalance costs.

Today, there exists a large variety of balancing mechanisms[241]. Efforts are made to harmonize these rules within Europe (see also 3.5.1), in order to improve efficiency and increase competition in the market of ancillary services. Dependent on the organisation of the market, which varies between countries, prices of ancillary services, settlement mechanisms in case of imbalance and incentives for BRPs to actively balance their portfolio differ substantially.

Note: besides the two main use cases as discussed above, DSF *could serve other objectives as well, such as DSO grid congestion cases, reactive power voltage support in the transmission grid,…. However, these use cases are less mature (e.g. DSOs are today not incentivized to contract flexibility as costs for flexibility are not remunerated) and the value of flexibility from smart appliances cannot be estimated based on today's situation.*

3.5.2. EU TARGET MODEL AND SCENARIOS

In 2007 the EU Member States agreed upon a clear set of targets for the integration of renewable energy. By 2020, the EU has a goal of a 20% reduction of greenhouse gas emissions, a minimum of 20% of energy savings and an increase of the share of renewable energy to at least 20% of the consumption[242]. Building upon the targets defined for 2020, in October 2014 the EU determined a policy framework for 2030 for climate and energy. The 2030 framework sets a target of 40% reduction in greenhouse gas emissions, a minimum of 27% of EU consumption to be produced from renewable energy sources and a 30% improvement in the EU energy efficiency compared to the projections[243]. The different EU targets with respect to the increase of renewable energy will have large effects on the grid, especially due to the intermittency of most renewable sources (wind and solar).

Besides increasing efforts in meeting the different climate and energy targets, steps are made at European level to stimulate the harmonisation of European energy markets. The European Target Model for Market Integration aims at a more integrated and efficient market with lower prices and increased stability that would benefit Transmission System Operators (TSOs), generators, investors,

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241 https://www.entsoe.eu/Documents/Publications/Market%20Committee%20publications/150127_WGAS_Survey_2014.pdf

242 Directive 2009/28/EC; Directive 2009/29/EC; Decision 406/2009/EC; Directive 2009/31/EC

243 http://ec.europa.eu/energy/en/topics/energy-strategy/2030-energy-strategy

traders and ultimately end-consumers. The European Target Model addresses all market segments from forward markets to day-ahead, intra-day, balancing markets and cross border capacity calculation. In the short term, congestion on cross border interconnections hinders the integration of markets. Increased capacity and new interconnections should provide a long term structural solution.

In 2015, progress has been made in the first place with the development of network codes and the harmonisation of day-ahead markets[244]. Less progress has currently been made on the level of balancing markets which are still mainly organised on a national level, resulting in a large variety of mechanisms across Europe[245]. An example of initiatives to harmonize the balancing markets, in particular, imbalance settlement, is the international grid cooperation control (IGCC)[246]. The IGCC enables netting of the imbalance volumes between the participating countries, and hence reducing the need for activation of reserves.

The targets for renewable energy, in combination with the ongoing harmonisation of energy markets will determine the future market design. In the following analysis, results are presented for 2015, 2020 and 2030. In addition, the expected market design of an integrated European market, although not yet a reality, is used as a reference case for market design.

3.5.3. DEMAND/LOAD, INSTALLED CAPACITY AND FUEL PRICES

3.5.3.1. DEMAND OR LOAD

The estimated demand for EU28 is based on the realised hourly load data of 2014 as published by the statistical database of ENTSO-E[247]. The load is corrected for import and export with countries not belonging to the EU28. In order to determine the load in 2020 and 2030, a yearly increase of 1.4% is assumed[248].

3.5.3.2. INSTALLED CAPACITY PER MEMBER STATE

The installed capacity of production units per Member State is based on the installed capacity of 2014 as published by the statistical database of ENTSO-E. For 2020 and 2030, the production mix per Member State is based on the PRIMES scenarios[249]. The PRIMES model simulates the European energy system and markets on a country-by-country basis and across Europe for the entire energy

[244] https://www.entsoe.eu/Documents/Events/2014/141013_ENTSO-E_Update-on-IEM-related%20project%20work_final.pdf

[245] https://www.entsoe.eu/Documents/Publications/Market%20Committee%20publications/150127_WGAS_Survey_2014.pdf

[246] http://www.tennet.eu/nl/fileadmin/downloads/About_Tennet/Publications/Other_Publications/plugin-Market_information_IGCC_tcm43-20521.PDF

[247] https://www.entsoe.eu/data/data-portal/Pages/default.aspx

[248] KPMG. Power Sector Development in Europe – Lenders' Perspectives 2011 - A survey of banks on the prospects for power infrastructure financing in Europe

[249] http://ec.europa.eu/transport/media/publications/doc/trends-to-2050-update-2013.pdf.

system. The model produces projections over the period 2015 to 2050 in 5-years intervals[250]. Utilized values for the installed wind capacity, solar capacity and peak load are summarized in

Table 34 Installed RES capacity and peak load per EU-28 Member State per year (Source: ENTSO-E database for 2014 for all Member States except Malta, PRIMES scenario outcomes for 2020 and 2030, and for Malta for 2014, and for peak load in Malta Enemalta[251])

	Installed solar capacity [MW]			Installed wind capacity [MW]			Peak load [MW]		
	2014	**2020**	**2030**	**2014**	**2020**	**2030**	**2014**	**2020**	**2030**
AT	400	787	1466	1529	3114	6051	12355	13430	15433
BE	1840	2429	4813	1966	4772	7068	13110	14251	16376
BG	1060	1116	1534	850	923	1515	8638	9390	10790
CY	79	194	658	145	249	329	871	947	1088
CZ	2011	2011	2068	277	307	387	10058	10933	12564
DE	35357	49089	53584	35600	48956	69949	81031	88081	101219
DK	282	360	762	4489	5960	7420	6163	6699	7699
EE	0	0	0	354	495	1056	1786	1941	2231
ES	7667	12655	16945	25028	25213	35707	39394	42821	49208
FI	7	50	60	411	1538	2556	13945	15158	17419
FR	4630	7470	13913	10238	25687	47354	84280	91612	105276
GB	1574	5985	8853	12140	38627	50721	50997	55434	63702
GR	3052	3286	3640	2195	3433	3745	8448	9183	10553
HR	16	27	182	394	640	713	3012	3274	3762
HU	3	93	712	413	903	1236	5712	6209	7135
IE	0	0	674	2088	11200	5992	4572	4970	5711
IT	16204	19553	28206	7371	222	22598	49523	53832	61861
LT	0	0	0	221	226	251	1408	1530	1758
LU	78	226	409	78	428	290	878	954	1097
LV	1	1	1	155	86	681	1172	1274	1464
MT	8	48	211	1	3561	191	290	316	363
NL	131	788	1037	4619	9624	12359	17850	19403	22297
PL	6	51	530	2472	6515	8843	23593	25645	29470
PT	1051	2212	5613	5398	5689	8324	8295	9017	10362
RO	214	679	1860	1566	1572	4043	8738	9499	10915
SE	13	182	248	3646	4447	5107	24295	26409	30348
SI	85	130	444	8	225	453	2074	2254	2591

[250] More information on the PRIMES model is listed on the website of E3Lab of the National Technical University of Athens - http://www.e3mlab.ntua.gr/e3mlab/index.php?option=com_content&view=category&id=35:primes&Itemid=80&layout=default&lang=en

[251]Enemalta:http://www.transport.gov.mt/admin/uploads/media-library/files/DAirMaltaStudyVisit_The%20Energy%20Sector%20in%20Malta.pdf

SK	539	787	1009	48	113	455	4523	4917	5650

3.5.3.3. Fuel prices

The fuel price for the different technologies will determine which power plant will run and at which price. The fuel costs in the model for (prices of oil, gas and coal) for 2020 and 2030 are based on an average of the price scenario's as defined in the World Energy Outlook 2013 and the price scenario's presented in the Energy Technology Perspectives[252]. Prices for 2014 are based on realised market prices[253]. The prices are not country specific.

The CO_2-prices in the model for 2014 are based on the average price of the EUA Dec 2014 contract as quoted during 2014 (published by ICE[254]). The prices for 2020 for CO_2 are based on the current published price (16/10/2015) of the EUA December 2020 contract (published by ICE). The price for 2030 is based on an analysis of Thomson Reuters[255].

The prices for biomass are based on typical values for wood pellets as published on FOEX[256]. For biomass, the assumption is taken that in most countries, support schemes exist. An average of 55€/MWh as support value for biomass is used[257]. Table 35 summarizes the fuel prices used in the simulation.

Table 35: Fuel prices for 2014, 2020 and 2030 used in the model

		Year 1 (2014)	Year 2 (2020)	Year 3 (2030)
Nuclear	[EUR/MWh_prim]	6,98	6,98	6,98
Coal	[EUR/MWh_prim]	9,20	11,93	11,97
Natural gas	[EUR/MWh_prim]	18,75	31,66	32,71
Hydro	[EUR/MWh_prim]	5,06	4,84	4,84[258]
Wood pellets	[EUR/MWh_prim]	48,48	53,54	57,42
Oil	[EUR/MWh_prim]	5,96	9,07	48,00
CO2	[EUR/tCO2]	6,98	6,98	6,98

252 http://www.iea.org/etp/etpmodel/assumptions/
253 http://knoema.com/wxgcxde/commodity-prices-forecast-2015-2019-charts-and-tables?variable=Natural%20gas%20(US%24%2FmBtu%2C%20Europe)
254 https://www.theice.com/market-data
255 http://www.changepartnership.org/wp-content/uploads/2014/10/Point-Carbon-2014-11042014-MSR-Point-Carbon.pdf
256 http://www.foex.fi/index.php?page=pix-rcp
257 https://ec.europa.eu/energy/sites/ener/files/documents/ECOFYS%202014%20Subsidies%20and%20costs%20of%20EU%20energy_11_Nov.pdf
258 XXX

CHAPTER 4 TECHNICAL ANALYSIS

The objective of Task 4 is to perform a technical analysis of products that are currently placed on the European market and have the potential to be placed in future as part of a smart grid system. This approach is to some extent different from the "traditional" Ecodesign product analysis since smart, demand response-ready appliances (with Demand Side Flexibility, DSF) are only available in very limited scale and are still far from been taken up by the market to their full potential. Appliances marketed as “smart appliances” are typically networked appliances, which can connect to mobile devices (smart phones, tablets etc.) for achieving notifications and/or being managed by these devices. In reality, there are no smart appliances on the market living up to the full scope definition in this study. This fact naturally limits the extent of an analysis of “existing products” and it has also limited the data input from the manufacturers. The study team therefore had to base the analysis on products similar in technical capabilities and on estimations.

There is furthermore an important assumption to make regarding how many appliances already are network connected and are equipped with circuitry, chipsets, software etc. necessary for the DSF functionality and thereby in the most advantageous case only need software update for being DSF ready. For these cases, the impact regarding needed changes, energy consumption of the appliance itself, costs etc. may be very limited. Opposite, there will be larger impacts for appliances currently without network connection and other needed components. This is further detailed in Section 1.1. The analysis has to determine relevant technical parameters that have an influence on the environmental life cycle performance of the products and of the production costs and selling price. This may include energy and material related product specifications. The Task 4 report provides the main input data for the later assessment of design options (Task 6) and scenarios (Task 7 - as part of an ongoing second phase of this Preparatory Study). It means that this report does not estimate any impact on the rest of the energy system (production, transmission and distribution), neither does it make any projections or scenarios.

Note that the focus of the Task 4 report will not so much be the products themselves (for which assessments have been carried out in the respective vertical regulations) but that it will specifically address the implications that go along with the connectivity and DSF functionality.

Against this background, the study team will focus exclusively on the impact on energy consumption in the use phase of the appliances, because this is the most relevant phase for smart appliances. We will just include brief descriptions of the production, distribution and end-of-life phase. The analyses of energy consumption is only at the end-user level, i.e. of the appliances and related products and systems in the use situation in homes and offices etc. and as mentioned above the energy impact at the power supply system is targeted in the Task 6 and 7 reports.

Finally, we focus on the additional components necessary to achieve the smart appliance functionality i.e. the Demand Side Flexibility. Some of the components may also provide other functionality than the demand response and some may be integrated in the product’s design.

The team based the work on the selected product group examples (see Section 1.4.3), which are also the focus in other task reports, mainly examples from the categories “high flexibility potential with few comfort and/or performance impacts” (dishwashers, washing machines, washer dryers, radiators, boilers, heat pumps, circulators, residential air conditioners and battery storage systems).

We briefly mention lighting and smart meters. Building automation systems, energy managers etc. are not in scope of the analysis (see Task 1 report).

4.1. Technologies for smart appliances

Smart appliances will - in the context of this study - be Demand Response (DR) enabled devices for achieving Demand Side Flexibility, which can be controlled by signals from an aggregator or alike typically through an energy manager, which can be a physical device in the home, office etc. or a virtual energy manager in the cloud.

The appliances will be traditional household appliances, HVAC units etc., which have been modified and redesigned for DSF by adding the necessary components and functionalities included for maintaining quality, safety, user comforts, privacy etc.

Smart appliances will typically contain the following additional components and design modifications compared to a non-networked and non-smart appliance:

- Network connection (fixed and/or wireless connection) corresponding to the network protocol and network interface technology used.
- Other control systems needed to be built in to process and react on the DSF signals.
- Other components needed for the demand response ability e.g. energy storage (electricity, heat, cold), safety circuits, measurement circuits, sensors etc.
- Required modifications in the existing control system programming to take into account needed changes related to the DSF mechanism relevant for the appliance for altering the electricity consumption pattern. E.g. modulate the heating, pre-heat building components or energy storage, delay start of the next program step, set part of an appliance in an off-state etc.
- Additional power supply to handle the voltage and power requirements by the electronics in a waiting for signal mode in order to comply with the ecodesign networked standby requirements (i.e. Commission Regulation (EC) No 1275/2008) and/or other regulative requirements.

There is only a limited amount of network connectivity within the appliance groups selected for study in this report. Some of them are called "smart" in the meaning of having the capability to be controlled over a network. These appliances will typically not need a further network connection, but can use the existing one. Typically there would be a need for other modifications to be DSF enabled.

4.2. Production phase

In the majority of the cases, the appliances will only need very limited additions of electronic circuitry and other components. This is partly because in many cases the DR enabled appliances will already be network connected for communication with a smart phone or other devices. Partly because major changes of the product and addition of hardware would be too expensive compared to the economic benefits of the DR enabling.

Therefore, the impact of the add-ons to the products to provide connectivity and DSF functionality on resources and energy used for the production phase is assumed to be marginal and not further assessed.

4.3. Distribution phase

The impact on the distribution phase is assumed to be marginal of the same reasons described under the production phase and the impact will not be further assessed.

4.4. Use phase (product)

4.4.1. Regulations on energy consumption

DSF will typically have an impact on the energy consumption in two ways:

- Additional consumption in control electronics, both due to the added electronics and due to the longer on time for the electronics, which typically will be always connected to the network in order to react on control signals
- Additional consumption due to increased losses in energy storage systems in broad term e.g. pre-heating or pre-cooling of building elements, storage water tanks and battery storage.

Regarding the additional consumption in control electronics, there are EU regulation, which set consumption limits in some cases.

The most relevant is the amended standby regulation (Commission Regulation (EU) No 1275/2008), which includes limits for power consumption in network standby and power management to networked standby. For the relevant appliances (household appliances, IT equipment with exceptions, consumer equipment and toys, leisure and sports equipment), the limits in network standby for non-HiNA appliances without HiNA functionality are:

- From 1 January 2015: 6.00 W
- From 1 January 2017: 3.00 W
- From 1 January 2019: 2.00 W (subject to review)

The power management requirement in effect from 1 January 2015 requires the product to automatically switch into networked standby, when it is not providing a main function.

In addition to this horizontal requirement, there may be additional product specific requirements. E.g. for lighting there is a requirement for lamp control gear on 1.0 W reduced to 0.5 W in September 2016.

4.4.2. Network connections applicable to all smart appliances

There are many kinds of network technologies, both wired and wireless, which can be used for the smart appliances and more are coming to the market and the existing technologies are further developed to typically higher speed and less power consumption. The trend is towards wireless technologies.

Examples of network technologies include:

- Bluetooth Classic and Bluetooth 4.0
- Wi-Fi
- ZigBee
- Z-Wave
- Ethernet, 10-1000 Mbps

Based on several sources, main network interfaces used currently excluding Wi-Fi would have a power consumption at dc level (see power supply losses below) of less than 0.5 W. A recent source, the EDNA report[259], states average power consumption of four Ethernet interface products to be 0.59 W (dc), where 2 of the products consume 0.43 W. These data confirm a BAT level of 0.5 W.

Regarding Wi-Fi, there are networked interfaces of less than 0.05 W, but also of several watts. The EDNA report states an average of three products to be 0.36 W, where the product with lowest consumption consumes 0.14 W.

There is ongoing work for developing a specification for low power Wi-Fi (IEEE 802.11ah) for sub 1 GHz frequency bands. Wi-Fi cards for several frequency bands (currently 2.4 GHz (most typical) and 5 GHz bands) typically have higher consumption levels, but mobile phones are examples of products with several radios (Wi-Fi 2.4 and 5 GHz, LTE, 2G, 3G, Bluetooth and NFC) and with low consumption levels.

The EDNA report reports ZigBee average consumption to be 0.13 W, where the product with lowest consumption consumes 0.09 W.

All in all and with the major developments of network interfaces for mobile devices, non-chargeable battery devices for Internet of Things and networked connected smart appliances, the expectation is that power consumption (dc) for network interfaces would be no below 0.6 W.

Price examples from Alibaba.com include:

- Wi-Fi module: 10$ (8.7€) (≥ 10 pieces)
- Zigbee wireless module: 3-4$ (2.6-3.5€) (≥ 10 pieces)

For product series with much larger numbers, the prices would naturally be much lower.

Power supply losses are typically larger at lower load points. If the active consumption of the product is more than 20 W, the load point would be at 10 % load or less, which may increase the losses. However, there are still much focus on reduction of power supply losses and also technologies on the market to obtain a more flat efficiency curve.

An alternative would be to have a dedicated auxiliary power supply for delivering low power for networked standby and standby/off designed for high efficiency at these power levels. An example of this is that an auxiliary power supply delivering 12 V, 3 A with 85 % efficiency and a price of 2-3$ (equivalent to 1.6-2.3€)[260].

Regulative activities include:

- A proposal on revised EPS regulation with the inclusion of a 10 % load point information requirement
- Code of Conduct on Energy Efficiency of External Power Supplies Version 5 setting requirements on 10 % load (e.g. 72 % efficiency at 10 W nominal power, 76 % at 20 W and 78 % at 30 W)

If the efficiency is 80-90 %, the loss would be maximum 0.2 - 0.4 W at 2 W consumption.

[259] "Energy Efficiency of the Internet of Things. Technology and Energy Assessment Report. Prepared for IEA 4[E] EDNA". April 2016.
[260] http://waweis.en.alibaba.com/productgrouplist-801270815/Fashional_Laptop_Adapters.html

4.4.3. APPLIANCE EXAMPLES

In this section, we assses the selected product group examples, which are also the focus in other task reports.

Each product group is assessed through these steps:

- Description of the appliance type
- Network connection: Description of the network connection regarding type of network and network interface technology (related to the type of network).
- Additional components: Possible additional components needed such as storage (electricity, heat, cold), safety circuits (eg. washing machine lock during more extended periods), modulating circuits, measurement circuits, sensors etc.
- Appliance modifications: Other hardware or software changes needed
- Demand response mechanism: Description of the kind of DSF expected to be relevant for the appliance and how the electricity consumption pattern will be altered. E.g. modulate the heating, delay the start of the next program step etc.
- Cost impact: Additional cost, indicated quantitatively or qualitatively
- Energy impact: The relevant energy impact will be indicated in the form of power draw for the
- various components or totally

There are necessarily considerable uncertainties related to these assessments. Not only how the total impact will be, but also how much of this impact is due to being the DSF functionality in the definition of this study. E.g. how many additional energy consuming components and/or how much will the existing component increase their consumption in order to be DSF enabled or be active in periods, where the product else would be switched off. And would an appliance be network connected only to be demand response enabled or would it in any case be network connected e.g. for being able to send notifications to the users' smart phone.

The uncertainty also relates to the fact that there are very few demand response enabled products on the market and also only few networked products, which are not IT or consumer electronics.
The study team has tried to estimate how much of the energy and cost impact is related to demand response enabling and provided the assumptions in the text.

4.4.3.1. Periodical appliances (dishwashers, washing machines, tumble dryers, washer-dryers)

Description

<u>Description of dishwashers</u>
A dishwashing programme is formed by several steps. The number of steps as well as their duration and temperatures are dependent on the respective programme. The basic steps are: pre-rinsing, cleaning, intermediate rinsing and drying. At the beginning of the dishwashing process, water is led into the tube until reaching a predefined quantity or level. The water is maintained throughout the individual steps of the cleaning process.

Depending on the programme selected by the consumer, the water is heated by a resistant heating system (rated power between 1,800 and 2,500 W) to a certain temperature (mainly 50/55°C, 60/65°C or 70/75°C). The cleaning process is continued for a defined period of time (programme-dependent).

The cleaning step is followed by one or more intermediate rinsing steps applying cold water. In a final rinsing step, the water and the load items are heated up again to a predefined temperature normally exceeding the temperature in the cleaning phase. The heat is used in the drying process to evaporate the water film from the surface of the dishes. At the end of the programme, the water is pumped to the water outlet by using a drainage pump.

Electrical energy is mainly needed for heating up the water (and indirectly the load items and the interior of the machine) to the desired temperature. About 25 to 50 % of the total water consumed in the dishwashing process is heated up. The remaining 50 to 75 % of the water is used as cold water in the pre-wash and the intermediate rinsing phase.

Besides the heating energy, additional energy is needed to operate circulation and drainage pumps, as well as displays and user interfaces. The rated power input of water circulation pumps is about 15-30 W. (JRC, 2015[261])

After the end of the programme, a small amount of energy may be needed to keep some safety functions alive (e.g. water protection sensor systems or remote control systems). (Stamminger et al., 2009[262]).

Description of washing machines

A washing programme is formed by several steps. The number of steps as well as their duration and temperatures are dependent on the respective programme. The basic steps are: main wash, several rinsing cycles and spinning cycle. A pre-wash step is optional. Depending on the programme chosen, the water is heated to a certain temperature (mainly 20, 30, 40, 60 and 95 °C) by using a resistant heating system (power rating between 1,800 and 2,500 W).

The heating process may be shortly interrupted for equalizing the temperature of water and load. The water is recirculated throughout the main wash cycle. The cleaning process is continued for a defined period of time (programme-dependent). The cleaning step is followed by several rinsing steps. The motor-driven drum is rotating in a reversing way at a certain speed during both, the main wash and the rinsing phases. After the main wash phase and between the rinsing phases, the drum rotates at a higher speed in order to remove water and soapsuds from the laundry. The highest rotation speed (programme-dependent) is reached in the final spinning phase. This is to extract as much water as possible from the load. At the end of the programme, the water is pumped to the water outlet by using a drainage pump.

Electrical energy is mainly needed for heating up the water (and indirectly the load items and the interior of the machine) to the desired temperature. About ¼ to ⅓ of the total water consumed in the washing process is heated up. The remaining water is used as cold water in the rinsing phase. Besides the heating energy, additional energy is needed to operate circulation and drainage pumps, the drum motor as well as displays/ user interfaces. During spin-drying, motors of washing machines reach power peaks of up to 950 W, whereas their typical operational power input is about 100 W.The rated power input of water circulation pumps is about 15-30 W. (JRC, 2015[263])

[261] JRC (2015): Ecodesign and Energy label revision: Household Washing machines and washer-dryers. Draft. Available online: http://susproc.jrc.ec.europa.eu/Washing_machines_and_washer_dryers/docs/Prepstudy_WASH_20150601_FINAL_v2.pdf

[262] R. Stamminger (2009): Synergy potential of smart domestic appliances in renewable energy systems. Shaker Verlag, Aachen.

[263] JRC (2015): Ecodesign and Energy label revision: Household Washing machines and washer-dryers. Draft. Available online: http://susproc.jrc.ec.europa.eu/Washing_machines_and_washer_dryers/docs/Prepstudy_WASH_20150601_FINAL_v2.pdf

After the end of the programme, a small amount of energy may be needed to keep some safety functions alive (e.g. water protection sensor systems or remote control systems). (Stamminger et al., 2009[264]).

Description of tumble dryers

During the drying process, hot air is circulated through the drum while the drum is rotated driven by a motor. The hot air causes the moisture from the laundry to evaporate and thus dries the laundry. The hot air can either be generated by an electrical heating system (rated power between 2,000 and 2,500 W) or by a gas-fired heater (low acceptance in Europe).

After taking up the moisture from the laundry, the resulting humid air can be either vented via an air duct to the outside of the house (vented dryer) or the water vapour may be condensed by cooling the air using a heat exchanger (condenser dryer). In the latter case, the condensing water is collected inside a tank or drained via a pipe. Alternatively, it is possible to regain the energy contained in the humid air by using a heat pump (heat pump dryer). While passing the heat pump, the water vapour condenses and the thermal energy is extracted and reused afterwards to heat up dry air going into the drum. In this way, energy savings of about 40 to 50% of the total energy consumption are possible. Heat pump dryers become more and more important in the European market.

The drying process can either be controlled by a sensor which detects the remaining moisture of the load finishes the drying process if a specific humidity is reached or by a timer function.

Electrical energy is mainly needed for heating up the air (and indirectly the load items and the interior of the machine) to a programme-specific temperature. Besides the heating energy, additional energy is needed to operate the drum motor, fans, the heat pump (in the case of heat pump dryers) as well as displays and user interfaces.

Description of washer-dryers

Washer-dryers are a combination of a washing machine and a tumble dryer in the same cabinet. The washing and the drying process are performed consecutively as described before.

Electrical energy is mainly needed to heat water and the load items during the washing process and to generate hot air for drying. Besides the heating energy, additional energy is necessary to operate the drum motor, pumps, fans and displays/ user interfaces. After the end of the programme, a small amount of energy maybe needed to keep some safety functions alive (e.g. water protection sensor systems or remote control systems).

Network connection

Models equipped with Wi-Fi (or other network connectivity), other type of gateway connection or frequency sensing are already available from a few manufactures in the European market, but the market penetration so far is believed to be marginal. Functionality includes notification of the progress of washing etc. and start of machines remotely.

To make a an appliance connected, there is, as fas as can be concluded for the moment, a need for a connectivity module (antenna, wireless electronics and interface), which connects to the existing device electronics[5].

Additional components

[264] R. Stamminger (2009): Synergy potential of smart domestic appliances in renewable energy systems. Shaker Verlag, Aachen.

Machines already being network connected and with sufficient computational power may have all the components needed for the DSF functionality. If not, there would be a need for computational power, printed circuit board and wires[265].

Appliance modifications
Enabling periodical appliances for DSF functionality requires new control software.

The software establishes the communication with the energy manager and receives the controls signals from the supply side. It controls the machine regarding start and stop and altered electricity consumption pattern, see next section.

Demand response mechanism
In view of periodical appliances, two different possibilities to shift energy or modulate power could be identified:

1. Remote or signal activation: The user selected programme is remotely activated before the user deadline is reached. E.g. the user fills the washing machine with clothes in the evening and select 07:00 in the morning the day after as the deadline for having the clothes washed.

2. Altered electricity consumption pattern: While the appliance is activated, the consumption patterns changed through pausing the operation, changing the temperatures, changing heating power, changing spinning speed (in the case of washing machines and washer dryers) etc.

In the first case, the machines are remotely started, e.g., when a surplus of (renewable) energy is available on the grid. As the operation of a single appliance is only shifted in time, the sequence of the programme and with this, the power demand curve of a cycle, remain unchanged.

In the second case, machines may change their operation after it has been started via the remote signal, e.g. if there is a shortage of energy available on the grid. Periodical appliances may react to the signal by the control software to reduce the power load and still finish the work witin a pre-defined deadline. Possible operation cycle changes include short-term interruptions, changes in temperatures or shifts of single programme phases (e.g. cleaning or final rinsing phase and spinning). This may change the power demand curve of a single appliance and the overall duration of a cycle.

Cost impact
If the machine already is network connected and has a sufficient control circuitry, the main cost will be for the software development, testing and documentation. This again depends on the amounts of products in the series of machines. If the machine is not network connected, there is a need for a wireless connectivity module.
CECED has provided the following information on costs[5] *(non exhaustive bill of materials):*
- *Wireless electronics (consumer electronics examples)*
  - *Asus Google Nexus Player & Gamepad TV500I-0009 SI38244-SBd (Wi-Fi; Bluetooth; FM Radio – Flip Chip, solder): 8.10$*
  - *Apple I Pad Air 2 (802.11 ac dual-antenna MIMO + BT 4.0 – Based on Broadcom BCM 4345 Chip): 4.50$*
- *Computational power*
  E.g.: Raspberry Pi Zero: 5€

Moreover, additional costs are due for the following components:
- *On board or external antenna*

[265] See also: CECED contribution to Ecodesign prep study on SA. Cost impact of connectivity". 15/01/2016.

- *Printed Circuit Board*
- *Wires*

In addition, CECED informs that costs for the bill of material would need to be multiplied by an “industrialisation factor” that would reflect manpower (production), adaptation of the appliance/platform functionalities and higher safety and quality requirements. Furthermore, the organisation states that there are other costs related to product adaptation to connectivity, which is certification process for materials related to connectivity and licensing costs related to the use of connectivity technology such as Wi-Fi.

Based on information from industry experts and the above information, the study team has estimated the following cost levels:

- A networked appliance only needing software modifications, testing, documentation etc.: 5-10€
- A non-networked appliance also needing a network connectivity module etc.: 15-20€

These are costs at the manufacturing level including testing and documentation, but without mark up for the distribution and retail level. Note that a pre-condition for these estimates is that modifications concern larger product series thus represent a situation after redesign and optimisation in the context of a future smart grid market.

Energy impact

For the additional energy consumption of the network connection, see the previous section on network connections. If the starting point is a networked appliance, the energy consumption of network connection should not be allocated the DSF.

In the case of remote activation, the machine may consume additional standby energy for safety functions (such as door lock) and a higher activity level for the electronics, while waiting for a start signal. For washing machines, the study team has been informed about power levels of about 5-10 W (e.g. the door lock consumed 5 W), however, the source also informed that new products are under development with much lower power consumption.

Regarding altered electricity consumption pattern, the energy consumption may be influenced in different ways. Short-term interruptions might be critical if they occur during the heating phase. Depending on their duration and the actual process temperature, heat energy may be lost to the surroundings and additional energy is needed to recover the process temperature. Investigations by Stamminger et al. (2009)[170] recommend interruptions not exceeding a time of 10 minutes (5 minutes in rinsing phase of dishwashers) in order to avoid significant losses in heat energy. If the temperature of single programme steps or the whole process is lowered, the total energy consumption may be reduced corresponding to the temperature reduction. If single programme phases are postponed, the total operation time (e.g. operation time of the circulation pump) is prolonged, which entails a slight increase in total power consumption.

A further aspect, which has to be taken into account in view of short-term interruptions, is the performance. If the operation of washing machines or tumble dryers is interrupted, for instance, the laundry may go mouldy or stick together or fading of colours may occur. In order to avoid such textile damages, the drum should be moved in regular intervals during interruptions longer than 5 minutes, which causes additional energy consumption.

Regarding tumble dryers, some kind of drum rotation or pre-drying is recommended for the time waiting for the start of the process to avoid the wet laundry of getting mouldy and wrinkled.

4.4.3.2. Radiators

Description
The operating principle of electric radiators consists in heating indoor air using an electric resistance through convection and sometimes both convection and radiation. Cooler indoor air will enter through the lower part of the convector and heated air will exit by the upper part. Some convectors are equipped with radiating surfaces (mainly conceived using aluminum) that are able to transfer 40 % of the total heat in form of irradiative power. The only controlled variable that modulates electric radiators is the indoor temperature, using an electronic thermostat (PI or PID). Most common installed electric radiators have a total installed power between 750 W and 2000 W and their operating mode is only on/off, controlled by an established set point. (Da Silva 2011)[266], (Bézian et al. 1997)[267].

Network connection
Network connection to external devices can be via cable or Wi-Fi (Da Silva 2011). Wireless signal may include Wi-Fi, Bluetooth, Zigbee, Z-Wave etc.

Additional components
No extra components needed for demand response enabling for electric radiators, if it already has an electronic thermostat that can switch off/on the appliance given an external signal.

Appliance modifications
Only software adaptability must be done, in order to allow an external signal from a grid operator to control the equipment. Software changes may refer to adapting the appliance to respond to different external signals (room temperature, energy pricing, external orders from the grid).

If the radiator does not have a communicating electronic thermostat, there is also a need to change the hardware.

Demand response mechanism
Different studies have taken place in France regarding the different signals and curtailment programs used to control electric radiators. The external signals are: On/off signal, mode-eco signal (lowering the set point e.g. 2°C under the regular set point), pre-heating (heating off peak periods prior to curtailment). For each kind of curtailment method an important factor is the ratio of the curtailed energy and the energy consumption after the curtailment. It is important to point that the results (occupants comfort, the ratio of energy saved and after-consumption) of the previously presented curtailment mechanisms are highly dependent on the building's thermal properties. Compared to the electric thermal storage heaters (see next section), the radiators store heat in the building components.

Cost impact
One source[268] reports that the total installation cost of a DR mechanism per home i.e. including the central energy manager and the connections to the radiators is approximately between 35€ and 85€ (including extra material, technical intervention and internet or telecom installations). However, this

[266] David Da Silva. Analyse de la flexibilité des usages électriques résidentiels : applications aux usages thermiques. ElectriC power. Ecole Nationale Supérieure des Mines de Paris, 2011. French. NNT : 2011ENMP0070
[267] Bézian, Jean-Jacques ; Barles, Pierre ; Claude François & Inard Christian. 1997. Les émetteurs de chaleur. Presses de l'école des Mines.
[268] Réseau de transport électricite (2015): Valorisation socio économique des réseaux électriques intélligents. (French)

intervention does not allow feedback from the demand side, it operates only in "slave mode" which means that the range could be an underestimation. On the other hand, not all the costs can be attributed only to the smart functionalities of the appliance.

For the purpose of this study, the study team has estimated the costs for the individual radiator at[269]:

- A networked radiator only needing software modifications, testing, documentation etc.: 5-10€
- A non-networked appliance also needing a network connectivity module etc.: 10-15€

Energy impact

Energy impact will be in the form of energy consumption of the network connection, if the demand response will be done over a network system that requires extra communicating technology.

In addition, if there is a need to pre-heat to a higher temperature than normal, there would be an additional heat loss from the building.

4.4.3.3. Electric thermal storage heaters

Description

These systems are capable to store heat in the radiators, when energy prices are low (actually off-peak hours during the night) due to the fact that they have a core made of refractive bricks, granite, aluminum or ceramic material. These systems are normally controlled with a variable speed ventilator that modulates the quantity of air that will pass through the radiator. The controlled variable that modulates electric thermal storage heaters is indoor temperature, using an electronic thermostat (PI or PID) and another thermostat that indicates when the "heat" charging takes place. Most common installed electric radiators have a total installed power between 500 W and 2000 W and their operating mode is only on/off, controlled by an established set point. (Da Silva, 2011).

Network connection

These equipments can be either controlled by their internal control or an external control. Communicating to external devices can be via cable or wireless connection such as Wi-Fi.

Additional components

No extra components needed to optimize the curtailment of electric thermal storage heaters, if the appliance already has an electronic thermostat that can switch off/on the appliance given an external signal.

Appliance modifications

Only software adaptability must be done, in order to allow an external signal from a grid operator to control the equipment. Software changes may refer to adapting the appliance to respond to different external signals (room temperature, energy pricing, external orders from the grid).

If the radiator does not have a communicating electronic thermostat, there is also a need to change the hardware.

[269] These are costs at the manufacturing level including testing and documentation, but without mark up for the distribution and retail level. Note that a pre-condition for these estimates is that modifications concern larger product series thus represent a situation after redesign and optimisation in the context of a future smart grid market.

Demand response mechanisms
The thermal storage of these radiators allows them to have certain flexibility when it comes to require electricity to charge the core. Normally, they are conceived to charge, when energy prices are low.

Cost impact
One source[270] reports that the total installation cost of a DR mechanism per home i.e. including the central energy manager and the connections to the radiators is approximately between 35€ and 85€ (including extra material, technical intervention and internet or telecom installations). However, this intervention does not allow feedback from the demand side, it operates only in “slave mode” which means that the range could be an underestimation. On the other hand, not all the costs can be attributed only to the smart functionalities of the appliance.

For the purpose of this study, the study team has estimated the costs for the individual radiator at[271]:
- A networked radiator only needing software modifications, testing, documentation etc.: 5-10€
- A non-networked appliance also needing a network connectivity module etc.: 10-15€

.
Energy impact
Energy impact will be in the form of energy consumption of the network connection, if the demand response will be done over a neetwork system that requires extra communicating technology. In addition, there will be a heat loss from the thermal storage.

4.4.3.4. Electric Boilers

Description
A boiler is a vessel or a closed reservoir where water or another fluid heats using an energy source, where the fluid is circulated in the building, where it gives off the heat to heat the room. Energy sources can be electricity resistances, gas or fuel; however in this study only electric boilers are considered. Electric boilers are similar to hot water electric storages for which the electric element is larger in order to be able to supply the heating needs of a dwelling. Normally, the main controlled variable is the boiler’s exiting water temperature, adjusting it to modulate the charge of the boiler.

Network connection
Connecting to the network will be done via a smart thermostat that will communicate the exiting water temperature, therefore controlling the boiler. If there is a smart thermostat, the network connection usually takes places over Wi-Fi (or other wireless technologies) or an Ethernet connection.

Additional components
A storage tank can be installed to allow energy curtailment. The boiler will run in off-peak periods and the stored water can be distributed in the dwelling. If the boiler already has an electronic thermostat that allows communication and external control, no extra pieces or hardware is required. Another way to enable communication is with an adaptor between the boiler and the energy manager / network, capable of sending and receiving signals.

[270] Réseau de transport électricite (2015): Valorisation socio économique des réseaux électriques intélligents. (French)
[271] These are costs at the manufacturing level including testing and documentation, but without mark up for the distribution and retail level. Note that a pre-condition for these estimates is that modifications concern larger product series thus represent a situation after redesign and optimisation in the context of a future smart grid market.

Appliance modifications
Software modifications must be done in order to allow an external signal from a grid operator to control the equipment.

If the boiler does not have a communicating electronic thermostat, there is also a need to change the hardware.

Demand response mechanism
Start and stop of the boiler can done with flexibility depending of the heat capacity of the building and on the size of a possible storage tank.

Cost impact
One source[272] reports that the total installation cost of a DR mechanism per home i.e. including the central energy manager and the connections to the boiler and the radiators is approximately between 35€ and 85€ (including extra material, technical intervention and internet or telecom installations). However, this intervention does not allow feedback from the demand side, it operates only in “slave mode” which means that the range could be an underestimation. On the other hand, not all the costs can be attributed only to the smart functionalities of the boilers and radiators.

For the purpose of this study, the study team has estimated the costs for the individual boiler at[273]:
- A networked boiler only needing software modifications, testing, documentation etc.: 5-10€
- A non-networked boiler also needing a network connectivity module etc.: 10-15€

Energy impact
Energy impact will be in the form of energy consumption of the communicating device, if the demand response will be done over a wireless system that requires extra communicating technology.

In addition, when the water in the storage tank is pre-heated there are additional thermal losses to be considered.

4.4.3.5. Heat pumps

Description
A heat pump is an electrical device that extracts heat from one place and transfers it to another, by circulating a refrigerant through a cycle of evaporation and condensation. The most common type of heat pump is the air-source heat pump, which transfers heat from the outside air and the dwelling . If you heat with electricity, a heat pump can reduce the amount of electricity you use for heating by as much as 30% to 40%.

[272] Réseau de transport électricite (2015): Valorisation socio économique des réseaux électriques intélligents. (French)
[273] These are costs at the manufacturing level including testing and documentation, but without mark up for the distribution and retail level. Note that a pre-condition for these estimates is that modifications concern larger product series thus represent a situation after redesign and optimisation in the context of a future smart grid market.

Other type of heat pumps include geothermal pumps and water-air heat pumps. Controlled variables of a heat pump system are: indoor temperature (set point) and speed of the compressor (modulating load).

Network connection
These equipments can be either controlled by their internal control or an external control. Communicating to external devices (i.e. smart grids) can be via cable or wireless connection such as Wi-Fi.

Additional components
No extra components needed to optimize the curtailment of heat pumps. Some heat pumps are used as well to supply hot water, and therefore there is a storage tank, which might be and extra part enabling more flexibility to the system as a whole (heating + domestic hot water).

Appliance modifications
Most heat pumps already have a thermostat that allows communication and external control so, no extra pieces or hardware is required. Only software adaptability must be done, in order to allow an external signal from a grid operator to control the equipment. According to some experts (heat pump manufacturer), several studies must be done to develop part load control via intelligent thermostats and improve heat pumps performance (nowadays, the main control is a communicative thermostat that sends on/off signals). Another way to enable communication is with an adaptor between the heat pump and the energy manager / network, capable of sending and receiving signals.

Demand response mechanism
The mechanism is very similar to the other heating technologies such as boilers. I.e. start and stop of the heat pump can done with flexibility depending of the heat capacity of the building and on the size of a possible storage tank.

In addition, the intelligent thermostat in order to avoid performance degradation, needs to be capable of not only sending on/off signals, but to work on part load (reducing the speed of the compressor by 20% i.e). This connectivity could be done through the smart thermostat or via an adaptor between the appliance and the external party.

Cost impact
One source[274] reports that) the total installation cost of a DR mechanism per home i.e. including the central energy manager and the connections to the radiators is approximately between 35€ and 85€ (including extra material, technical intervention and internet or telecom installations). However, this intervention does not allow feedback from the demand side, it operates only in “slave mode” which means that the range could be an underestimation. On the other hand, not all the costs can be attributed only to the smart functionalities of the appliance.

According to one manufacturer, enabling demand response to a heating device using a vapor-compression cycle would raise the retail price approximately 100€ to 200€ (software adaptability and development, installation costs, intervention etc.).

The 100-200€ range should be considered as the high end of the range of additional costs. These costs are assessed to include research & developement costs and costs associated with the first appliances being produced in small series in a short term perspective. The material costs in the 100-

[274] Réseau de transport électricite (2015): Valorisation socio économique des réseaux électriques intélligents. (French)

200€ range are estimated to apply to brand materials before complete redesign and optimization in the longer term. As an illustration, there are different types of adaptors in the market (connectivity via WLAN, Wireless, KNX Bus) that have the same function of establishing a communication pathway between the appliance and the third party control. Most air conditioners and heat pumps already have an integrated port capable of receiving signals (from the remote control for example), which in this case the only additional price should be the adaptor. Prices for the cheapest available adaptors and electronic thermostat are listed in the table below.

Table 2. Prices for additional components to enable demand side flexibility

Component	Function	Produced by / reference	Model	Unit retail price
Adaptor	RS485 Modbus	RealTime / Alibaba	RTD-RA	10 €
Electronic Thermostat	Receive external signals	Kampa / Alibaba	BC109	2 €

Energy impact

Energy impact will be in the form of energy consumption of the communicating device, if the demand response will be done over a wireless system that requires extra communicating technology.

In addition, if there is a storage tank and/or a need to pre-heat to a higher temperature than normal, there would be an additional heat loss.

4.4.3.6. Circulators

Description

Boiler circulating takes suction from a header that is connected to several downcomers from the bottom of the boiler drum and discharge through additional tube circuits. Boiler circulating pumps must develop only enough head to overcome the friction of the tube circuits. The controlled variable corresponds to the water temperature, that will indicate to stop or run the circulator pump. New, efficient models will include variable speed pumps in order to modulate the consumption according to the demanded heat.

Network connection

In new boilers, where the circulating pumps are controlled by the boiler's integrated system, the connection to the network follows the same logic as for radiators, boilers, heat pumps, which is via the electronic thermostat. This thermostat will regulate the boiler circulator according to the heat demand. The connection to the network will be via the electronic thermostat over the ethernet or wireless technologies (Wi-Fi, Zigbee, Bluetooth etc.). For already installed boilers whose circulators pumps are independent from the measured temperature, their control relies on the on/off of the pump. These pumps normally run all heating season.

Additional components

No additional components are needed to enable demand response to circulator pumps. The pumps will be turned on and off depending on the boiler's command.

Appliance modifications

To enable demand response in circulator pumps, they need to be connected to the boiler's control system, whch in all of the cases is done over an electronic thermostat. This thermostat, depending on the heating demand, will send a signal to the circulator pumps (on/off signal, or a variable speed drive pump).

Demand response mechanism
The mechanism is very similar to the other heating technologies such as boilers. I.e. start and stop or modulating the speed of the circulator can done with flexibility depending of the heat capacity of the building.

Cost impact
There is no available information regarding the costs of enabling demand response in circulators, but the cost impact is assumed to be similar to the other heating system components[275]:

- A networked circulator only needing software modifications, testing, documentation etc.: 5-10€
- A non-networked circulator also needing a network connectivity module etc.: 10-15€

Energy impact
Energy impact will be in the form of energy consumption of the communicating device, if the demand response will be done over a wireless system that requires extra communicating technology. Additional, there will be larger heat losses of the building if more heat is stored in the building components.

4.4.3.7. Residential air conditioners (< 12 kW)

The air conditioners consist of a thermodynamic refrigerating system to transfer heat from two different sources (indoor air and outdoor air). It is based on the same principle of a heat pump, with the condenser and evaporator having different roles to transfer heat in either direction. Air conditioners are used as a source of ventilation and dehumidification during summer periods. Mainly residential units are either split systems or centralized units. Controlled variables are indoor temperature via a thermostat and sometimes compressor speed.

Network connection
Most air conditioners have a control unit capable of receiving external signal from a centralized controller or a remote control. Connectivity can be easily incorporated, via Ethernet or wireless technologies (Wi-Fi, Zigbee, Bluetooth).

Additional components
No extra components needed to optimize the curtailment of air conditioners if a communicating thermostat already exists. Another way should be an adaptor between the air conditioner and the energy manager / network, capable of sending and receiving signals.

Appliance modifications
Most air conditioners already have a thermostat that allows communication and external control, no extra pieces or hardware is required if the thermostat can comunicate. In this case, only software adaptability must be done, in order to allow an external signal from a grid operator to control the equipment. Another possibility is to enable communication is with an adaptor between the air

[275] These are costs at the manufacturing level including testing and documentation, but without mark up for the distribution and retail level. Note that a pre-condition for these estimates is that modifications concern larger product series thus represent a situation after redesign and optimisation in the context of a future smart grid market.

conditioner and the energy manager / network, capable of sending and receiving signals (via WLAN, Zigbee, KNXBus, Wifi).

Demand response mechanism

Two different mechanisms are described in Air conditioning Australian AS 4755, on/off of the air conditioners and modulating the charge of the air conditioner (25%, 50%, and 75%). However, this intervention does not allow feed back from the demand side, it operates only in “slave mode”.

Cost impact

Two sources are studied: AS 4755 states that two different cost scenarios are possible. If the air conditioner already has an enabled DR interface, only 185$ are need to enable the DR program (contact the client, visit customer site and connect the air conditioner to the grid). In the air conditioner does not comply with a DR interface, the whole installation cost rises up to 300$. However, these costs include much more than the technology changes in the air conditioners and cannot be used for the purpose of the current study.

According to another manufacturer, enabling demand-response would rise the retail price of the air conditioner by 100€ to 200€ (software adaptability and development, installation costs, intervention etc.).

The 100-200€ range should be considered as the high end of the range of additional costs. These costs are assessed to include research & developement costs and costs associated with the first appliances being produced in small series in a short term perspective. The material costs in the 100-200€ range are estimated to apply to brand materials before complete redesign and optimization in the longer term. As an illustration, there are different types of adaptors in the market (connectivity via WLAN, Wireless, KNX Bus) that have the same function of establishing a communication pathway between the appliance and the third party control. Most air conditioners and heat pumps already have an integrated port capable of receiving signals (from the remote control for example), which in this case the only additional price should be the adaptor. Prices for the cheapest available adaptor and electronic thermostat are listed below:

Table 3. Prices for additional components to enable demand side flexibility

Component	Function	Produced by / reference	Model	Unit retail price
Adaptor	RS485 Modbus	RealTime / Alibaba	RTD-RA	10 €
Electronic Thermostat	Receive external signals	Kampa / Alibaba	BC109	2 €

Energy impact

Energy impact will be in the form of energy consumption of the communicating device, if the demand response will be done over a wireless system that requires extra communicating technology.

In addition, if there is a need to pre-cool to a lower temperature than normal, there would be an additional cool losses from the building.

4.4.3.8. Ventilation

Description

Ventilation includes energy using products whose main function is to renew the air of occupied buildings. In the residential sector, local and central extraction fans and local and central heat recovery ventilation units are used. Two different types of ventilation are used: simple mechanical ventilation, and double flow ventilation, being the main difference between these two the possibility to recover heat from the extracted air. Two types of controlled are used: hygrometric control and auto-regulated. The controlled variables are: internal air humidity.

Network connection, additional components and appliance modification

Given that most of the mechanical ventilation units do only have an on/off switch, the connectivity to the network must be done via a hardware installation. New circuits that can receive signal from the aggregator/utility and can turn on/off the ventilation, must be installed.

Demand response mechanisms

Mechanical ventilation units do not consume too much energy, compared to other HVAC equipments. The interest in enabling demand response on ventilation is to reduce the thermal gains (or losses) that would raise the heating/cooling needs.

Cost impact

There is no available information regarding cost impact, but it is assumed to be in the same size as the heating system components described in the previous sections

Energy impact

Energy impact will be in the form of energy consumption of the communicating device, if the demand response will be done over a wireless system that requires extra communicating technology.

4.4.3.9. Residential energy storage system

Description

The battery storage systems in scope of the study, are residential energy storage systems, which stores electric energy in batteries. Products on the market are currently mainly used to store excess electricity for house PV systems (photovoltaics). Many storage systems can also get their energy from small wind turbines, cogeneration units or directly from the grid. This new market did not find already a clear appliance identifier. The following terms are used, amongst others:

- storage battery for home use
- residential energy storage system
- solar-energy storage unit
- solar battery
- home battery

A separated market exists for storage units that are uniquely dedicated to back-up power. These are out of the scope, as determined in Task 3 report.

Residential energy storage systems consist of a diverse family of devices. Since it is a new category of appliances on the market, they are not well known currently for their possibilities. A difference with most appliances is that they cannot be installed everywhere in Europe without a national approval:

all electricity sources, have to be approved for each European country according to the rules of the local electricity grid operators.

Storage batteries for home use increase drastically the self-consumption of generated electricity by PV systems and other local sources. This can be interpreted as a demand side response, although strictly speaking demand response concerns the end-user, what storage is not, except its own consumption due to conversion and standby losses. The current systems can have more features than other types of smart appliances. Storage batteries with included control systems can furthermore be seen as smart appliances, because they can alleviate the distribution grid by peak-shaving the power to the grid without curtailing the electricity source like a PV installation or small wind turbine. Another feature and focus of the current study is that several storage system providers aggregate all their storage appliances to supply ancillary grid services, recently indicated as 'swarm power'.

Many home storage systems have implemented load management functionality to switch devices like washing machines and heat pumps in order to maximise the direct self-consumption of the residential electricity source, like a PV installation. This makes part of the energy management system that is built into the storage device.

Concerns

Several technical issues have to be noticed regarding capacity, efficiency, partial load use, standby losses and also their place in a dwelling.

The battery capacity is not necessarily the useful capacity. The latter depends on the allowed depth of discharge. A 10 kWh home battery that allows 80% discharge, results into a storage of 8 kWh effectively. It is the latter value that really counts.

The inverter, charger and battery have each an efficiency. The combined efficiency has to be taken to assess the energy loss. The manufacturers give values between 75 and 97 %. Values over 90 % seem unrealistic since batteries alone have roughly 90% efficiency (both for Li-ion and valve regulated lead-acid batteries (VRLA) according to representative test cycles in the battery laboratory of VITO. The charger and inverter efficiency have to be subtracted. Unfortunately, no public standard exists to determine the efficiency of a home battery. This lack makes the efficiency statements questionable. The chain efficiency for over 40 brands is given in an overview[276]. An average of 88±5% can be deduced.

The devices also have a stand-by consumption due to the controllers, power electronics and internet connection. Sources give a large spread in standby losses: from 5 to 80 W. The average is 30 ±20 W. This means that storage systems can have a high impact on a dwelling's energy consumption. This will be treated under 'energy impacts'.

Home batteries cannot be connected to the domestic at an arbitrary place. At least in Germany they should be connected to the distribution box in the dwelling[277].

[276] PV Magazine. Storage Special. Available < http://www.pv-magazine.com/fileadmin/PDFs/pv-magazine_Storage_Special_Jul_2015.pdf >. [Accessed 15.10.15]

[277] Forum Netztechnik/ Netzbetrieb im VDE. ‚FNN-Hinweis Anschluss und Betrieb von Speichern am Niederspannungsnetz', Berlin, Juni 2014,

Network connection
The residential energy storage system all seem to have at least one internet connection. This is used for the owners, so that they can follow up the operation and impact of the storage device on the electricity use.

Many systems are able to implement energy management to maximise the use of solar power or other renewable power by enabling load management. The load actions can be achieved by digital outputs on the inverter, by special AC connections on the inverter, by controllable wall plugs or with help of a communication protocol technologies and protocols between the smart appliances. The energy management system has to perform conversion of protocols and mappings into neutral data models.

The home batteries seem well equipped to act as a smart, communicating appliance.

Additional components
The need for additional components depends on the level of smartness that is anticipated. All home batteries can discharge towards the grid. If the storage should also be able to absorb excess electric energy from the grid, then an AC connection to the battery is needed. From Figure 1 this appears valid for 2/3 of the available systems. The ones that have a DC connection would need a software update to allow bi-directional operation of the inverter.

Appliance modifications
Storage batteries for home use have the possibility to go further in grid services than other smart appliances are able. Below an overview of the possible services can be found, apart from demand side management[278]:
Currently deployed practices:

- peak-shaving at generation side: less PV towards grid (mandatory for the German subsidy system).
- mandatory primary frequency support during exceptional deviations (> 50.2 Hz).
- real-time primary frequency support when activated anteriori by the aggregator.
- aggregated secondary frequency down-regulation support (charging the battery).

Future possibilities:

- peak shaving at consumption side: draw less power from grid;
- reactive power correction (cosine phi correction);
- balancing between the three electric phases: possible when using three separate single phase inverters;
- real-time voltage droop control.

Delivering the currently deployed and future services requires new control software to be integrated in the existing software of the dc-dc converters and inverters. The basic software to allow current injection in the grid and to maintain the voltage and frequency in island-grids is already available. However, some additional software will be required to implement the functions above which can be divided in three categories:

- Energy management software: This software is installed at the highest level within the residential energy system. The software determines the power set-point of the battery, with the purpose to e.g. maximize self-consumption, provide primary frequency reserve, etc. or a combination of

[278] F. Geth, e.a., „Multi-objective battery storage to improve PV integration in residential distribution grids," *IEEE Trans Sust Energy*, vol. 4, 2013.

these services. The energy management software can be a very basic system which only takes rudimentary PV predictions into account and only controls the PV module and the battery. However, the software can also consist of a much more elaborate system: to predict the PV generation, it can take into account local weather predictions, measured temperature etc. It can employ distributed measurements and self-learning algorithms to estimate the current consumption, the flexibility and near-term power requirements of the household. The software does not have to be limited to the PV and battery system, but can also control white goods, heat pumps and electric vehicle charging. As such, the energy management software does not have to be deployed within the PV-battery system. It can be an integral part of the PV-battery system, but it might as well be a separate system that controls not only the PV-battery system but also appliances such as white goods, heat pump etc. It is important to notice that the energy management software can also receive set-points from a third party, such as an aggregator to adjust the households power set-point.

- Grid interaction software: This software is implemented in the control of e.g. the inverter itself and thus resides at a lower level than the energy management software. Examples are real-time voltage and primary frequency droop control, where the measurements of the inverter are used to adjust the power set-point in support of the grid. Another example is the reactive power control where reactive power can be injected into the grid when the inverter notices grid voltage deviations. A third example is the redistribution of currents if the system uses 3 single-phase inverters, such that the current balance is restored. This software needs to be implemented on the inverter which connects PV and battery to the grid.
- Due to the nature of the software development process and the difference in the complexity (e.g. PV prediction, demand response management and self-learning consumption algorithms) and extensiveness (including PV modules, stationary battery, white goods, heat pumps, electric vehicles) of the developed software, it is not possible to put a price tag on the development and implementation of the software.

For these services additional precise measurement may be necessary, an improved controller strategy and probably the hardware that runs the algorithms.

Demand response mechanism

The main mechanism is the storage of the energy in batteries from where the energy can be drawn. In the case of PV systems, energy from PV can also be used to reduce the grid consumption.

All devices can act as smart appliance with a different degree of services:

- providing electricity to the grid or to the residence in case of generation shortage,
- absorbing PV or grid electricity in case of over-generation
- services such as reactive power support, primary frequency reserve, secondary frequency reserve for down-regulation, local voltage support.

Cost impact

The cost impact depends on the complexity of the implemented solution, see above. Little to no hardware modifications are required since many available systems do not need extra components and communication with aggregators is already available. Some software developments will be necessary to improve the performance of the system, possibly necessitating more accurate measurement equipment.

Energy impact

The energy impact is high since residential electric energy storage devices have a high capacity in comparison to other smart appliances. They can also be more dynamically used during the day than e.g. dish washers. Task 3 report deduces 5.5 TWh/y impact.

Notwithstanding the positive impact there is also a serious negative energy impact. This can be split into conversion losses and stand-by losses.

The conversion loss is around 10% (see the paragraph 'concerns' above for a more precise description of the losses). Assuming a 5 kWh storage system performing 250 cycles/y, the loss is 125 kWh/yr. In economic studies this loss has to be taken into account for the profitability of storage systems.

The stand-by loss of storage systems are on average high: 30 W, with outliers down to 5 W and up to 80 W. This means that most of the storage systems are serious consumers of electric energy. This is elucidated in Table 4 and compared with an average consumption of 3500 kWh/y. Storage is thus part of the high consumers in a house. This is quite unknown to the public and also ignored in most on the economic studies. From above calculation on conversion loss it appears that the stand-by loss is probably the highest of both.

Table 4: Impact on stand-by loss on yearly electric energy consumption

Standby loss (W)	5	30	80
Yearly consumption (kWh)	44	263	701
Contribution to average household of 3500 kWh/y (%)	1%	8%	20%

Important is to take notice that the introduction of storage devices outside Germany is hindered by the tariff structures. It has to be attractive to store PV energy locally. This will only be so if the feed-in tariff of PV energy is low and the buy-back price high. Also the cost contribution to the distribution grid operator has to be 'smart'. If a flat-rate annual cost is paid for his services in case a PV installation is present, then this is not encouraging to optimise the self-consumption of PV energy. A net metering structure is economically excluding the introduction of electric energy storage in dwellings.

4.4.3.10. Lighting

Description

Lighting includes lighting in residential and commercial indoor areas and public street lighting by use of different kind of light sources such as LFL (Linear fluorescent lamp), CFL (Compact fluorescent light), HID (High intensity discharge lamp) and LED (Light emitting diode). As described in previous task reports there are several lighting comfort constraints because light is used when there is a need for light and for most cases, reduction of light intentensity will result in a comfort loss.

This section will therefore only briefly assess lighting.

There are already systems on the market for remotely controlled lighting, both for the homes and for commercial indoor areas and for public street lighting. Recently, there have been introduced new systems for home use, where the light can be controlled via a smart phone, which gives a better opportunity for also regulation lighting through demand response. There are basically two systems on the market: One with the use of a control box that the smart phone communicates through and one with direct connection from the smart phone to the light bulb through Wi-Fi and Bluetooth.

Network connection

Network connection includes wired (mainly Ethernet) and wireless connections (Wi-FI, Bluetooth, Zigbee etc.). For demand response enabling the lighting bulbs and systems need to be connected to the central energy manager for receiving remote control signals.

For non-networked lighting devices and lighting systems, there is a need to build in a network connection.

Additional components
Lighting devices and light systems need electronics to be able to communicate with the central energy manager and to switch on/off and modulate the lighting output. As mentioned above, some systems comes with a control box for controlling the light bulbs.

Appliance modifications
The appliances need none or few modifications if they are able to communicate with the central energy manager.

Demand response mechanism
The demand response mechanism will be to reduce the light intensity or to swith off the light.

Cost impact
There is a substantial cost impact on remotely managed systems and especially in the home lighting area because the systems are quite new on the market.

Examples of lighting devices (not larger systems) include:

- Philips Hue LED Lamps starter set with 3 bulbs 10 W, Wi-Fi bridge etc.: 161 EUR (Amazon.de)
- OSRAM Lightify Starter Kit with wireless gateway and 1 LED Bulb dimmable 9.5W: 76 EUR (Amazon.de)
- ELINKUME Wi-Fi LED lamp (without bridge / gateway needed): 39 EUR (Amazon.de)

Energy impact
There is an additional energy consumption for the light bulbs and the related systems, mainly due to the networked components.

For products within the scope of Commission Regulation (EU) No 1194/2012 (directional lamps, light emitting diode lamps and related equipment) the requirement is that the no-load power of a lamp control gear intended for use between the mains and the switch for turning the lamp load on/off shall not exceed 1.0 W. From stage 3 (1 September 2016), the limit shall be 0.50 W. For lamp control gear with output power (P) over 250 W, the no-load power limits shall be multiplied by P/250 W.

4.4.3.11. Smart Meters

Smart Meters may be part of a DSF system. There is already roll-out of smart meters in many EU Member States (see Task 2 report) though typically mainly for other reasons. The impact on energy and costs is therefore not included in the analyses.

One example of energy and cost impact can be provided here based on the planned roll-out of about 1 million meters in the supply area of Dong Energy (Denmark), which will take place from 2017-2020. The selected smart meter is Kamstrup Omnipower, which has a ZigBee communication channel.

Own power consumption of the meter is maximum 0.2 W[279].

The total contract value of the change of the 1 million meters is about 240 million EUR resulting in a cost of 240 EUR per meter including the replacement[280].

4.5. END-OF-LIFE PHASE

The impact of the connectivity and DSF functionality on the end-of-life phase is assumed to be marginal of the same reasons described under the production phase and this is why the impact will not be further assessed.

[279] http://products.kamstrup.com/ajax/downloadFile.php?uid=5162b47e9a3ff&display=1
[280] https://ing.dk/artikel/kamstrup-skal-udskifte-1500-elmaalere-om-dagen-dong-175081

CHAPTER 5 DEFINITION OF BASE CASES

Following the MEErP Methodology for Energy related products, Task 5 should describe the environmental impact of the base-case product life cycle, the product life cycle impacts of new products entering the market and the annual impacts of the existing products. These impacts are expressed in base-case environmental impact data (usually by means of the Bill-of-Materials at the level of the EcoReport Unit Indicators, annual resources consumption and direct emissions during product life and at end-of-life) and the accompanying life cycle cost data on EU level.

Almost all individual products in the scope of this Lot 33 Preparatory Study are subject to vertical (product-specific) Ecodesign measures; however this Preparatory Study specifically addresses the implications underlying the connectivity and demand side flexibility (DSF) functionality aspect of these products. These environmental and economic implications need to be considered on two different levels. On the one hand, the DSF functionality will have implications on the level of the individual product and the network connections through which the product functions (see Task 4). On the other hand, the aggregated DSF that potentially can be provided by a whole group of smart appliances gives rise to environmental and economic impacts which go beyond the product level and can be found at the level of the entire energy system. If the study would be limited to the usual MEErP base-case environmental and economic impact data, these system impacts would be kept out of consideration.

Smart appliances can provide balancing services by shifting operation, thereby adapting the consumption to short term positive or negative discrepancies between forecasted and real generation by intermittent energy sources. Such activities may not reduce electricity consumption in total. However the optimised use of renewable energy reduces the need of conventional energy peaking generation units for the provision of balancing capacities. This therefore provides both monetary savings by less consumption of fuel as well as reduced CO_2 emissions[281], which in the framework of the Emission Trading System (ETS) not only has an environmental but also an economic value.

In Task 6 and 7 these benefits are evaluated, but before such an evaluation can be done, the approach needs to be defined how these impacts will be quantified and a reference needs to be set as a point of comparison. Therefore, the goal of Task 5 is to define the base cases which serve as a reference case for the evaluation of the future environmental and economic costs and benefits in case more flexibility of the energy demand is achieved under various scenarios. These base cases assume a situation in which no flexibility is available from smart appliances. This means that for the reference scenario we make abstraction of the limited ongoing Demand response (DR) practices in the scope of this Lot 33 Preparatory Study (residential and commercial segments as defined in Task 1) and which are described in Task 2.

In order to quantify the economic and environmental benefits of smart appliances from an energy system perspective, the following key performance indicators (KPIs) are considered relevant:

1. KPI1: Economic value in terms of total energy system costs. This KPI quantifies the avoided costs related to the more efficient use of the energy system following the achieved flexibility.

[281] In this project, CO_2 emission is considered, and not CO_2-equivalent emission.

2. KPI2: Total amount of CO_2 emissions over the considered period. This KPI quantifies part of the environmental benefits of decreased utilization of the less efficient and more CO_2 emitting peaking power plants in the system.
3. KPI3: Energy efficiency of the utilized generation mix over the considered period. For the purposes of this report, the efficiency is defined as the quotient of the output energy (produced electrical energy) and the input energy (the total primary energy) used to fire the different types of power plants. This KPI more specifically reflects the increased share of Renewable Energy Sources (RES) integrated in the generation mix, and decrease in utilization of low efficient, often peaking, generating units. Energy efficiency of the utilized generation mix as defined here is related to the primary energy savings in the electricity production. It is not related to e.g. decrease in total consumption due to more efficient energy utilization.

A generic optimisation model, based on [1], is developed for the purpose of this study to assess the value of flexibility from the smart appliances by means of these KPIs. To quantify the KPIs, the model is run over a time horizon of one year for each of the three chosen benchmark years: 2014, 2020, and 2030. Specifically for the use cases defined in Task 2 (day-ahead use case and imbalance use case), the results of the KPIs will be compared for a situation without flexibility provided by smart appliances (Task 5) and a situation in which a part of these appliances (ones with medium and high potential as identified in Task 3 and for which data are available from Task 2) become smart, thus providing flexibility to the energy system (Task 6 and 7).

Note that apart from the benefits related to the use of flexibility from an energy system perspective, other benefits and costs are relevant from an end-user perspective (e.g. potential higher price of products and/or remuneration for available flexibility, potential impact on energy consumption of products) and from an industry perspective (e.g. costs related to redesign of products, new business opportunities). These impacts have been described in previous reports (mainly Task 4) and as they relate to impacts in a situation with flexibility, will be summarised and discussed in Task 6 and 7.

5.1. ASSESSMENT MODEL DESCRIPTION

5.1.1. DEFINITION OF THE MODEL FOR THE DAY-AHEAD USE CASE

A generic optimisation model is developed based on [1] for the purposes of this study to assess the value of flexibility from the smart appliances. This section explains the model in more detail.

The developed model is an extension of the unit commitment (UC) model described in [1]. The model is utilized to determine the optimal schedule and costs of a given set of power plants over the considered time period , for the specified input data, as presented in Figure 60. Optimality is defined in terms of minimizing the total costs over the considered time period.

The total costs are defined as the sum of fuels costs, variable operational and maintenance costs, ramping costs, start-up and shut-down costs for generator units, CO_2 emission costs, variable RES (VRES) curtailment costs, and costs of loss of load.
The model takes into account the technical constraints of each type of generation technology, transmission system constraints, and also the energy balance constraints.

The modelled technical constraints of generation units include maximal ramp up rate, ramp down rate, maximal power output, minimal power output, minimal down time, minimal up time, CO_2 emissions per produced MWh, etc.

Due to the technical constraints of generation technologies, such as minimum time down or up, unit commitment models belong to the class of mixed integer linear programs (MILP). For solving this type of problems, there is efficient commercially available software. In this study, IBM ILOG CPLEX Optimization Studio solver was utilized to solve the optimization problem.

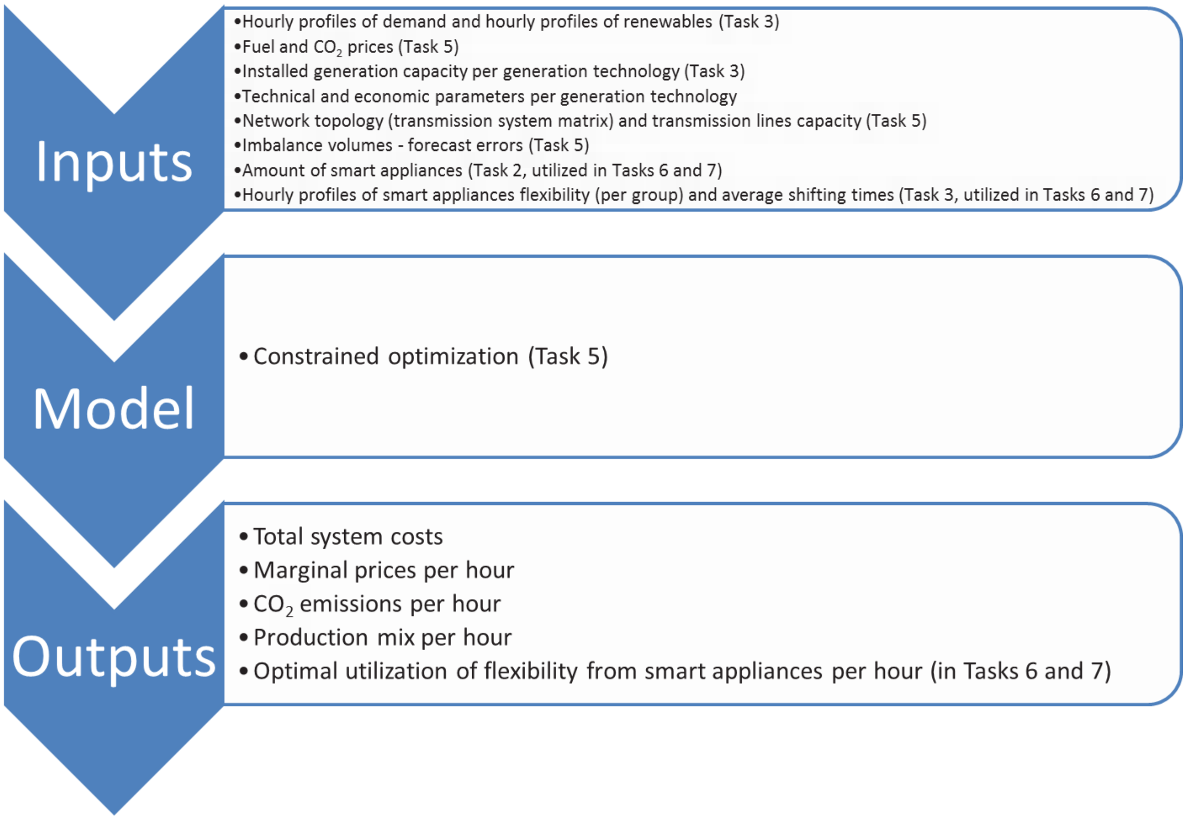

Figure 60 Overview of inputs and outputs of the utilized model.

The transmission system network within EU28 area is modelled by means of the net transfer capacity (NTC) matrix[282]. The NTC values represent an estimation of the transmission capacities of the joint interconnections on a border between two neighbouring countries. The exchange of energy between two neighbouring countries cannot be larger than the NTC specified value.

The number of existing power plants in EU28 mounts up to several hundreds. It is computationally demanding to solve MILP problems for a large number of variables and constraints, i.e., for a large number of power plants (generation units). Therefore, to reduce the modelling and computational effort, there is one representative generation unit modelled per generation type per Member State. The generation unit has maximal capacity equivalent to the aggregated capacity of this technology type of the considered EU28 Member State. According to [9], this results in a negligible error in the computed utilized power generation mix, total system costs, and CO_2 emissions. The value of parameters defining the technical constraints is chosen so that an average (typical) unit for the given technology is represented in the model. These parameters are taken from literature, see [2].

[282] www.entsoe.eu/publications/market-reports/ntc-values/ntc-matrix/Pages/default.aspx

The geographical scope of the model is limited by the EU28 Member States, i.e., the power system of the EU28 is modelled[283]. The resolution of the model is one hour.

The model utilizes as input the hourly data of the total demand per EU28 Member State, and profiles of renewable energy sources (wind and solar power production) per EU28 Member State. Next to this, in the imbalance use case, it is necessary to feed the hourly imbalance volumes, i.e., forecast errors in the model.
Next to the input described above, to run the model, it is necessary to define the fuel and CO_2 price, installed generation capacity per generation technology per EU28 Member State, network topology and transmission lines capacity of the EU28 interconnected power system, and technical and economic parameters per generation technology.

The model is optimized, and as a result, relevant indicators are obtained for assessment of benefits of smart appliances flexibility, such as: the total system costs, marginal electricity prices per hour, CO_2 emissions per hour, and utilized production mix to serve demand (per hour). In TTask 6, where the model is extended to include the flexibility from smart appliances, the optimal utilization of flexibility from smart appliances per hour is also one of the outcomes of the optimization (only in Task 6).

The EU targets on integrated energy markets and the expansion of international grid control cooperation (IGCC) mechanism implementation (see section 2.3.1 of Task 2 report), indicate that the European electricity network is developing towards a more integrated market. TaskAs a result, the energy system of EU28 is modelled as one integrated market where energy is freely imported and exported to neighbouring countries, still considering the physical limitations of the transmission network system.

The model can represent the European electricity system in the benchmark years 2014, 2020 or 2030 by adapting the input data to reflect realistic circumstances in the future.

For the purposes of this study, the considered period for optimization is defined to be a period of 1 year (8760 hours). The utilized temporal resolution is 1 hour, which is also in line with the electricity market resolution.

The identified use cases from Task 2 are the day-ahead use case and imbalance use case. For the imbalance use case, the hourly forecast errors, which are the main imbalance driver, have to be modelled. We describe the developed approach in the following section.

5.1.2. EXTENSION OF THE MODEL FOR THE IMBALANCE USE CASE

5.1.2.1. Modelling the imbalance volumes

Imbalances in power systems are defined as the real-time differences in instantaneous power production and consumption. Imbalances are caused by the forecast errors of hourly demand profiles and intermittent RES production (VRES production); see also section 2.3.1 in the report of Task 2 of this study for a more detailed discussion on the cause of imbalances in power systems. These forecast errors are the main driver for the imbalance and, hence, they correspond to the imbalance volumes.

[283] The scope of the model is EU28, however in phase 2 of the study it will be extended with EEA countries and Switzerland for the sake of completeness.

To assess the value of smart appliances in the use case related to the imbalance settlement, the imbalance volumes, i.e. the hourly forecast errors for demand, wind and solar power production are needed. It was shown in literature, [4], that the forecast errors of VRES power profiles follow the Gaussian probability distribution. In [5], it was shown on the basis of historical data that day-ahead load forecast errors nearly follow the Gaussian normal distribution as well. Alternatively, these errors could be modelled by hyperbolic distribution. Moreover, in the same paper, it was shown that “the shape of day-ahead wind power forecasting errors is similar to those of day-ahead load forecasts”. Therefore, all the forecast errors are modelled as realizations of a Gaussian process.

To generate the imbalance volumes as a Gaussian process, mean and standard deviation values are needed. From historical data for Belgium, obtained from webpages of the Belgian TSO[284], firstly normalized forecast error profiles were obtained. The normalized generation forecast errors are forecast errors divided by the monitored active wind or solar capacity at the corresponding time instances. The hourly load forecast errors are normalized by the observed peak load in the considered year. The mean and standard deviation values for Belgium for a period of one year are reported in section 5.2.6.
From the devised mean and standard deviation values, and installed VRES capacity and peak load for each EU28 Member State, hourly forecast errors are generated. The utilized values are reported in section 5.2.4. The forecast errors are generated for solar production, wind production, and load curve, for each of the three considered reference years, and for each EU28 Member State, respectively. Finally on a yearly basis, the generated load, wind and solar forecast errors are summed for each of the EU28 Member States to obtain a single imbalance volume hourly profile per EU28 state. Data utilized to generate imbalance volumes are further discussed in section 5.2.6.

5.1.2.2. Computation of the balancing costs in the imbalance use case

The imbalance costs are computed as multiplication of the difference in hourly prices between the hourly prices obtained in the day-ahead market use case and in the imbalance use case by the generated hourly imbalance volumes.

5.2. ASSESSMENT DATA

5.2.1. TRANSMISSION NETWORK

The transmission network within EU28 area is modelled by means of the NTC matrix. NTC values can be adapted seasonally, and are in general computed ex-ante at several important moments before real-time: year-ahead, month-ahead, and day-ahead. We utilized month-ahead data wherever possible, and where not possible, year-ahead computed NTC values were utilized. All the data can be downloaded from the ENTSO-E transparency portal[285], under the tab “Transmission”. High voltage DC (HVDC) interconnector capacity was also taken into account.
For 2020 and 2030, the network capacity was extended according to expectations presented in the ENTSO-E Ten-Year Network Development Plan (TYNDP) from 2014[286].

[284] ELIA, http://www.elia.be/ or http://www.elia.be/en/grid-data/data-download
[285] ENTSO-E transparency portal is at transparency.entsoe.eu
[286] All the documents related to the ENTSO-E Ten-Year Network Development Plan can be found here https://www.entsoe.eu/major-projects/ten-year-network-development-plan/tyndp-2014/Pages/default.aspx

5.2.2. FUEL AND CO_2 COSTS

The fuel cost for the different technologies will largely determine which power plant will run and at which price. The fuel prices used in this study were presented in Task 3, and are repeated here in Table 36 for convenience. Moreover, in , the assumed CO_2 prices per reference year are summarized. Fuel costs for nuclear power plants are taken from IEA, NEA & OECD: Projected Costs of Generating Electricity, 2015 Edition, [8][287], where the fuel costs are given under the following assumption “For nuclear power plants, fuel cycle costs include front-end costs as for all other generating technologies, but also back-end costs associated with waste management”, see also [7] [288], 2010 edition of the report. Therefore, as the front-end and back-end costs are taken into account in the fuels price, it is necessary to set the power plant efficiency to 100% instead of normally utilized 32-34%, see [2].

In [8], nuclear fuel costs are disclosed for a few European countries, in particular, for Finland, France, Hungary, Belgium, Great Britain, and Slovakia. These costs vary from 5.09$/MWh in Finland, to 9.33 in France to 9.6 in Hungary to 10.46 in Belgium to 11.31 in Great Britain to 12.43 in Slovakia. As the model works with a unique fuel price, we took an average of these prices, which is 9.7$/MWh. This price is converted to euro by assuming that 1$_{2014}$ = 0.72 €$_{2014}$. Under this assumption, the fuel price for nuclear power plants is computed to be 6.98€$_{2014}$.

The same value is assumed for 2020 and 2030 nuclear fuel prices as to the best of our knowledge, there was no good reference to forecast future nuclear fuel price. This is supported by a very slight change in the price in the period from 2010 [7] to 2015 [8], of less than 5% (own calculation), which is comparable to the inflation rate.

Table 36 Fuel prices per fuel type and reference year

Fuel	2014	2020	2030
Nuclear [€/MWh$_{prim}$]	6,98	6,98	6,98
Coal [€/MWh$_{prim}$]	9,20	11,93	11,97
Natural gas [€/MWh$_{prim}$]	18,75	31,66	32,71
Wood pellets [€/MWh$_{prim}$]	5,06	4,84	4,84[289]
Oil [€/MWh$_{prim}$]	48,48	53,54	57,42

Table 37 CO_2 prices per reference year

CO_2 price	2014	2020	2030
CO_2 [€/t$_{CO2}$][290]	5,96	9,07	48,00

[287] See page 49 of the reference.
[288] See Table 3.7 a of the reference.
[289] http://pellets-wood.com/wood-pellets-b327.html and http://www.foex.fi/index.php?page=pix-rcp

[290] http://www.changepartnership.org/wp-content/uploads/2014/10/Point-Carbon-2014-11042014-MSR-Point-Carbon.pdf
http://carbon-pulse.com/higher-co2-price-would-help-eu-utilities-but-it-remains-a-pipe-dream-moodys/
http://www.changepartnership.org/wp-content/uploads/2014/10/Point-Carbon-2014-11042014-MSR-Point-Carbon.pdf

The fuel and CO_2 prices in the model (prices of oil, gas, coal) for 2020 and 2030 are based on the growth assumptions as defined in the World Energy Outlook 2013. Prices for 2014 are based on current market prices. All the prices are presented in Table 36 and Table 2 . For CO_2, for the period 2014 and 2020, the forward prices for EUA as published by ICE Endex on 16/10/2015 are used. The current forward value for 2020 is in line with a recent report from Platts (June 2014) and Moody's (July 2015) that also estimates CO_2-prices between 5 and 10€/ton. The value for 2030 is an estimate based on scenarios developed by Thomson Reuters (2014). The values for CO_2 are supported by the recent reference scenario of the EU (PRIMES[291]) where it is mentioned that CO2 prices will only slightly increase till 2025, followed by a steep increase after 2025[292]. For biomass, the fuel cost is based on the estimated costs for wood pellets (today most common source of biomass[293]). In addition, the average subsidy of biomass is subtracted from the price of wood pellets in order to calculate the marginal cost for biomass. The average value for biomass is based on the average subsidy for biomass in 2012[294]. To note that currently, debates are ongoing with respect to the sustainability criteria of certain types of biomass. In the course of 2017 a new Renewable Energy Directive for the period beyond 2020 is expected, setting out amongst others a bioenergy sustainability policy[295]. This might result in a shift of subsidies from one type of biomass to another type of biomass, dependent on the outcome of the sustainability assessment. Independent of which biomass technology will be subsidized, according to studies[296][297], it is clear that also after 2020 biomass will play an important role in the European energy mix.

From Table 36 and , it can be noted that the forecasted prices are expected to remain relatively stable (show minor changes) between 2014 and 2020. In 2030, the expectations are that mainly the price of CO_2 will have risen significantly, which will have an impact on the profitability of thermal plants and hence the system costs. It is expected that the price for biomass will remain constant, although it is possible, see remark above, that based on new sustainability criteria, different types of biomass will be subsidized. Nevertheless, the assumption is made that subsidies would be adapted in order to reach the same level of competitiveness as today.

[291] More information on the PRIMES model is listed on the website of E3Lab of the National Technical University of Athens - http://www.e3mlab.ntua.gr/e3mlab/index.php?option=com_content&view=category&id=35:primes&Itemid=80&layout=default&lang=en

[292] https://ec.europa.eu/energy/sites/ener/files/documents/REF2016_report_FINAL-web.pdf

[293] http://www.europarl.europa.eu/RegData/etudes/BRIE/2015/568329/EPRS_BRI(2015)568329_EN.pdf

[294] https://ec.europa.eu/energy/sites/ener/files/documents/ECOFYS%202014%20Subsidies%20and%20costs%20of%20EU%20energy_11_Nov.pdf

[295] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52015DC0080

[296] http://ec.europa.eu/agriculture/bioenergy/potential/index_en.htm;

[297] http://www.eurelectric.org/media/26720/resap_biomass_2020_8-11-11_prefinal-2011-113-0004-01-e.pdf

5.2.3. Load shedding and VRES curtailment costs

Next to the fuel costs, there are possible additional costs related to the load shedding and VRES curtailment. The load shedding costs are defined as the multiplication of the total shed load by the value of the lost load.
It is very complex to determine the value of lost load, and there are numerous studies with extensive discussion on the topic, [3], [10]. The value is highly dependent on, among other factors, the type of lost load, duration of supply interruption, advance notice, and time of the day of the supply interruption. For the purposes of this study, the price for lost load is chosen to be 20,000 €/MWh, which corresponds to the estimated value of lost load for Austria[298] for combined residential and non-residential load for the duration of 1 hour in summer at 10 am, see Figure 19 on page 31 of [10][299].
In the model, VRES curtailment is allowed, however VRES curtailment is not free. There are also costs related to the curtailment of VRES. These costs are set to be 2,900 €/MWh, so that they are lower compared to the load shedding costs.

5.2.4. Demand profiles and installed capacity

Both, demand and installed production capacity are based on real 2014 data as published by ENTSO-E. For the 2020 and 2030 scenarios, the PRIMES-model reference scenario[300] [15] results for installed capacity per EU28 Member State, and price scenarios of the International Energy Agency (IEA) are utilized[301].

Demand hourly profiles are downloaded from the ENTSO-E[302]. So, published data of 2014 for EU 28 are utilized. No demand profile for Malta was found, so for Malta, a scaled demand profile from Cyprus was utilized.

Demand hourly profiles are corrected for import and export with countries not belonging to the EU28 interconnected power system. Lastly, in order to determine the load in 2020 and 2030, a yearly demand growth factor is applied. The demand growth is assumed to be the same as assumed in the PRIMES scenario: 0.5% per year until 2020, and 1% per year after 2020.

[298] Austria is chosen in [10] as a representative European country.
[299] The value reported in the reference is 21,988 $\$_{2012}$/MWh
[300] Data can be found in Appendix of the report published at http://www.e3mlab.ntua.gr/e3mlab/reports/trends_to_2050_update_2013.pdf
[301] http://ec.europa.eu/transport/media/publications/doc/trends-to-2050-update-2013.pdf.

[302] https://www.entsoe.eu/data/data-portal/Pages/default.aspx

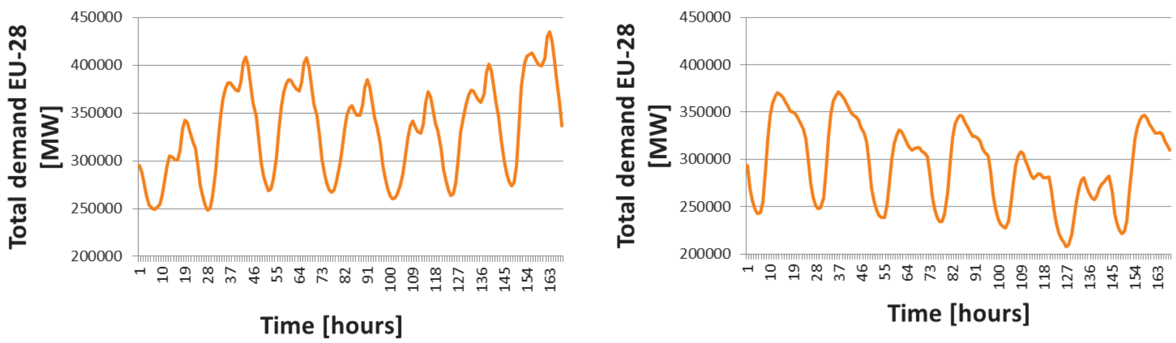

Figure 61 Total EU28 demand hourly data for an arbitrarily selected week in winter (left-hand side) and for an arbitrarily selected week in summer (right-hand side) in 2014. Data source: ENTSO-E transparency database (transparency.entsoe.eu)

Figure 61 shows a total EU28 demand hourly data for an arbitrarily selected week in winter and for arbitrarily selected week in summer in 2014. Significant variations in the total demand, and also in the shape of demand curves, are observable.

The installed capacity of production units per country is based on the installed capacity of 2014 as published by the statistical database of ENTSO-E. For 2020 and 2030, the production mix per country is based on the PRIMES scenarios. The PRIMES model simulates the European energy system and markets on a country-by-country basis and across Europe for the entire energy system. The model produces projections over the period from 2015 to 2050 in 5-years intervals. The installed capacity mix is obtained by the PRIMES model under the assumption of electricity demand growth rate of 0.5% per year up to 2020; and almost 1% per year thereafter.

Utilized values for the installed wind capacity, solar capacity and peak load are summarized in

Table 34. Installed capacities of other EU28 Member States are not presented here.

From the utilized generation data, a large increase in renewable energy sources capacity can be observed. This growth of VRES capacity is shown for wind and solar installed capacity in Figure 62. The wind installed capacity is expected to almost triple and solar installed capacity to double. This increase in VRES capacity will increase the system's need for flexibility in both identified use cases.

According to the PRIMES projections (reference scenario), the capacity of power plants that is equipped with the carbon capture and storage (CCS) technology is and will remain negligible. Therefore, there is no generation unit equipped with CCS technology in the model. In other words, no CO_2 emitted as a consequence of electricity production is captured and stored for further processing.

Hydro generators are assumed to be dispatchable. This is justified by the fact that hydro generation is partially dispatchable. This assumption is necessary due to a lack of existence of measured historical hourly profiles for hydro power generation. The yearly availability factor is adapted such that a realistic power output (and load factor) from hydro power plants is obtained, and is set to approximately 0.4.

Table 38 Installed VRES capacity and peak load per EU28 country per year (Source: ENTSO-E database for 2014 for all the countries besides Malta, PRIMES EU reference scenario outcomes for 2020 and 2030, and for Malta for 2014, and for peak load in Malta Enemalta[303])

[303]Enemalta:http://www.transport.gov.mt/admin/uploads/media-library/files/DAirMaltaStudyVisit_The%20Energy%20Sector%20in%20Malta.pdf

	Installed solar capacity [MW]			Installed wind capacity [MW]			Peak load [MW]		
	2014	**2020**	**2030**	**2014**	**2020**	**2030**	**2014**	**2020**	**2030**
AT	400	787	1466	1529	3114	6051	12355	12731	14928
BE	1840	2429	4813	1966	4772	7068	13110	13508	15839
BG	1060	1116	1534	850	923	1515	8638	8901	10437
CY	79	194	658	145	249	329	871	897	1052
CZ	2011	2011	2068	277	307	387	10058	10364	12152
DE	35357	49089	53584	35600	48956	69949	81031	83493	97902
DK	282	360	762	4489	5960	7420	6163	6351	7446
EE	0	0	0	354	495	1056	1786	1840	2157
ES	7667	12655	16945	25028	25213	35707	39394	40590	47595
FI	7	50	60	411	1538	2556	13945	14369	16848
FR	4630	7470	13913	10238	25687	47354	84280	86840	101827
GB	1574	5985	8853	12140	38627	50721	50997	52546	61615
GR	3052	3286	3640	2195	3433	3745	8448	8705	10207
HR	16	27	182	394	640	713	3012	3103	3639
HU	3	93	712	413	903	1236	5712	5885	6901
IE	0	0	674	2088	3561	5992	4572	4711	5524
IT	16204	19553	28206	7371	11200	22598	49523	51028	59834
LT	0	0	0	221	222	251	1408	1450	1701
LU	78	226	409	78	226	290	878	905	1061
LV	1	1	1	155	428	681	1172	1207	1416
MT	8	48	211	1	86	191	290	299	351
NL	131	788	1037	4619	9624	12359	17850	18392	21566
PL	6	51	530	2472	6515	8843	23593	24309	28505
PT	1051	2212	5613	5398	5689	8324	8295	8547	10022
RO	214	679	1860	1566	1572	4043	8738	9004	10558
SE	13	182	248	3646	4447	5107	24295	25033	29354
SI	85	130	444	8	225	453	2074	2137	2506
SK	539	787	1009	48	113	455	4523	4661	5465

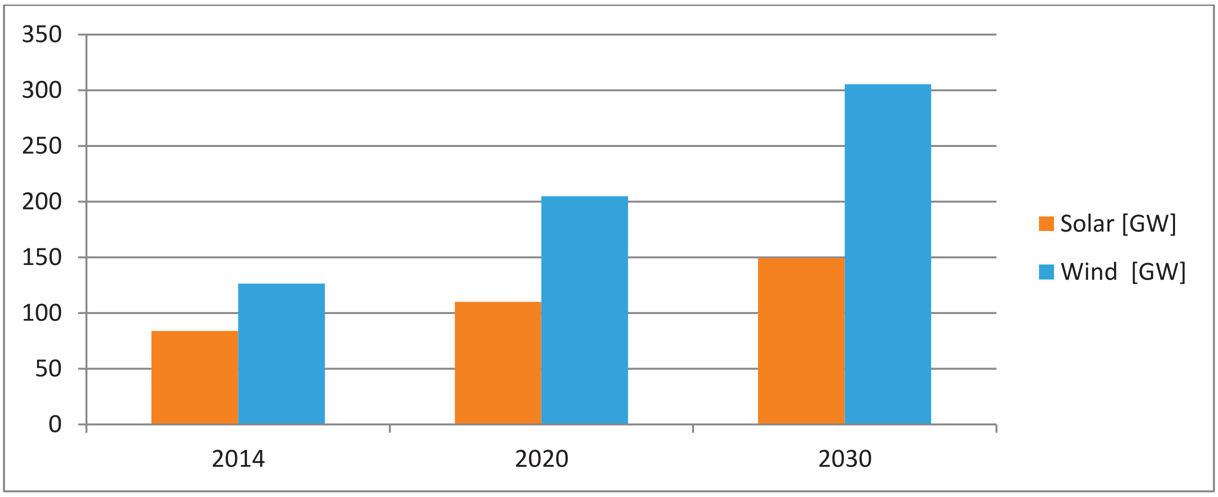

Figure 62 Installed VRES capacity in [GW] for the whole EU28 area in the reference years. Source: ENTSO-E database for 2014 for all the countries besides Malta, PRIMES scenario outcomes for 2020 and 2030, and for Malta for 2014, and for peak load in Malta Enemalta

5.2.5. WIND AND SOLAR HOURLY PROFILES

Hourly profiles of wind and solar power production are obtained from the TSO webpages of EU28 countries.

The TSOs of the following countries have publicly available wind hourly time series for 2014: Austria, Belgium, Czech Republic, Denmark, Estonia, Latvia, Lithuania, France, Germany, Ireland, Romania, and the United Kingdom. Hourly wind profiles for Finland, Spain were available only for 2013, and not 2014, so these profiles were utilized. For Italy, data from August 2013 until August 2014 was utilized.
For other countries, the hourly time series were estimated from the published profiles by rescaling the realised profiles of a comparable country, based on the difference in realised monthly production:

- Hourly wind profiles of Portugal were estimated from the Spanish profile;
- Cyprus and Greece were estimated from the Italian profile;
- Hourly wind profiles of Luxembourg and the Netherlands were estimated from the Belgian profile;
- Hourly wind profiles of Hungary were estimated from the German profile;
- Hourly wind profiles of Sweden were estimated from the Danish profile;
- Hourly wind profiles of Poland and Bulgaria were estimated from the Czech profile.

Slovenia, Slovakia and Malta have negligible installed wind capacities for 2014, and hence their hourly profiles are set to 0.

The TSOs of the following countries have publicly available solar photovoltaic hourly time series for 2014: Belgium, Czech Republic, France, Germany, Denmark, and Romania. For Spain hourly profiles for PV produced power hourly are available for 2013.
For other countries, the hourly time series were estimated from the published profiles (according to the same methodology as for the wind profiles):

- Hourly solar profiles of Portugal, Greece and Italy were estimated from the Spanish profile;
- Hourly solar profiles of Slovakia, Slovenia and Bulgaria were estimated from the Czech profile;

- Hourly solar profiles of Luxembourg and the Netherlands were estimated from the Belgian profile.

Other EU28 countries have negligible amounts of installed PV capacities, and therefore their hourly profiles are set to 0.
An example of hourly intermittent RES (VRES) time series for the whole EU28 area is shown in Figure 63. On the left side, an arbitrarily selected winter week is shown, and on the right side, an arbitrarily selected summer week. Large differences in volatility and amplitude of produced power are obvious.

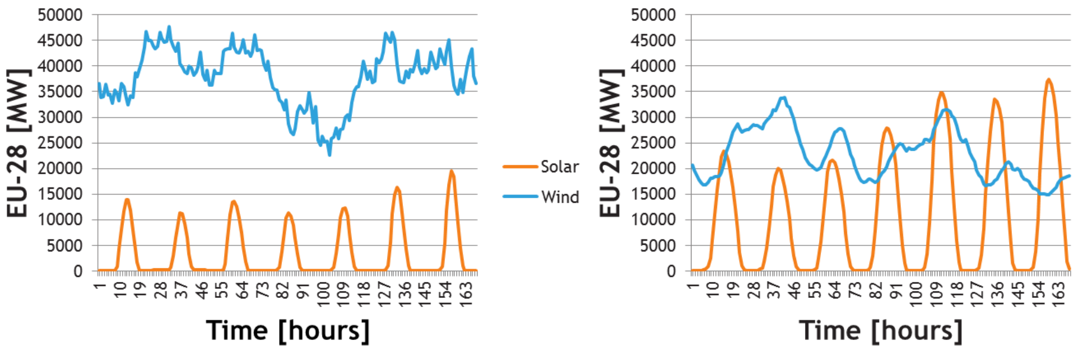

Figure 63 Intermittent RES hourly profiles for an arbitrarily selected week in winter (right-hand side), and for an arbitrarily selected week in summer (left-hand side).

For reference years 2020 and 2030, the hourly profiles are obtained by scaling the profiles of 2014. The increase in the VRES power production is assumed to be proportional to the increase of the installed capacity. In such a way, the same load factor is obtained for each VRES technology nowadays and in the future. For countries for which no realized profiles were published for 2014, the same methodology is used as for the construction of the 2014 profiles, i.e., by estimation from available profiles of nearby countries. .

5.2.6. FORECAST ERROR HOURLY PROFILES

The statistical properties of the hourly load, wind and solar forecast errors are necessary for indication of net imbalance volumes. From historical data for Belgium, from webpages of Belgian TSO[304], the normalized forecast error profiles are obtained. The mean and standard deviation of these profiles are computed, and presented in Table 39. On the basis of the computed standard deviation and mean value, the forecast errors, which are equivalent to the net imbalance size, are computed as explained above in Section 5.1.2.

Figure 64 compares the realized and forecasted wind production of two days in 2014 in the overall EU28 area. The difference of the two forms a part of the total forecast error, and hence, the imbalance volume.

Table 39 Statistical data for normalized forecast errors on basis of historical data for Belgium in 2014 (Source: Elia.be)

[304] ELIA, http://www.elia.be/ or http://www.elia.be/en/grid-data/data-download

	Mean [MW]	Standard deviation	Normalization factor
Hourly load forecast error	0,5615	0,6522	10353
Hourly wind forecast error	-0,0054	0,0775	[931, 1835]
Hourly solar forecast error	0,0059	0,0549	[2211, 2502]

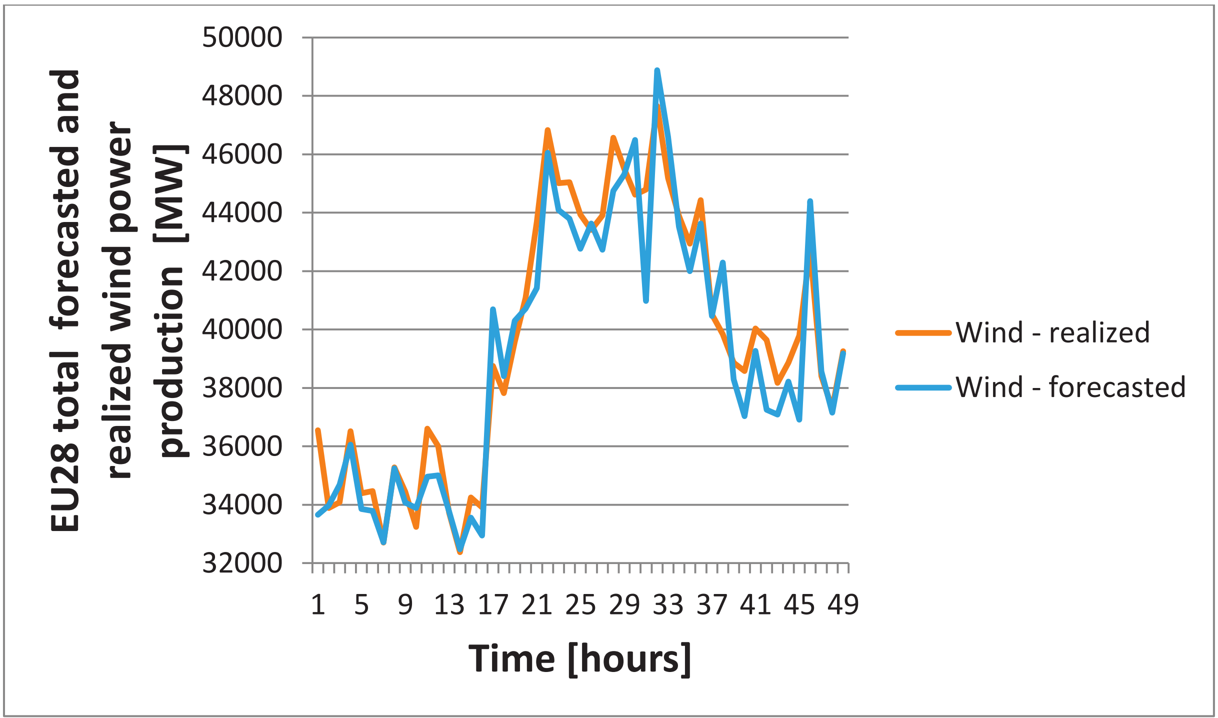

Figure 64 Comparison of the realized and forecasted wind production over two days in 2014 in the overall EU28 area. The difference of the two forms a part of total forecast error, which is equivalent to the imbalance volume.

5.2.7. The technical parameters

Parameters for each technology (start-up time, minimum load, etc.) are based on the report of DIW (Prospective Costs of Electricity Generation until 2050 (2013) [2], in particular, see Tables 25-27, 29, 31, 33-35 in the reference. Parameter values that were not reported in this reference were taken from other literature. Namely, start-up costs of hydro units are taken from [11], ramp up/down rate of hydro and biomass units are taken from [12]. Variable operational and maintenance costs for hydro units are taken from [13], and for biomass units are taken from [14]. For biomass fired generation units, the values for minimum up time, minimum down time, start-up costs, and ramping costs were not found in literature, and are assumed to be the same as for gas units.

5.3. Summary of assumptions

In summary, the assumptions made are listed as follows:

1. All the input data for benchmark year 2014 are based on 2014 realized data.
2. The influence of the transmission system within EU28 is modelled by means of the net transfer capacity (NTC) matrix. Transmission constraints within EU28 Member States are not considered.

3. The generation units are clustered per generation type, e.g., nuclear, hydro, coal fired power plants, etc. For each generation type, there is one cluster. There is one equivalent unit for each generation type for each EU28 country.
4. Hydro generators are assumed to be dispatchable, with the accordingly adapted yearly availability factor, which is set to approximately 0.4.
5. Undispatchable renewable generation, such as wind and solar power production, is represented in the model by the hourly generation profiles. Load factors of wind and solar power production are assumed to remain the same in 2020 and 2030 as it was in 2014.
6. The marginal price of wind power and solar power is chosen to be 0. The efficiency of these units is set to 100%, as there is no input fuel directly utilized for these types of generation technologies.
7. Fuel prices are based on the realised fuel prices in 2014 and the assumptions for 2020 and 2030 as published by the World Energy Outlook 2013. For biomass, it is assumed that the price level will be the same, although different types of biomass might be subsidized.
8. For future scenarios, growth of demand is assumed to be 0.5% per year up to 2020; and 1% per year thereafter. Generation installed capacity and mix is assumed to grow as predicted by PRIMES scenarios, as specified earlier in Task 2.
9. Forecast errors are assumed to be normally distributed, and proportional to peak load, and installed intermittent RES capacity (installed wind and solar capacity).
10. In the lack of better references, forecast quality is assumed not to improve in the future, i.e., statistical properties of demand, load and wind forecast errors will remain the same in 2020 and 2030 as they are in 2015.
11. No generation unit is equipped with the carbon capture and storage (CCS) technology. No CO_2 emitted as a consequence of electricity production is captured and stored.

5.4. Definition and computation of KPIs

5.4.1. Definition of KPIs

The relevance of smart appliances is expressed in economical and environmental terms, and is measured by the three defined key performance indicators (KPIs). For each use case, three KPIs are defined to assess the impact of flexibility from smart appliances. These are:

4. KPI1: Economic value – total system costs [€/MWh].
5. KPI2: Total amount of CO_2 emissions over the considered period [Mt].
6. KPI3: Energy efficiency of the utilized generation mix over the considered period (defined as produced electrical energy divided by the total primary energy utilized to produce the electrical energy) [%].

Comparing KPIs over use cases without and with utilization of flexibility from smart appliances will give an indication on the economic and environmental impacts of smart appliances. This Task is concerned only with the base cases, i.e., cases without utilization of flexibility from smart appliances; whereas in Task 6, the cases with utilization of flexibility from smart appliances are presented.

The purpose of KPI1 is to provide a measure for economic benefits due to the provision of flexibility to the system. This value is relevant for the evaluation of costs and benefits of smart appliances.
KPI2 and KPI3 define environmental benefits from smart appliances. They are defined to measure firstly, the potential of smart appliances to decrease utilization of the less efficient, and more CO_2 emitting peaking power plants (especially gas and coal fired units) in the system, and secondly, the impact of utilization of smart appliances' flexibility on the VRES integration in the system.

5.4.2. CALCULATION OF KPIS

5.4.2.1. Day-ahead use case

KPI1, total system costs over the given time horizon of a year, is defined as the sum of the following costs:

- fuel costs of generator units,
- variable operational and maintenance costs of generator units,
- ramping costs of generator units,
- start-up costs of generator units
- shut-down costs of generator units,
- CO_2 emission costs of generator units,
- VRES curtailment costs (if curtailment is allowed), and
- costs of loss of load (if load shedding is allowed).

KPI2 is simply defined as the sum of all CO_2 emissions from all the generation units over the considered time horizon. The CO_2 emission factors[305] are defined for fossil fuel fired power plants per generation technology as given in Table 36Table 40. The other technologies, such as nuclear power plants, hydro power plants, biomass power plants, or VRES (wind and solar) do not emit CO_2 during the electricity production [2] and are therefore assumed to be CO_2 neutral. The emission factor for these technologies is set to 0. An overview of the utilized CO_2 emission factors in [t_{CO2}/MWh_{prim}] for different generation categories is presented in Table 40 CO_2 emission factors in [t_{CO2}/MWh_{prim}] for different generation categories. These factors are taken from [6].

Table 40 CO_2 emission factors in [t_{CO2}/MWh_{prim}] for different generation categories

Category	CO_2 emission [t_{CO2}/MWh_{prim}]
Coal fired	0,34
Gas fired	0,21
Oil fired	0,27

Note that KPI2 by no means represents total CO_2 emissions in the EU28 area, it only gives an indication of the CO_2 emissions due to the production of electricity[306]. These emissions are originating from fossil fuel fired electricity generation technologies. No emissions from other sectors, such as industrial or transport sector are taken into account.

KPI3 is the efficiency of the total utilized generation mix that is used to satisfy the demand. For the purposes of this report, the efficiency is defined as the quotient of the output energy (produced electrical energy) and the input energy (the total primary energy) used to fire the different types of power plants, i.e., the total primary energy utilized to produce the electrical energy. It is computed from individual efficiency factors that are defined for each generation technology. The efficiencies are given in the table below, and are taken from [2]. For coal fired, gas fired, oil fired, and biomass plants, a plausible interval of the efficiency factor is given in the reference. The chosen values are presented in Table 41. For the calculation of the KPI, for hydro, wind and solar power plants, the energy efficiency factor of 100% is utilized, although this is not the real efficiency factor for these types of power plants. This is justified by absence of primary energy that was utilized to fire the hydro, wind and solar power plants. In line with the definition of efficiency used for the purposes of

[305] These are CO_2 emission factors, and not CO_2-equivalent emission factors.

[306] As in this study only the electricity energy system is modelled, and because the majority of CHP plants is gas fired, CHPs are here modelled as the gas fired units.

this report, and because hydro, solar and wind power plants are not fired in the same way as for instance thermal power plants, their efficiency is set to 100%.

Table 41 Output to input energy efficiency for different generation categories

Category	Nuclear	Coal	Gas	Oil	Biomass
Efficiency [%]	33[307]	45	50	39	45,5

5.4.2.2. Imbalance use case

In the imbalance use case, KPI1 is calculated as the sum of the total costs incurred by correcting the imbalance. It is computed as the multiplication of the imbalance volume and the marginal price of the marginal unit utilized to correct the imbalance.

To compute the KPI 2, i.e., the CO_2 emissions, in the imbalance use case, we define the generation mix that balances the system as the difference in the generation mix between the day-ahead and the imbalance use case. For 2014, based on the modelling results, the generation mix that covered the imbalance volumes consisted of 8,5% nuclear generation (90% coming from France), 58% from gas-fired units, and remaining 33,5% was due to coal-fired generation. These generation shares are multiplied by the accompanying emission factors that can be found in Table 40The KPI2 value is obtained by multiplication of the emission factor per technology, the change in generation production per technology, and the hourly imbalance volumes of each EU28 Member States.

Given this definition,KPI2 can be interpreted as the amount of additional CO_2 emissions that were emitted or saved due to the balancing actions. In this sense, the emissions from the day-ahead use case are not taken into account in this KPI2 definition. Note that by definition, KPI2 can be negative. If it is negative, the total system CO_2 emissions after balancing actions are lower than the computed CO_2 emissions from the day-ahead market use case.

KPI 3 is calculated in the same was as in the day-ahead use case, with the difference that we only consider the efficiency of the generation mix used for balancing.

The value of each KPI could be linked directly to the value it might represent for the entire value chain and in particular the end consumer. Both the cost of the day-ahead energy purchases and the imbalance costs are part of the final energy bill of the end-consumer. This means that a change in these costs will logically result in a decrease of energy costs billed to the end consumer. In Task 6, the benefits for end consumers are further discussed.

5.5. BASE CASE (BENCHMARK CASE)

In this section, the developed model and utilized data are validated by comparison of the model outcome to the available realized numbers from the electricity energy data. Next, the KPIs are presented for the benchmark case, i.e. for the case with no activation of smart appliances flexibility. The KPIs are given and explained for both use cases: day-ahead use case, and imbalance use case.

[307]As mentioned above, for the utilized nuclear fuel costs, the accompanying efficiency should be 100%. This efficiency factor of 33% is utilized only for the generation mix efficiency calculation.

5.5.1. MODEL AND DATA VALIDATION

Results of the base case scenario for the reference year 2014 are used to validate the utilized model. The validation is done by comparison of the model output and the real observed data for 2014.
In Figure 65 Comparison of the outcome of the model for input data defined for 2014, and the realized generation mix (electricity production by source) in 2014 in EU28 area., the outcome of the model in terms of committed generation mix is compared against the realized generation mix in EU28 in 2014. The realized data is obtained from the provisional data for 2014 published in the Eurostat database and available on the Eurostat webpage[308]. The data is also presented and interpreted in the Eurostat report on Electricity and heat[309].

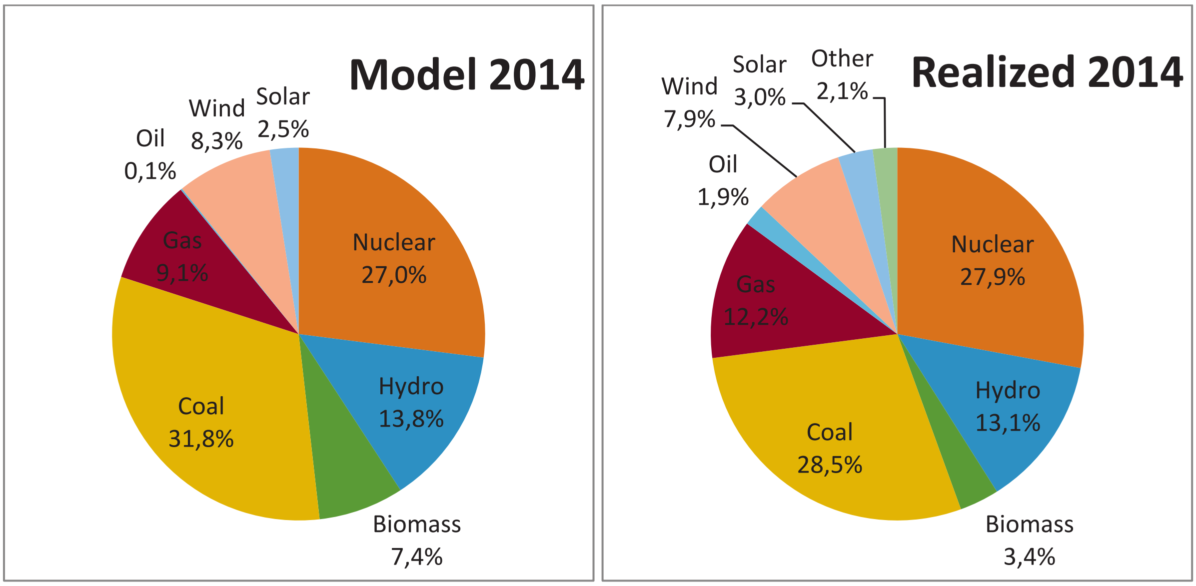

Figure 65 Comparison of the outcome of the model for input data defined for 2014, and the realized generation mix (electricity production by source) in 2014 in EU28 area.

As can be observed in Figure 65 Comparison of the outcome of the model for input data defined for 2014, and the realized generation mix (electricity production by source) in 2014 in EU28 area., the coincidence of the model results and realized numbers is very high. The outcome of the model corresponds very closely to the data as measured in reality for share of total generation per type: for nuclear, the model outcome is 27,0% against 27,9% realized, for hydro generation, model outcome was 12,8% against 13,1% realized. Share of other intermittent RES generation shows good resemblance of the model outcome to the realized data as well: for wind the model outcome is 8,3% against realized 7,9%, and for solar the model outcome is 2,5% against 3% realized share of total electricity generation. Furthermore, if the total sum is considered for the fossil fuels fired power plants, very good overlap can be observed: gas and coal fired power plants produced 40,7% of total electricity in the year, whereas according to the model computation, it was 40,9%.

There is a minor mismatch in fuel fired generation (gas, oil, coal fired) if these technologies are considered individually. The mismatch in model-obtained and realized share of gas fired units and coal fired units is mostly due to the interchangeability of these technologies: both can be used as peaking units. Some of the mismatch can also be contributed to the limitations of the model, such as

[308] ec.europa.eu/Eurostat
[309] http://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_and_heat_statistics#Production_of_electricity

limiting the transmission network to the cross-border connections, and the fact that hydro power plants are modelled to be completely dispatchable. Lastly, the mismatch can be contributed to the choice of fuel prices and their variability over the year, which was not taken into account.

Lastly, there is a discrepancy in the electricity production by biomass and oil fired technologies. This is explained by a low price of wood pellets utilized by the biomass power plants. The green certificates are already incorporated in the defined fuel price. The green certificates value varies significantly from country to country. Nevertheless, a single value had to be assigned to the wood pellets price as the model takes a single price for each resource. As a result, a slight overestimation of the electricity production from the biomass power plants has occurred at the cost of lower electricity production by the oil-fired power plants.
In conclusion, the input data and model parameters are shown to be reliable and satisfactory for further purposes of the study.

5.5.2. DAY-AHEAD USE CASE

This section presents results for the day-ahead benchmark use case for the chosen benchmark years 2014, 2020 and 2030. Firstly, the outcome of the model in the form of a realized generation mix is presented in Table 42. As expected, the ratio of the electricity produced by the intermittent RES will increase over the years with the increase in the installed capacity, and according to the current load factor of these technologies.

Table 42 Total realized generation mix for EU28 area per benchmark case, for 2014, 2020 and 2030.

Generation type	2014 [%]	2020 [%]	2030 [%]
Nuclear	27,0	23,5	21,1
Hydro	13,8	14,1	12,8
Biomass	7,4	8,7	9,0
Coal	31,8	27,5	19,9
Gas	9,1	9,8	15,5
Oil	0,1	<0,1	<0,1
Wind	8,3	12,9	17,3
Solar	2,5	3,6	4,6

The planned decrease in the installed nuclear power plant capacity is expectedly accompanied by the decrease in the share of electricity produced by nuclear generation units, and will drop from current 27,0% to around 21% in 2030.
Whereas the share of fossil fuel plants remains constant over the years, there is an expected restructuring in shares per technology within the group. From the table, it is obvious that the gas-fired technologies will have a higher share in 2030 compared to 2014. There are multiple reasons for this effect. Firstly, there is more installed capacity of gas fired technologies in 2030 than in 2014. At the same time, there is less coal fired technologies installed in 2030 than in 2014. This decrease in coal capacity, together with the decrease in nuclear capacity causes need for more baseload technologies. Baseload technologies are technologies that provide a more or less continuous supply of electricity throughout the year. Base load power plants are often less responsive (e.g. nuclear power plants) compared to more flexible units (e.g. gas fired power plants). Gas fired units can take part in compensating it. Moreover, with more VRES capacity, more flexibility is needed, and given the

technical constraints of gas-fired units (such as fast ramping rates and low minimum down time and minimum up time), it is well known that they are suitable as a peaking technology. Lastly, the much higher general CO_2 emissions price, in combination with the lower CO_2 emissions factor (see Table 40) of gas fired units compared to coal fired units give the final argument for explanation of the switch in the gas fired and coal fired power plants in 2030.

The share of biomass power plants is expected to increase over the coming years. This is largely a consequence of a relatively low assumed fuel price for this technology, due to maintaining or increasing the green certificates and subsidies for such generation type. The share of biomass units in the generation mix is sensitive to variations in fuel prices for fossil fuels and subsidies.

The shares of electricity production per type, which are presented in Table 42, along with the emission factors given in Table 40, can later serve very well to explain the amounts obtained for KPI2, total CO_2 emissions from electricity production.

In Table 43, the share of total energy produced by VRES that had to be curtailed is presented. In 2014 and 2020, no VRES curtailment was necessary. Only in 2030, a small portion of produced VRES energy had to be curtailed. Note that this is also due to the modelling assumptions, according to which only cross-border transmission network capacity is considered. In reality, VRES curtailment could be a larger problem and lead to lower load factor of VRES.

Table 43 Load shedding and VRES curtailment for EU28 area per benchmark case, for 2014, 2020 and 2030.

	2014 [%]	2020 [%]	2030 [%]
Load shedding	0	0	0,004
VRES curtailment	0	0	0,008

Next to it, Table 43 shows the amount of load shedding as a percentage of the total load in the whole EU28 area. Load had to be shed only in the 2030 benchmark scenario. Over the whole year, 0,004% of the total EU28 demand, or 119 GWh had to be shed. The load was shed in 11 EU28 countries, exclusively in winter months (between mid November and mid February). For most of these countries, the load was shed during less than 5 hours in the year.

The KPIs per benchmark year for day-ahead use case are presented in Table 44. These values are interesting on their own; however, their main purpose within the scope of the study is to serve as benchmark for the cases with utilized flexibility from smart appliances. Therefore, they are just briefly discussed in this Task, and more elaborately in Task 6 along with the KPIs from the use cases presented therein.

Table 44 KPIs for the day-ahead use case for each of the benchmark years

Day-ahead use case	KPI1 (total system costs) [M€]	KPI2 (CO_2 emissions) [Mt]	KPI3 (efficiency of the utilized generation mix) [%]
2014	63.613,6	803,3	55,74
2020	75.079,2	736,2	59,51
2030	115.504,3	698,6	62,32

In the day-ahead use case, an increase in total costs for electricity production, i.e. KPI1, is observable over the years. All the costs are given in €$_{2014}$ value, so the most interesting outlier is for year 2030, in which the costs are significantly higher than in the other two benchmark years. The main reasons for this increase is in the increase of CO_2 emission price by factor 9 and 5 compared to 2014 and 2020, respectively, see also Table 36.

The development of the efficiency of the utilized generation mix (KPI3) over the benchmark years shows the slight increase in efficiency. Main reasons for this are firstly, the increased VRES installed capacity, and secondly, the switch from electricity production by coal-fired power plants to the gas-fired power plants, see also Table 42, which are more efficient than the coal-fired ones: 50% compared to 45%, see Table 41.

5.5.3. IMBALANCE USE CASE

The KPIs per benchmark year for the imbalance use case are given in Table 45.
The same trends in KPI3 as observed in the day-ahead use case are observable in the results for the benchmark imbalance use case. This is expected as the generation mix that supplies energy in the day-ahead markets is not very different from the generation mix that supplies the imbalance market needs and also provides reserves.
In KPI1, the same trends can be observed as in the day-ahead use case: first a slight increase in total balancing costs can be observed from year 2014 to 2020, and after that in 2030, a significant increase in costs. This increase is, same as in day-ahead use case, caused by the load shedding, which put the market prices very high.

Table 45 KPIs for the imbalance use case for each of the benchmark years

Imbalance use case	KPI1 (total system costs) [M€]	KPI2 (CO_2 emissions) [Mt]	KPI3 (efficiency of the utilized generation mix) [%]
2014	7,21	1,55	46,46
2020	11,20	1,65	46,59
2030	143,66	1,78	48,1

The CO_2 emitted by the generation mix to provide balancing services decreases over the years. This can be explained by the methodology for generating imbalance volumes in the model. The imbalances are determined based on predicted future errors in load forecast and VRES production (wind and solar). The load forecast error has a much larger mean value compared to the VRES forecast errors. From Table 39 Statistical data for normalized forecast errors on basis of historical data for Belgium in 2014 (Source: Elia.be), it can be observed that the load prediction error has the tendency to be positive over long periods, whereas the VRES prediction error is neutral (mean is almost zero). From 2014 to 2030, the VRES installed capacity increased three times i.e. 300%, whereas the load grew around 15%. There is a decreasing portion of load prediction error compared to VRES prediction error in the imbalance volumes. Consequently, the total mean of the generated imbalance volumes will move towards zero in the period 2014 to 2030. The contribution of VRES forecast error in the total forecast error increased over time, and moved the average more towards zero. This caused the emissions amount used to correct this imbalance to move towards zero as well.

5.6. CONCLUSIONS

This Task introduced and validated the model and data utilized for the purposes of this study. Moreover, it sets the ground for the evaluation of the potential impacts from smart appliances, which is continued in Task 6. Therein, the results of the cases with smart appliances will be put in perspective with these benchmark results.

CHAPTER 6 DESIGN OPTIONS

Following the MEErP Methodology for Energy related products, the scope of Task 6 consists of the identification of the identified (aggregated clusters of) design options, their monetary consequences in terms of Life Cycle Costs for the consumer, their environmental costs and benefits and pinpointing the solution with the least Life Cycle Costs (LLCC) and the Best Available Technology (BAT) compared to the base-cases described in Task 5. The comparison of the Life Cycle Costs and the environmental costs and benefits should be done for the design options using the same approach as was done for the base-cases.

As explained in the introduction of Task 5, the approach taken in this Lot 33 Preparatory Study is slightly different, as it specifically addresses the implications underlying the connectivity and demand side flexibility (DSF) functionality aspect horizontally over a large group of various products. This implies that the DSF functionality will have implications on the level of the individual product and the network connections through which the product functions (see Task 4). Besides this individual product level, the aggregated DSF which potentially can be provided by a group of smart appliances also gives rise to environmental and economic benefits which can be found at the level of the entire energy system. If the study would be limited to the usual MEErP base-case environmental and economic impact data, these system impacts would be kept out of consideration.

In this context, the Task 6 report of this Lot 33 Preparatory Study mainly focuses on the assessment of the economic and environmental benefits the use of flexibility from smart appliances can have. In this Task 6 report it is investigated how potential (future) flexibility provided by smart appliances can support the power system and an attempt is made to quantify the value of the economic and environmental benefits potentially provided by the flexibility of smart appliances to the energy system. The focus is on the impacts for the day-ahead use case and imbalance use case, however additional use cases exist where the flexibility of smart appliances would have significant value. A use case with a lot of potential is the use of flexibility by distribution system operators (DSOs) to solve local grid constraints (congestion management and voltage control) in specific areas of the distribution grid. Although today it is not yet possible to build a sound evaluation of the extent of these opportunities due to a lack of data, (preliminary results of) several research projects show that they are expected to become promising in the future for specific areas of the grid.
The benefits of flexibility from smart appliances are evaluated according to the three key performance indicators (KPIs) already defined in Task 5: CO_2 emission savings[310], impact on the utilized generation mix in terms of efficiency (which indirectly shows primary energy savings and additional Renewable Energy Sources (RES) which can be integrated in the system) and impact on the total energy system costs and marginal energy prices. The resulting KPIs are compared with the KPIs calculated in Task 5 for the base case. Where the base-case scenario served as a reference situation which did not take into account flexibility, in this Task 6 report the KPIs are calculated for a situation in which a certain share of smart appliances (based on Task 2), each with their flexibility profile (based on Task 3), could provide flexibility to the system in the future.

The aim of this Task is to answer the following questions: How can flexibility provided by smart appliances support the power system? What is the value of the benefits provided by the flexibility of

[310] In this project, CO_2 emission is considered, and not CO_2-equivalent emission.

smart appliances to the system? How do these benefits compare to the costs of smart appliances and flexibility utilization from smart appliances?

The value of the benefits provided by the flexibility of smart appliances to the system is extracted from the computed KPIs in Tasks 5 and 6. It is expressed in environmental and economic terms for the day-ahead market use case and for the imbalance use case. The obtained value for the day-ahead use case is the highest value that can be obtained, as the perfect foresight is assumed, all the flexibility is utilized in a holistic aggregated way to benefit the system, and no control imperfections, such as communication delay, suboptimal controller tuning, etc. exist.

It is of interest to compare the economic value from flexibility provided by smart appliances to the power system with the costs related to the smart appliances providing flexibility. Although it is not feasible in the context of this Preparatory study to make a full cost-benefit analysis, the comparison of the costs and benefits for the system with the additional costs and benefits for the end-user and manufacturer bring some perspective in the derived values.

6.1. ASSESSMENT MODEL DESCRIPTION

In Task 5, the optimisation-based model is described that allows simulating the behaviour of the energy system for the entire EU28. In order to analyse how smart appliances could support the energy system for different use cases (day-ahead use case and imbalance use case), a first step to be taken is the identification of the type of flexibility from smart appliances that is available. For instance, flexibility can be identified as load shifting, load shedding, storage, etc. Once the flexibility type is identified, it is possible to develop an additional flexibility model and incorporate it in the system model presented in Task 5.

The identification of flexibility type per smart appliance group, and the accompanying developed flexibility model are described in this section in more detail.

The outcomes of Task 1 were used to define the categories of smart appliances with sufficient flexibility potential. For each of these categories, the flexibility potential was determined.

The following categories of appliances were identified as appliances with high potential, and, as a result, are considered further in this Task:

1. Periodical appliances (Dishwashers, Washing machines, and Tumble dryers),
2. Energy storing appliances (Refrigerators and freezers, and storage water heaters, for residential and commercial purposes),
3. HVAC heating in residential and tertiary buildings (electric heating),
4. HVAC cooling in residential and tertiary buildings (air conditioning),
5. Residential energy storage system (home batteries),
6. Tertiary cooling or commercial refrigeration,

Washer-dryers, which belong to the periodical appliances group, were also identified to have potential for flexibility provision. Nevertheless, they are omitted from further consideration in this Task due to relatively small amounts throughout the EU28 area, and a lack of data in terms of hourly profiles, and average maximal shifting period.

The flexibility or demand response potential of each category of smart appliances is quantified by two parameters:

- **The energy shifting potential** = the amount of energy that can be shifted, expressed in [MWh/h], i.e. what is the maximum consumption of a group of smart appliances that could be consumed at a different moment in time. The energy shifting potential is based on an hourly flexibility profile.

- **Average maximal shifting period =** the maximum number of hours [h] that the demand of the appliance can be shifted, i.e. how much later/earlier should take consumption by the smart appliances take place, compared to the initially planned time.

The flexibility model is determined based on the outcome of Task 3. The flexibility potential per category was used to model the hourly amount of available flexibility and its shifting potential. The hourly flexibility profiles reported in Task 3 are utilized to represent the shifting potential. These profiles represent the amount of flexibility that can be shifted by the corresponding shifting potential given in hours.

Additionally, in the energy shifting potential, the following aspects are covered:

- Seasonality: the seasonal effects in availability of flexibility from smart appliances are considered for the appliances of which the energy utilization depends on the seasons. As discussed in Task 3, there is no difference in average consumption profile for e.g., dishwashers, washing machines, refrigerators and freezers.
- Climatic zone: the effects on the amount of flexibility from smart appliances due to the different climatic zones are considered for the appliances of which the energy utilization depends on the climatic zone, in particular, outside temperature, radiation levels etc. The methodology to take these effects into account was discussed in Task 3 for residential heating and cooling, tertiary heating and cooling, and commercial refrigeration groups.
- Time zone: Hourly flexibility profiles of countries in different time zones are shifted to match with the model time zone[311].

The seasonality and climatic zone aspects are not relevant for all the groups of smart appliances. For these groups, no such patterns are contained in the energy shifting potential profiles. Nevertheless, for the appliances from residential heating and cooling, tertiary heating and cooling, and commercial refrigeration, these aspects are relevant and hence included in the hourly profiles of energy shifting potential.

Besides constraints on the shifting potential and shifting period, additional constraints are also taken into account for some groups of smart appliances, such as:

- **Rebound constraints.** A shift in demand means that the consumption is reduced at a certain moment in time and transferred to another period of time, where an increase in scheduled consumption can be seen. This is often referred to in literature as rebound effect. Note that there is no reduction in total consumption, nor increase in total consumption due to flexible operation; there is only shifting of demand to consume at a more appropriate moment. The rebound effect is valid for all the considered groups of flexible smart appliances. Hence, this constraint is added to all the flexibility models[312]. To note that a possible increase in consumption, due to smart operation of appliances is not taken into account in the flexibility model.
- **Coupling of the home batteries and the PV installed capacity**. It is assumed that the home batteries are not utilized for arbitrage on the energy and reserve markets, but in combination with PV production capacity to store the excess of solar power production.

Home batteries are modelled as storage appliances, and consequently not as demand shifting. The first order storage model of given efficiency is chosen to represent the home batteries.

[311] The model time zone is chosen to be GMT+1. The same results would have been obtained for any choice of the model time zone.
[312] With the exception of residential energy storage system, as this group is not modelled as demand shifting.

To summarize, the flexibility models are mapped to the smart appliance groups as follows:

- First order storage model with losses: home batteries.
- Demand shifting: periodical appliances (washing machines, dishwashers, tumble dryers), energy storing appliances (residential refrigerators and freezers, electric storage water heaters), commercial refrigeration.

The developed optimisation model determines the optimal utilization of flexibility from each appliance group so that the total system costs are minimized, while taking into account the constraints on flexibility as defined above.

The computed benefits for the day-ahead use case give the upper boundary of the flexibility impact, as the flexibility is used in the optimal way assuming that the renewable generation power profiles of wind and solar power plants, and the demand profile, and flexibility amount of the smart appliances are perfectly known in advance. However, on the other hand, some assumptions on flexibility from smart appliances may be considered conservative thus underestimating the economic value of the flexibility. For instance, the assumption taken on the flexibility shifting times may be considered slightly conservative for some appliance categories (e.g. 3 hours for periodical appliances). Nevertheless, these assumptions are chosen to mimic the business-as-usual case, i.e., the situation in which there are no additional policy approaches and incentives for the end-users to operate the appliances in a smart grid way. The impact of the effects of changes in these assumptions will be treated later in Task 7, as part of an ongoing second phase of this Preparatory Study.

The KPIs are defined on the system level, and as such, they quantify the operation of the system as a whole using the flexibility of all the smart appliances together. Therefore, KPIs cannot be determined separately per smart appliances category. This means that no distinction in resulting benefits from flexibility is made between smart appliance groups. Nevertheless, the optimal schedule of different flexibility models (storage, demand shifting) can be extracted from the model. Therefore, the monetary benefits can be defined per smart appliance group. Of course, not only benefits but also the different costs of smart appliances to exploit the flexibility potential have to be taken into account. Costs are specific to each type of appliance. These costs are not taken into account in the model, but are evaluated against the obtained value of the benefits. The cost perspective is further discussed in section 6.4.

6.2. ASSESSMENT DATA

In this section, an overview of the used data related to the developed flexibility model of smart appliances is given. Wherever possible, it is only referred to a previous Task where the data is collected or generated. Herein, only the numbers and figures that were not presented in one of the previous Tasks are given.

6.2.1. NUMBER OF SMART ENABLED APPLIANCES

The utilized model is the zonal model of the interconnected EU28 area. Therefore, among others, the model utilizes as inputs the following hourly profiles:

- hourly profiles of total demand,
- hourly profiles of wind and solar power production, and
- hourly profiles of flexibility (per smart appliances group)

for each EU28 Member States. To calculate the total amount of available flexibility for each category of smart appliances in each country of EU 28, the numbers of smart enabled appliances in each country for 2014, 2020 and 2030 are needed.

The number of smart enabled appliances is calculated by multiplying the share (%) of smart enabled appliances, as described in Task 2, with the total number of smart appliances per considered smart appliance group. The share of smart enabled appliances and the corresponding number of smart enabled appliances in the EU28 area for each of the benchmark years are presented in Table 46.

TaskTable 46 Share (%) and amount (#) of smart enabled appliances per benchmark year in the EU28 area

		2014		**2020**		**2030**	
Group	Smart appliance	#	%	#	%	#	%
Periodical appliances	Dishwashers	0	0	2300720	2	11884240	8
	Washing machines	0	0	2008050	1	8189760	4
	Tumble dryers, no heat pump	0	0	718010	2	622224	16
	Tumble dryers, heat pump based	0	0	718010	2	11822256	16
Energy storing appliances	Refrigerators and freezers (residential)	0	0	15400000	5	63520000	20
	Electric storage water heaters (continuously heating storage)	0	0	2500000	5	9100000	20
	Electric storage water heaters (night storage)	0	0	950000	5	3440000	20
	Tertiary cooling - compressor[313]	0	0	11501466	10	70101114	50
	Tertiary cooling - defrost	0	0	11501466	10	70101114	50
Residential cooling and heating (heat pump based)	HVAC cooling, no storage	1053000	5	3790800	18	11408963	54
	HVAC cooling, with thermal storage	567000	5	2041200	18	6143288	54
	HVAC heating, no storage	104000	5	374400	18	1126811	54
	HVAC heating, with thermal storage	56000	5	201600	18	606744	54
Tertiary cooling and heating	HVAC cooling, no storage	78000	5	280800	18	845109	54
	HVAC cooling, with thermal storage	42000	5	151200	18	455059	54

[313] For tertiary cooling processes (compressor and defrost), instead of number of appliances, total nominal square meters, obtained as explained in Task 3 report, are given.

(heat pump based)	HVAC heating, no storage	106167	5	382200	18	1150287	54
	HVAC heating, with thermal storage	57167	5	205800	18	619385	54
Joule based tertiary and residential cooling and heating	Electric radiators, no inertia	0	0	6696000	3	46985342	21
	Electric radiators, with inertia	0	0	555000	3	3894394	21
	Boilers	0	0	30000	3	210508	21

Task

The model requires distribution of flexibility from smart appliances per EU28 Member States, and consequently also the number of smart appliances per EU28 Member States. For the periodical appliances, it is valid to assume that this distribution follows closely the distribution of the number of households in each country within the EU 28. Due to a lack of data, no differentiation in terms of smart appliances acceptance and uptake between EU28 countries is considered. In other words, it is assumed that the penetration of periodical smart appliances in each EU28 Member States is the same for each of the benchmark years. For HVAC and tertiary appliances, the exact numbers of smart enabled appliances per Member State are provided from the previous Tasks, in particular Task 2 – 4.

Table 47 gives an overview of the number of households in each EU28 country for 2014, which is utilized to derive the flexibility from smart appliances from the EU28 level to the Member State level. The data representing the number of households per EU28 Member State is obtained from the EU28 population data for 2014[314], and average household size per EU28 country[315], which are both downloaded from Eurostat data portal[316].

[314] See http://ec.europa.eu/eurostat/statistics-explained/index.php/Population_and_population_change_statistics

[315] http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Average_household_size,_2014_(average_number_of_persons_in_private_households).png

[316] http://appsso.eurostat.ec.europa.eu/nui/setupDownloads.do

To determine the share of the number of households in each EU28 country for 2020 and 2030, trends in population shares for each of EU28 countries were assessed over the last decade. Data from 1994 until now with the population size per country is downloaded from Eurostat data portal and from this data, the population shares in the total EU28 population per country and year are computed. These shares are presented in Figure 66. On the horizontal axis, the years are given, from 1994 until 2014. On the vertical axis, the share in the total EU28 population per country is given as a percentage. For each country, there is a line that represents the trend in its share in total EU28 population over the last ten years.

In Figure 66, it can be observed that besides the slight decrease in population of Germany (top brown curve), Poland and Romania, and slight increase in population of Spain (green curve), France, and United Kingdom, the population shares remained constant over the last 10 years. Therefore, it is reasonable to assume that the share of the population and the number of households in each EU28 country in 2020 and 2030 will remain constant over the years to come, i.e., the same as in 2014.

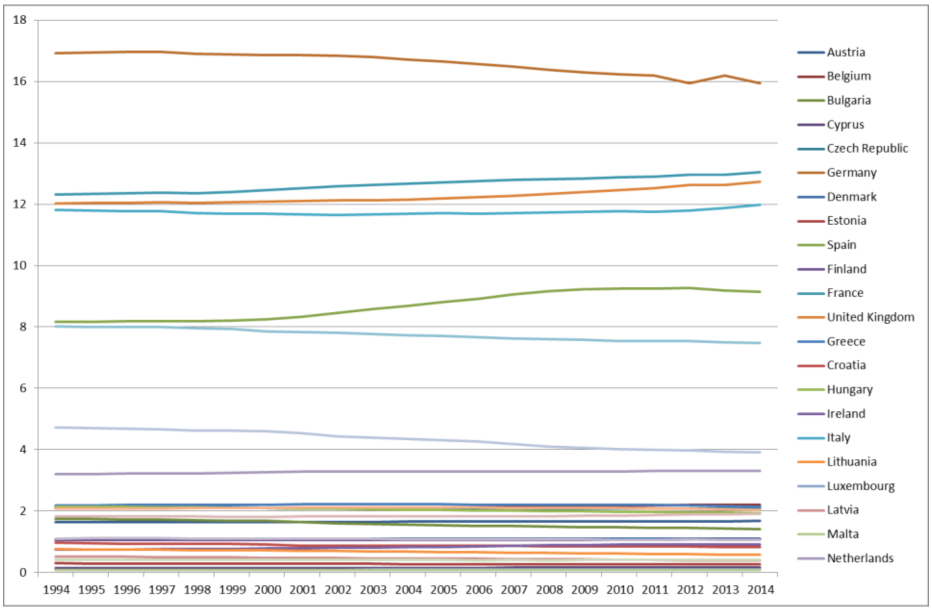

Figure 66 Trend in population share per EU28 Member State over the last decade, own compilation, data source: Eurostat web portal. Population share is defined as share of population of EU28 Member State in the total EU28 population, and is expressed in %.

Table 47 Number of households per EU28 Member State in 2014, and the share of households per Member State in the total number of households in EU28 area, source: own computation on basis of data from Eurostat data portal[317]

EU28 member	Number of households	% households
Austria	3882534	1,75
Belgium	4679672	2,11
Bulgaria	3009974	1,36
Cyprus	315742	0,14
Czech Republic	4576238	2,07
Germany (including former GDR)	40491250	18,28
Denmark	2687369	1,21
Estonia	597521	0,27
Spain	18592353	8,39
Finland	2600720	1,17
France	30119230	13,60
United Kingdom	28092678	12,68
Greece	4538505	2,05
Croatia	1512880	0,68
Hungary	4289769	1,94
Ireland	1710083	0,77
Italy	26430061	11,93
Lithuania	1332894	0,60
Luxembourg	231800	0,10
Latvia	830743	0,38
Malta	158283	0,07
Netherlands	7665913	3,46
Poland	14078420	6,36
Portugal	4000409	1,81
Romania	7373696	3,33
Sweden	4848055	2,19
Slovenia	859158	0,39
Slovakia	2006907	0,91

Next to the shifting potential, the average maximal shifting period per smart appliance group is also a required input to the model. This parameter was discussed in detail in the previous Tasks, and for the purposes of overview and completeness, in Table 48, the maximal shifting period per smart appliance group is presented.

[317] http://ec.europa.eu/eurostat/statistics-explained/index.php/Population_and_population_change_statistics and http://appsso.eurostat.ec.europa.eu/nui/setupDownloads.do and http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Average_household_size,_2014_(average_number_of_persons_in_private_households).png

Table 48 Maximal average shifting time [h] for each group of the considered smart appliances

Group	Smart appliance	Maximal average shifting time [h]
Periodical appliances	Dishwashers	3
	Washing machines	3
	Tumble dryers, no heat pump	3
	Tumble dryers, heat pump based	3
Energy storing appliances	Refrigerators and freezers (residential)	0,17
	Electric storage water heaters (continuously heating storage)	0,17
	Electric storage water heaters (night storage)	0,17
	Tertiary cooling - compressor[1]	0,25
	Tertiary cooling - defrost	1,5
Residential cooling and heating (heat pump based)	HVAC cooling, no storage	0,17
	HVAC cooling, with thermal storage	6
	HVAC heating, no storage	0,17
	HVAC heating, with thermal storage	6
Tertiary cooling and heating (heat pump based)	HVAC cooling, no storage	0,17
	HVAC cooling, with thermal storage	6
	HVAC heating, no storage	0,17
	HVAC heating, with thermal storage	6
Joule based tertiary and residential cooling and heating	Electric radiators, no inertia	0,17
	Electric radiators, with inertia	0,17
	Boilers	0,17

6.2.2. NUMBER OF RESIDENTIAL STORAGE APPLIANCES (HOME BATTERIES)

For residential storage appliances, under which we understand home batteries for the purposes of this study, the significant number of home batteries is assumed to be present only in Germany, as today, in no other countries, the investment of home batteries is subsidized today[318]. The numbers are taken from the same market study, and are presented in Table 49. There are other countries that might also have potential to develop a market for residential storage appliances. The Energy Storage in PV report (2015) from IHS Technology mentions Italy and the UK as key markets for Europe[319]. However today in Italy and UK the market is still very premature due to several regulatory barriers (i.e. net metering). This means that, even in countries with a large share of solar panels, the uptake of residential storage appliances is largely dependent on the chosen regulatory framework (metering, subsidies, grid costs,…). Today, besides Germany, no clear indications exist how the market will develop in other EU countries by 2020 and 2030. Therefore, we use a relatively conservative approach, only taking into account the market for home batteries in Germany.

The aggregated energy capacity of the batteries is given under the column energy capacity and is expressed in MWh. The charging rate, which corresponds to the maximal input and output charging power, are given in the column "charging rate". Lastly, the electricity-to-electricity efficiency factor is given in the most right column of the table.

Table 49 Installed numbers, energy and power capacity[320] of home batteries (only for Germany), source: B. Normark et al, "How can batteries support the EU electricity network?", technical report, 2014

Year	Charging rate [MWh/h]	Energy capacity [MWh]	Efficiency η [%]	Number
2014	37,95	73,6	85	11500
2020	264	512	85	80000
2030	676,5	1312	85	205000

6.2.3. FLEXIBILITY PROFILE

In Task 3, the relevant parameters to determine the aggregated flexibility potential of smart appliances are described. These profiles are utilized in this Task, and not repeated in the text of this report.

6.2.4. ASSUMPTIONS

In this section, an overview of assumptions related to the flexibility of smart appliances is presented. Note that the assumptions below are both based on reflections made in earlier Tasks and additional assumptions made in Task 6.

318 B. Normark et al, "How can batteries support the EU electricity network?", technical report, 2014, http://www.insightenergy.org/ckeditor_assets/attachments/48/pr1.pdf

319 http://www.pv-magazine.com/news/details/beitrag/residential-storage-market-to-increase-to-900-mw-by-2018_100017137/#axzz3cS5pdCgg

320 Energy and power capacity is deduced from battery numbers based on specifications of Tesla Powerwall, see https://www.tesla.com/powerwall

12. The optimisation model used is the model as explained in Task 5. It determines the value of flexibility for each individual EU28 country, taking into account that:
    a. Import and export between countries is possible, but it is constrained by the capacity of the transmission lines.
    b. There are different time zones between countries.

13. The flexibility of smart appliances is modelled as two conceptually different groups:
    a. load shifting, for all the appliance groups besides batteries;
    b. storage: home batteries

14. The price to activate flexibility from smart appliances is set at zero in the model, to allow determining the maximum potential and evaluate the maximal benefits of smart appliances. Benefits computed in such a way do not take into account costs, and can be seen as gross benefits. The computed benefits are later evaluated against costs further in this report. The computed benefits should be interpreted as an upper bound for the flexibility payments in the value chain for activation of this flexibility. In this sense, this model's assumption of a zero price for flexibility activation is not equivalent to the assumption that there is no price to activate flexibility from smart appliances in the overall analysis.

15. For a certain category of smart appliances, in case the flexibility has the same characteristics (same shifting period), the smart appliances are considered of equal value for the energy system. This means that for example, no real distinction can be made in the model optimization between washing machines and dish washers, as they have the same average shifting time (see also Table 48). Further in this report, it will be explained that although benefits could be considered similar for certain appliances, differences in costs could still result in a preference for one type of appliance to provide flexibility.

16. The total amount of flexibility of periodical and energy storing appliances is based on the assumption that on average, there is one appliance per household, meaning that in order to calculate the entire base of smart enabled periodical and energy storing appliances, it is sufficient to multiply the % of smart enabled appliances (data provided in Task 2) with the number of households for a certain country. This methodology was only used for periodical appliances and energy storing appliances.

17. EVs and possible flexibility from EVs is not represented in the model. Also flexibility coming from industrial demand response is not taken into account in the model. This means that the value of flexibility to be awarded to smart appliances is slightly overestimated, as a part of the need for flexibility could (and will) be covered by industrial demand response or EVs instead of smart appliances. Today, it is unclear for which flexibility provider it will be most profitable to offer flexibility (industrial demand response, EVs, smart appliances). It will depend on both, the costs to enable this flexibility (including infrastructure, communication technology,…), the use case (day-ahead optimization of portfolio, balancing,…), and the characteristics of the flexibility (reaction time, availability,…).

18. For home batteries, it is assumed that only in Germany, this market will develop in the scope 2020 and 2030, due to the fact that today, in no other countries, the investment of home batteries is subsidized[321].

[321] http://www.insightenergy.org/ckeditor_assets/attachments/48/pr1.pdf

6.2.5. COMPUTATION OF KPIS

The economic and environmental benefits of smart appliances from an energy system perspective are quantified by means of the following key performance indicators (KPIs), as defined for the base case in Task 5.

1. KPI1: Economic value in terms of total energy system costs. This KPI quantifies and links to the avoided costs related to the more efficient use of the energy system following the introduction of the flexibility from smart appliances.
2. KPI2: Total amount of CO_2 emissions over the considered period. This KPI quantifies part of the environmental benefits of decreased utilization of the less efficient and more CO_2 emitting peaking power plants in the system.
3. KPI3: Energy efficiency of the utilized generation mix over the considered period. This KPI more specifically indicates the increased share of Renewable Energy Sources (RES) integrated in the generation mix, and decrease in utilization of low efficient, often peaking, generating units. Energy efficiency of the utilized generation mix as defined here is related to the primary energy savings in the electricity production. It is not related to e.g. decrease in total consumption due to more efficient energy utilization.

For the flexibility case, the KPIs are computed in the same way as presented in Task 5, with the exception of the KPI2 (CO_2 emissions) in the imbalance use case.

In the base case, to compute the KPI 2, i.e., the CO_2 emissions, in the imbalance use case, we define the generation mix that balances the system as the difference in the generation mix between the day-ahead and the imbalance use case. KPI2 value is obtained by multiplication of emission factor per technology, the change in generation production per technology, and the hourly imbalance volumes of each EU28 Member State.

Herein, the assumption is that as large part of the imbalance volume as possible is resolved by utilization of smart appliances flexibility. The remaining imbalance volume (if any) is assumed to be covered by the generation side. As the imbalance case is an extended case of the day-ahead use case, and as it is modelled by running the unit commitment model once again, the volume by which the smart appliances contribute to the balancing is computed as a difference between the baseline flexibility and the optimally scheduled flexibility. Similarly, the remaining volume is covered by the differences in generation between the day-ahead and imbalance use case schedule.

Finally, to compute the KPI2, the imbalance volumes that were balanced by the flexibility of smart appliances are assigned with the emission factor 0, and the remaining is assigned by the corresponding generation type emissions factor, see Table 4 in Task 5.

Given this definition of KPI2, it can be interpreted as the additional CO_2 emissions that were emitted or saved due to the balancing actions. In this sense, the emissions from the day-ahead use case are not taken into account in this KPI2 definition. Flexible case

In this section, the results of the KPI calculation are described for the two selected use cases: day-ahead use case and imbalance use case. In addition, the results are compared with the KPIs calculated for the benchmark case in Task 5.

Same as in Task 5, for each of the three chosen benchmark years: 2014, 2020, and 2030, the model is run over a time horizon of one year. The KPIs represent the yearly values: KPI1 are the yearly electrical energy production costs, KPI2 are the yearly CO_2 emission quantities from the generation mix utilized to produce electricity, and KPI3 is the efficiency of the utilized generation mix throughout the whole year, which is defined as the quotient of the produced electrical energy and the total primary energy utilized to produce the electrical energy.

6.2.6. DAY-AHEAD USE CASE

In Table 44, KPIs for the day-ahead use case with flexibility from smart appliances are presented. The same trends over the benchmark years that were observed in the base case can be seen here:

- there is an increase in total costs over the years, which is largely due to the increased fuel and in particular increased CO_2 emission costs
- there is a decrease in CO_2 emissions over the years, which is largely due to the increased installed capacity of RES
- there is an increase in generation mix efficiency, which is due to the increased installed capacity of RES.

All the observations reported in Task 5 still hold. In the table, it can be seen that the numbers for KPI3 are very similar to those presented in Task 5. These KPIs are the most interesting when put in perspective with the KPIs computed for the base case. The analysis of these differences is presented below, after a short discussion on the effects of flexibility on the residual load curve.

Table 50 KPIs for the day-ahead use case for each of the benchmark years

Day-ahead use case	KPI1 (total system costs) [M€]	KPI2 (CO_2 emissions) [Mt]	KPI3 (efficiency of the utilized generation mix) [%]
2014	63.601,5	803,35	55,74
2020	75.079,2	736,18	59,51
2030	115.504,3	698,62	62,32

6.2.6.1. Effects of flexibility

The residual load curve is determined as the difference in total demand and total production of intermittent, non-dispatchable renewable energy sources. It is in fact the remaining load that has to be satisfied by the production of dispatchable generation. The residual load curve is of the same resolution as the original profiles, i.e., it is an hourly curve. It has been observed that the lowest total system generation costs are obtained for flat residual demand curves, (Matek and Gawell, 2015). Therefore, it is expected that the optimal utilization of the flexibility from smart appliances will result in a residual curve with lower peak (minimum and maximum values), and a lower volatility, i.e. of smoother nature.

In Figure 67, effects of the utilization of flexibility on the residual demand curve are shown for the 2030 scenario, in which there was the highest number of smart appliances flexibility available (compared to other benchmark years). A week in winter, in particular, the second week in 2030, is shown in the figure. In red, the base scheduled demand is shown, without utilization of flexibility, and in black the optimized demand with the utilization of flexibility from smart appliances, coming from the flexible case. The residual demand curve is shown for the aggregated EU28 area, but individual residual curves of each EU28 Member State show the similar patterns.

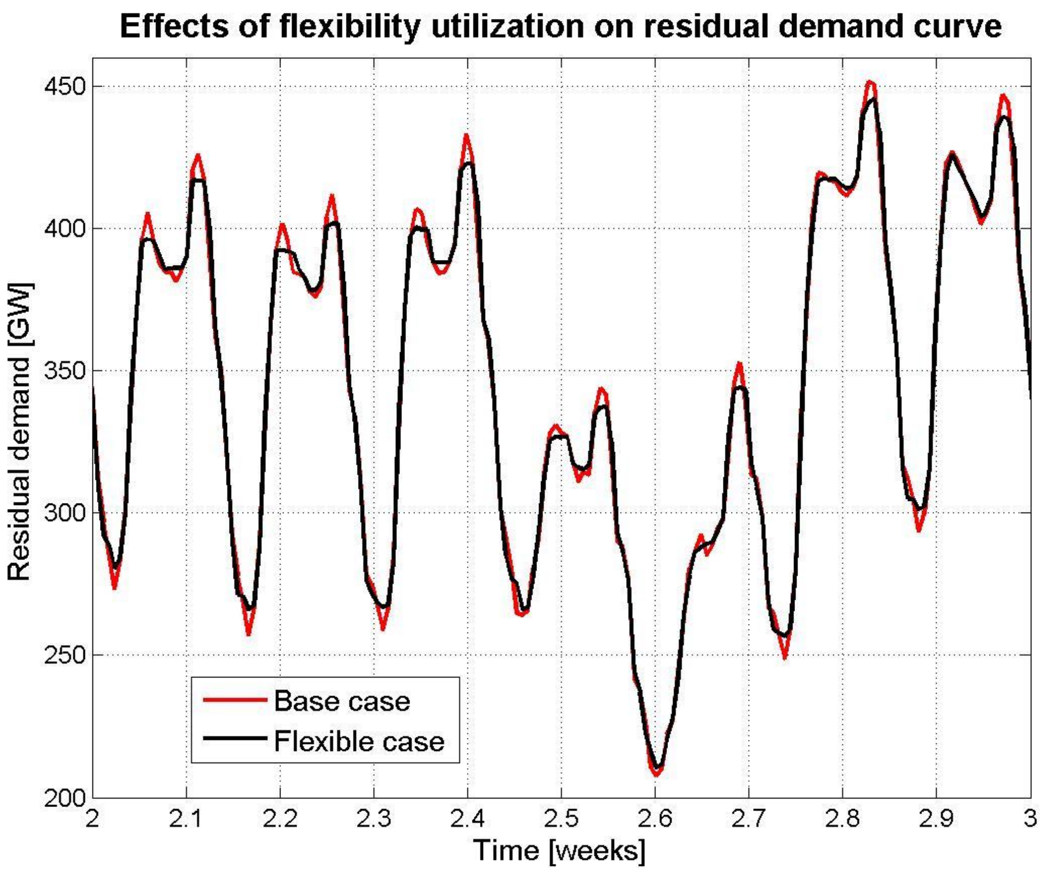

Figure 67 Effects of utilization of flexibility on the residual demand curve on a winter week (second week in the year) in the EU28 area for 2030. In red, the base scheduled demand is shown, without utilization of flexibility, and in black the optimized demand with the utilization of flexibility from smart appliances. The week shown in figure starts with Wednesday 00.00 am and ends with Tuesday 11.00pm.

According to the expectations, the figure shows that the flexibility from smart appliances is used to flatten the peaks in the residual demand curve caused by the intermittent RES production and the base case demand curve. The flexibility is used optimally, but within own specified constraints, such as for instance, limited shifting time. Therefore, there are still some peaks remaining in the residual curve from the flexible case.

In the figure, on the fifth day of the second week, just after mark for 2.6 weeks on the horizontal axis, there were two small sharp peaks in the base case residual curve (red line). They were compensated by the flexible demand shifting in the flexible case, as can be seen in the black line. By smoothing the residual curve in this way, the system experienced benefits. For instance, the ramp up and ramp down costs of the conventional dispatchable units were decreased, which had a positive effect on the total costs.

In general, it can be observed that the flexibility is used in particular to reduce the peaks in the residual demand curve. These peaks take place during the peak moments, which in winter take place around noon, and in the late afternoon hours, and during the low residual demand time, which typically takes place in the night, between 2 and 5 am. Secondly, it can be seen that the flexibility is utilized to smoothen the residual demand curve, as explained above. The smoother the residual curve is, the more of cheaper baseload technologies can be scheduled. This impacts all the chosen KPIs in a positive way.

In Figure 68, a stack diagram of the demand side flexibility from smart appliances is shown against the fixed, nonflexible part of the demand. It is shown for a summer week in Germany in the 2030 scenario, in which there was the largest number of the enabled smart appliances compared to all the other benchmark years. The demand is shown for Germany; however, similar trends and ratios can be observed in all the Member States, and therefore also in the aggregated EU28 area. Green stack in the figure represents the flexibility from periodic appliances and energy storage appliances, which are modelled purely as demand shifting. Dark red stack represents the flexibility from HVAC appliances, which are modelled as complex demand shifting. Finally, the nonflexible, fixed part of the demand is shown in blue stack. Flexibility from residential energy storage is not shown in the figure, as it is modelled as storage and not demand shifting, and as such, it has no defined base demand. Nevertheless, this flexibility is utilized in the use case for the same purposes as the demand shifting flexibility.

Although at every time instance, there is some flexibility from smart appliances, and also from both, periodic appliances and energy storage appliances, and from the HVAC group of appliances, the shares of flexible demand compared to the total demand are quite low, as also summarized in Table 51. In fact, yearly average share of flexible smart appliances demand in the total demand in EU28 is as low as 4.6% in 2030, 1.22% in 2020, and 0.18% in 2014. These shares are expressed as the total energy of flexible demand in a year over the total demand energy in the same year. The peak power of flexible demand is a relevant indicator of the amount of demand side flexibility. The peak power of flexible demand from smart appliances is computed to be 2.76GW, 9.77GW, and 43.37GW for 2014, 2020, and 2030, respectively. Expressed as percentage of the total demand, these numbers result in 0.92% for 2014, 3.17% for 2020, and 10.68% for 2030.

Table 51 Share of flexible demand over the benchmark years

Year	Share of flexible demand energy in the total demand energy	Share of peak flexible demand in the total demand	Peak flexible power in the EU28 area [GW]
2014	0,18%	0,92%	2,76
2020	1,22%	3,17%	9,77
2030	4,6%	10,68%	43,37

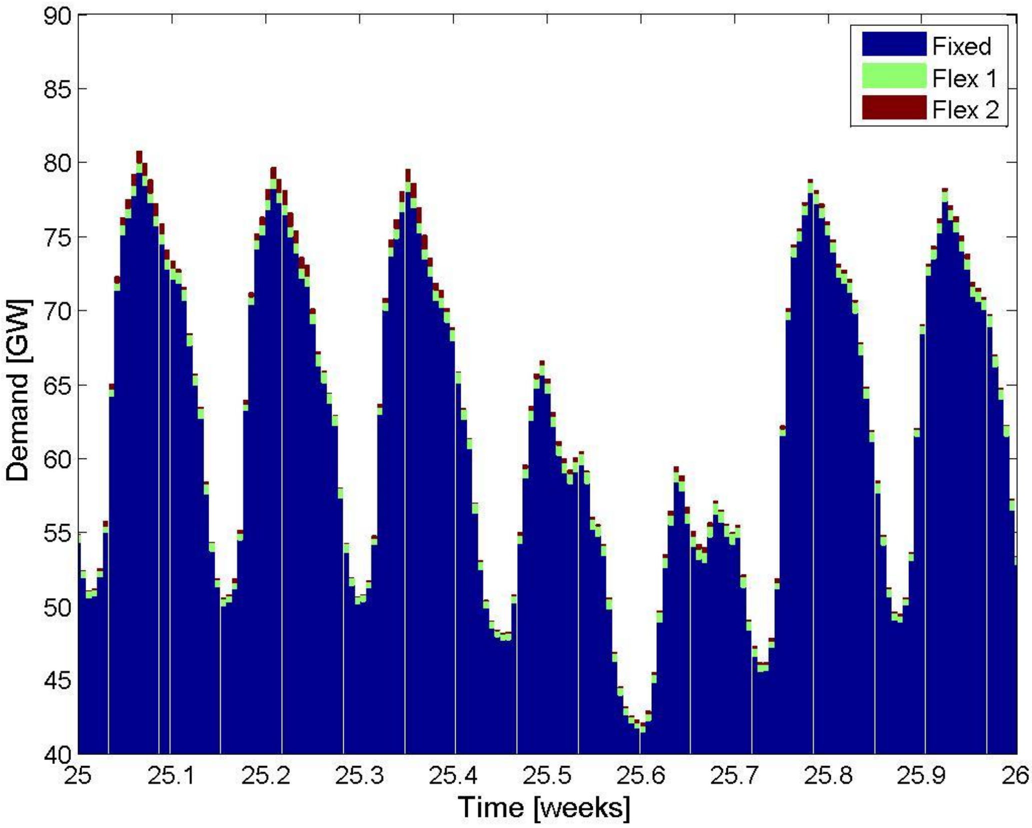

Figure 68 Demand side flexibility from smart appliances (green from periodic appliances and energy storage appliances, and red from HVAC appliances) against the fixed demand (blue) in Germany on a summer week in 2030.

Figure 69 is an equivalent of Figure 68, but instead of a summer week as in Figure 68, a winter week is chosen in Figure 69. The colour legend remained the same, as well as the Member State (Germany) and benchmark year for which the data is shown. It is interesting to observe a shift in flexibility potential in the two groups of flexibility: whereas in winter, more flexibility from HVAC appliances is available, in the summer months, there is more flexibility available from the energy storage and periodic appliances. Moreover, it is clearly visible that the demand in winter months is higher than in the summer months, and that also there is more of flexible demand in winter months than in summer months.

Both figures, Figure 68 and Figure 69, clearly show how much more demand is nonflexible than flexible. Nevertheless, even with such an amount of unlocked flexibility from demand side[322], benefits to the system can be observed, as will be discussed next in more detail.

[322] Flexibility from demand side is not necessarily only flexibility from smart appliances.

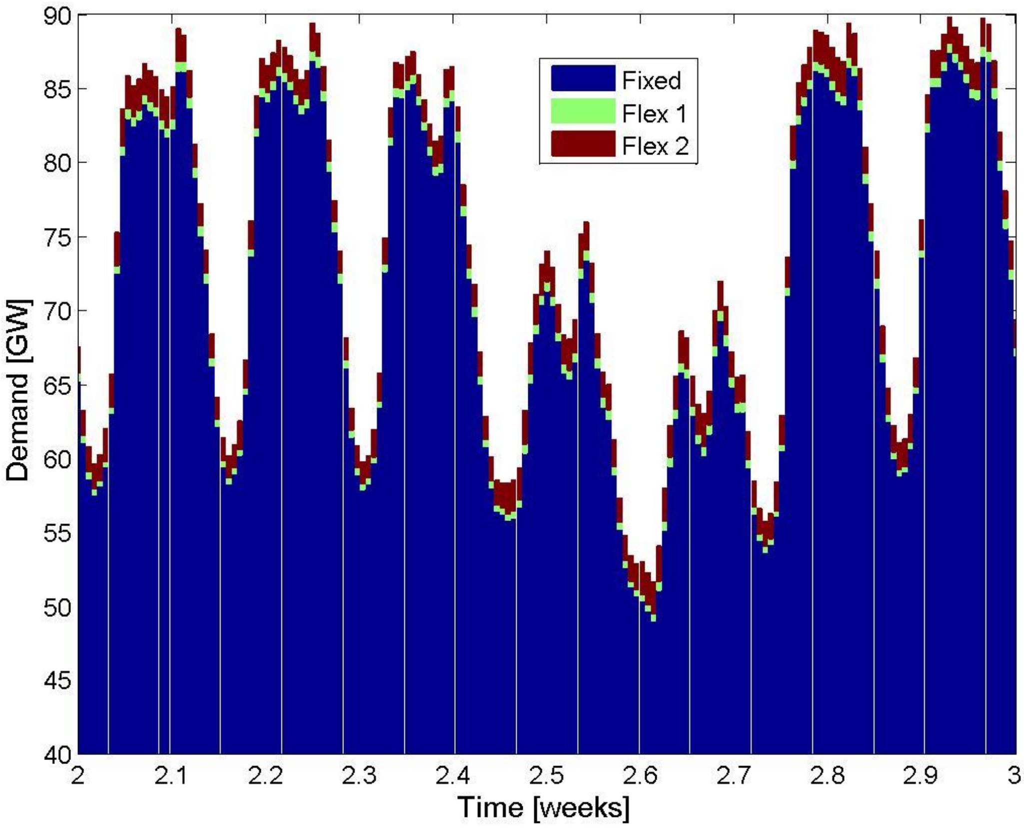

Figure 69 Demand side flexibility from smart appliances (green from periodic appliances and energy storage appliances, and red from HVAC appliances) against the fixed demand (blue) in Germany on a winter week in 2030.

6.2.6.2. Calculated benefits from the smart appliances

To put a value on the flexibility of smart appliances, let the indicator ΔKPI be the difference in the KPIs computed in the base case, and the KPIs computed in the flexible case. Previously, the three KPIs, namely the total costs, total CO_2 emissions and the efficiency of the utilized generation mix, which is related to the primary energy savings, were determined for the base case in Task 5, where no flexibility of the smart appliances is used. These indicators are denoted by $KPI1_{ref}$, $KPI2_{ref}$, and $KPI3_{ref}$. Here in Task 6, the same indicators are computed for the case with the modelled smart appliances flexibility, as presented in Table 50 KPIs for the day-ahead use case for each of the benchmark years These indicators are denoted by $KPI1_{flex}$, $KPI2_{flex}$, and $KPI3_{flex}$.

Finally, on the basis of these numbers, ΔKPIs (the savings in total costs, savings in CO_2 emissions, and increase in utilized generation mix efficiency) are computed as the difference between the two. More precisely, the savings in total costs and CO_2 emissions are computed as the difference in obtained KPIs with and without flexibility from the smart appliances:

$\Delta KPI1 = KPI1_{ref} - KPI1_{flex}$, $\Delta KPI2 = KPI2_{ref} - KPI2_{flex}$, $\Delta KPI3 = KPI3_{flex} - KPI3_{ref.}$

Note that the sign in ΔKPI3 is different from the one defined in ΔKPI1 and ΔKPI2. This is chosen so that ΔKPIs are always positive if smart appliances are contributing to better economical and/or environmental system performance.

In Table 52 Differences in KPIs as a consequence of utilization of flexibility from smart appliances for the day-ahead use case and each of the benchmark years, differences in KPIs, ΔKPIs, as a consequence of utilization of flexibility from smart appliances for the day-ahead use case and each of the benchmark years are presented.
The general trend that can be observed in the results is that the more flexibility there is, the better economic and environmental indicators become, which was to be expected. Note that ΔKPI2 is given in kt of CO_2 emissions, whereas KPI2 was expressed in Mt of CO_2 emissions.

Table 52 Differences in KPIs as a consequence of utilization of flexibility from smart appliances for the day-ahead use case and each of the benchmark years

Day-ahead use case	ΔKPI1 (savings in total system costs) [M€]	ΔKPI2 (savings in CO_2 emissions) [kt]	ΔKPI3 (primary energy savings) [%]
2014	12,1	13,9	0,002
2020	137,9	127,3	0,021
2030	2342,6	57,6	0,114

There is a remarkable effect in the amount of savings in CO_2 emissions in 2030 compared to the amount of savings in CO_2 emissions in 2020: whereas one would expect it to be larger in 2030, it is larger in 2020. The reason for this lies in the load shedding that occurred in the base case for 2030, whereas there was no load shedding in 2020. In the flexible case for 2030, there is still load shedding, but less compared to the base case. Therefore, more energy is produced to satisfy the load in the flexible case for 2030 than in the base case for 2030. This explains a lower increase in CO_2 emissions savings compared to 2020 where there was no load shedding and the same amount of electrical load was served in both reference and flexible case.

The increase in the efficiency of the utilized generation mix, ΔKPI3, changes the least with the addition of flexibility of smart appliances, and can be considered negligible.

The defined ΔKPI3 gives an indication of the primary energy savings, which increase with increased efficiency of the utilized generation mix. Nevertheless, because the difference between the base and flexible case is small, it might be interesting to look directly into the numbers defining the primary energy savings. These numbers can also serve as an upper bound on the additional energy consumption that smart appliances can have for being able to act smart.

The primary energy savings due to utilization of flexibility from smart appliances per benchmark year are presented in Table 53. Similarly as for ΔKPI3, an increase over the years can be observed. This increase is due to the increased share of smart enabled appliances.

Table 53 Primary energy savings due to utilization of flexibility from smart appliances in TWh of primary energy, per benchmark year

Year	Primary energy savings [TWh]
2014	0,14
2020	1,10
2030	3,36

To put the savings in total system costs further in perspective, Table 54 gives the savings as percentage of the total system costs for the electricity production, and compares it to the share of flexible demand in the total demand (in terms of energy and not peak power). Over the years, not only the absolute value of savings increases, but also the savings computed as percentage of the total system costs tend to increase, with the largest amounts for the 2030 scenario, when there is the most flexibility, and when also the fuel and CO_2 emission prices are the highest.

Table 54 Savings in total costs due to utilization of flexibility from smart appliances, and share of flexible demand in the total system demand

	Savings as % of the total costs	Share of flexible demand in the total demand (energy-wise)
2014	0,02%	0,18%
2020	0,18%	1,22%
2030	2,03%	4,6%

In Table 53 Primary energy savings due to utilization of flexibility from smart appliances in TWh of primary energy, per benchmark year, an overview is given from the evolution of the average value of the hourly marginal electricity prices with and without the use of flexibility. In general, electricity prices are expected to increase significantly by 2030, primarily driven by the increase in CO_2 costs (see assumptions on fuel costs in Task 5). Nevertheless, the table below shows that the use of flexibility from smart appliances in 2030 could lead to an average decrease of marginal electricity prices of around 11% (without considering the cost to use this flexibility), which is a significant decrease in the electricity price, in particular taking into account that the peak share of flexible demand was maximally 10,7 % and the energy share of flexible demand was on average 4,6%.

Table 55 Average marginal electricity prices[€/MWh] for the day-ahead use case, base and flexible case: differences due to utilization of flexibility from smart appliances

year	flexible case	base case
2014	42,70	42,70
2020	52,93	52,94
2030	85,88	97,03

The KPIs as presented above are defined on the system level, and as such, they quantify the operation of the system as a whole using the flexibility of all the smart appliances together. Therefore, KPIs cannot straightforwardly, without introducing additional assumptions, be determined separately per smart appliances category or even per individual smart appliance. In other words, there is no simple way to completely accurately distinct in resulting benefits from flexibility among smart appliance groups. Nevertheless, on the basis of this schedule and additional information from Tasks 1-3, and the optimal schedule of different flexibility groups (group 0 – group 3), an approximation of the value of benefits per enabled smart appliance per year from the computed total system benefits is extracted as described below.

In order to calculate the value per appliance for 2014, 2020 and 2030, the following steps are taken: Firstly, the total benefits (ΔKPI1), are distributed across all smart appliance groups on the basis of the optimal shifted flexible demand profile. This is done by multiplying the hourly marginal realized prices from the reference case with the difference in baseload flexibility profile (= the available amount of flexibility during each hour before any shifting) and optimal shifted flexibility profile for each of the smart appliance groups. This means that if flexibility from a certain group of smart appliances is mainly used during 'expensive hours', the value of benefits will be higher. These values are presented in Table 56.

Then, in order to calculate the value for each individual appliance, the benefits per appliance group are divided by the number of smart enabled appliances (see Task 2). The overview of the theoretical monetary benefit per individual appliance is given in Table 57.

Table 56 Theoretical monetary benefits from providing flexibility per group of enabled smart appliances in €/MWh shiftable energy capacity

Group	Smart appliance	2014	2020	2030
Periodical appliances	Dishwashers	0	9,36	166,46
	Washing machines	0	4,77	62,47
	Tumble dryers, no heat pump	0	3,43	10,13
	Tumble dryers, heat pump based	0	2,76	155,35
Energy storing appliances	Refrigerators and freezers (residential)	0	7,41	103,61
	Electric storage water heaters (continuously heating storage)	0	5,78	85,91
	Electric storage water heaters (night storage)	0	1,28	7,57
	Tertiary cooling - compressor	0	10,22	196,11
	Tertiary cooling - defrost	0	10,95	211,9
Residential cooling and heating (heat pump based)	HVAC cooling, no storage	0,61	3,57	10,93
	HVAC cooling, with thermal storage	2,39	13,77	41,53
	HVAC heating, no storage	0,95	4,68	117,91
	HVAC heating, with thermal storage	3,6	18,61	320,46
Tertiary cooling and heating (heat pump based)	HVAC cooling, no storage	0,54	3,11	9,37
	HVAC cooling, with thermal storage	3,11	18,38	53,76
	HVAC heating, no storage	0,1	0,86	15,79
	HVAC heating, with thermal storage	0,48	3,51	50,49
Joule based tertiary and residential cooling and heating	Electric radiators, no and with inertia, boilers	0	7,45	395,32

Table 57 Theoretical monetary benefits from providing flexibility per enabled smart appliance per year (given in [€/year/appliance] or [€/year/m^2] for tertiary cooling)

Group	Smart appliance	2014	2020	2030
Periodical appliances	Dishwashers	0,00	4,07	14,01
	Washing machines	0,00	2,37	7,63
	Tumble dryers, no heat pump	0,00	4,77	16,28
	Tumble dryers, heat pump based	0,00	3,84	13,14
Energy storing appliances	Refrigerators and freezers (residential)	0,00	0,48	1,63
	Electric storage water heaters (continuously heating storage)	0,00	2,31	9,44
	Electric storage water heaters (night storage)	0,00	1,35	2,20
	Tertiary cooling - compressor[323]	0,00	0,09	1,40
	Tertiary cooling - defrost	0,00	0,10	1,51
Residential cooling and heating (heat pump based)	HVAC cooling, no storage	0,58	0,94	0,96
	HVAC cooling, with thermal storage	4,22	6,75	6,76
	HVAC heating, no storage	9,16	12,51	104,64
	HVAC heating, with thermal storage	64,24	92,29	528,17
Tertiary cooling and heating (heat pump based)	HVAC cooling, no storage	6,87	11,09	11,08
	HVAC cooling, with thermal storage	74,07	121,54	118,13
	HVAC heating, no storage	0,96	2,25	13,73
	HVAC heating, with thermal storage	8,45	17,04	81,51
Joule based tertiary and residential cooling and heating	Electric radiators, no inertia	0,00	1,24	9,55
	Electric radiators, with inertia	0,00	1,99	15,28
	Boilers	0,00	9,93	76,41
Residential energy storage systems	Home batteries	27,74	71,62	1030,80

6.2.7. IMBALANCE USE CASE

Imbalances between production and consumption of energy should be mitigated in real-time. The three sources of imbalance are deviations in the expected production of wind and solar and deviations in the forecasted consumption. In general, deviations in consumption will remain the most important cause of imbalance and are expected to increase by 2030 due to the average increase in consumption. However, although the share of wind and solar in the total imbalance across the year might be relative small (but increasing), it does not mean they do not put the system under pressure. On the contrary, the deviations in wind and solar might be very big at particular moments, and if they happen in combination with for example low consumption (holiday, weekend, night), there is a need for fast responding and flexible devices that could react to guarantee security and stability of the electricity system. Smart appliances can play a role during these specific events.

[323] For tertiary cooling processes (compressor and defrosting), the value is given in [€/year/m^2].

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Table 58 gives the overview of the imbalance use case for 2014, 2020 and 2030. On average, the cost for imbalance (KPI1) increases between 2014 and 2030, mostly due to the increase of forecast errors (by load, wind and solar), and also due to the increase in fossil fuel and CO_2 emission prices. For KPI2, the CO_2 emissions decrease to almost zero in 2030. This is due to the fact that basically all imbalances are solved by the use of smart appliances (instead of conventional generation), which have a zero emission. Also the efficiency of the utilized generation mix increases due to the higher share of smart appliances.

Table 58 KPIs for the imbalance-ahead use case for each of the benchmark years

Imbalance use case	KPI1 (total system costs) [M€]	KPI2 (CO_2 emissions) [Mt]	KPI3 (efficiency of the utilized generation mix) [%]
2014	5,55	1,37	57,839
2020	9,76	0,90	88,751
2030	226,93	0,24	100

In Table 59, the difference of comparing the calculated KPIs with the benchmark values (as presented in Task 5), show that there is an important decrease in system costs, most noticeable in 2030, due to the use of smart appliances. Also with respect to CO_2 emissions, a large decrease can be observed, due to the zero emission factor applied for smart appliances. Overall, it is clear that, mainly in 2030, due to increasing CO_2 costs and fuel prices, the benefits coming from smart appliances are high.

Table 59 Differences on KPIs as a consequence of utilization of flexibility from smart appliances for the imbalance use case and each of the benchmark years

Day-ahead use case	ΔKPI1 (savings in total system costs) [M€]	ΔKPI2 (savings in CO_2 emissions) [kt]	ΔKPI3 (increased in efficiency of the utilized generation mix) [%]
2014	1,66	0,18	11,37
2020	1,44	0,75	42,16
2030	143,66	1,54	51,94

The individual values per appliance for the imbalance use case are not detailed here but are in the same order of magnitude as for the day-ahead use case. This statement is further supported by the fact that the values awarded today for flexibility in the reserve market (R3DP) in Belgium (= imbalance use case) are in the same order as the values reported in Table 56 of this report (day-ahead use case). For 2016, a value of 3,14€/MWh was awarded for flexibility, coming from the distribution grid[324].

[324] http://www.elia.be/en/suppliers/purchasing-categories/energy-purchases/Ancillary-Services-Volumes-Prices

6.2.8. OTHER USE CASES

Within the scope of this preparatory study, the benefits of the flexibility from smart appliances are evaluated for the day-ahead case and imbalance use case, as presented above. Nevertheless, these are not the only possible use cases for the flexibility from smart appliances, as discussed earlier in Task 2. In addition to the day-ahead and imbalance use case, additional use cases exist where the flexibility of smart appliances would have significant value. One of the most potentially interesting use cases is the use of flexibility by distribution system operators (DSOs) to solve local grid constraints (congestion management and voltage control) in specific areas of the distribution grid.

Today, it is not yet possible to build a sound evaluation of benefits from smart appliances flexibility, similar to the day-ahead and imbalance use case, due to a lack of data. However, several research projects are ongoing to explore the opportunities for flexibility used by DSOs.

The increase of distributed renewable energy sources (DRES) creates new challenges for DSOs. DSOs are responsible for the management and operation of the distribution network, guaranteeing security and quality of supply. A large share of DRES is connected at the distribution grid. Dependent on the situation of the DSO-grid, the increase of DRES could create additional problems, such as local congestion or voltage violations. This is in particular true in areas with low demand and a high share of DRES connected as in these areas, the electricity generation from RES might easily exceed the consumption[325]. In addition, the risk of having additional local constraints to be violated by the increase in RES, puts also a barrier for the further development of RES connected at the distribution grid.

Traditionally, DSOs use network planning and network reinforcements as means to solve local constraints. However, only relying on the extension or reinforcement of the grid might not be cost-efficient. An alternative or complementary solution could be found in the use of flexibility, offered by customers connected at the distribution grid. Flexibility offers many potential benefits for DSOs[326]:

- It solves local congestion.
- It can be used for voltage control.
- It increases the amount of curtailment of RES, increasing the hosting capacity for RES in the system.
- It allows the DSOs to shift peak consumption, making a more efficient use of the distribution grid possible.

The use of DR by DSOs is also supported by European legislation. The Energy Efficiency Directive (EED) 2012/27/EU[327] states for example that DSOs should be incentivised to improve efficiency in their operations, using demand response alongside traditional network reinforcements to solve local grid constraints. Flexibility offered could temporally defer future grid reinforcements or even replace them.

Today, flexibility is not yet used by DSOs as a system service. This could be explained by several key elements:

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[325] http://www.edsoforsmartgrids.eu/wp-content/uploads/public/EDSO-views-on-Flexibility-FINAL-May-5th-2014.pdf

[326] http://www.edsoforsmartgrids.eu/wp-content/uploads/public/EDSO-views-on-Flexibility-FINAL-May-5th-2014.pdf

[327] http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1399375464230&uri=CELEX:32012L0027

- DSOs do not have processes or tools in place to contract flexibility (this is in contrast to TSOs and BRPs who have used flexibility for years).
- There is no organized local market yet where local flexibility is offered.
- Current national regulatory frameworks do not yet sufficiently recognize and incentivize the complementary role of non-conventional smart grid solutions (flexibility) used by DSOs[328].
- The use of flexibilities by DSOs implies the adoption of new roles by the DSO and the evolution of current roles. The evolution of the roles of DSOs is further discussed in the context of the FP7 project EvolvDSO[329].
- Etc.

The potential use of flexibility by DSOs is an important research topic. Another H2020 project, Smartnet[330], investigates for example how TSOs and DSOs will collaborate together in case of the provision of ancillary services connected at the distribution grid.

Several projects tried to estimate the value flexibility has for the DSOs but most results are based on small-scale research and innovation projects. In a following phase, the value for flexibility for DSOs will need to be demonstrated on a larger scale to have a more in depth understanding of the costs and benefits. Important remark is that the value is very dependent on the specific grid conditions (amount of RES connected, demand, availability of flexibility, investments in grid reinforcement,…). Some examples are listed below.

A CRE-study from 2015 examines 14 case studies in total. The value of flexibility ranges between 30€ and 90€/kW/year for flexibility used locally[331]. However, this value fluctuates a lot (between 0€ and 200€/kW/year) dependent on the type of grid reinforcement that could be postponed. To note that these values only represent the average value for areas where flexibility has a value, i.e. mainly rural areas. In many areas in the distribution grid, flexibility has no value at all due to the lack of constraints. The study also explains that the level of income from using flexibility locally is in the same order of magnitude as using flexibility on a national level. In the iPower-project, a value of 50€/kW/year was calculated in a case-study as flexibility value for the provision of DSO system services for a specific area[332].

In conclusion, DSOs might have a potential interest in using flexibility provided by i.e. smart appliances. However, this value is highly dependent on the local grid situation and the type of grid reinforcements the DSO could postpone or avoid due to the use of flexibility. Today, the use of flexibility by DSOs is still in a research phase and has only been demonstrated in small-scale pilots. In the coming years, large scale demonstration projects will have to confirm the value of flexibility for DSOs and the total potential on national and European scale.

[328] http://www.evolvdso.eu/getattachment/6f0142bf-0e66-470c-a724-4a8cbe9c8d5c/Deliverable-1-4.aspx

[329] http://www.evolvdso.eu/

[330] http://smartnet-project.eu/news/smartnet-projects-kick-off-meeting-26-27-january-2016/

[331] http://www.cre.fr/en/documents/publications/studies/(entreprise)/r%C3%A9gie+de+bazas/(theme)/distribution/(type)/Electricit%C3%A9

[332] https://files.conferencemanager.dk/medialibrary/3b2dee4c-69cc-4783-9f05-1d08954095c3/images/2_Business_cases_of_flexible_demand_-_Morten_Stryg.pdf

6.2.9. EVALUATION OF COSTS AND BENEFITS FOR THE ENERGY SYSTEM

Smart appliances can provide energy system services both in day-ahead and in real-time by shifting operation and as a result, adapting the consumption. In day-ahead, this leads to a reduced cost and CO2 emission compared to a situation without smart appliances, due to the fact that additional generation by conventional power plants could be avoided due to a smart shift in load. In real-time, the same benefit of smart appliances can be observed in case a shift in demand by smart appliances avoids additional production by conventional generation units. In addition, the use of smart appliances also leads to a reduction in curtailment of RES in case there is too much intermittent energy production compared to the demand.

In conclusion, the use of flexibility from smart appliances is not necessarily reducing the electricity consumption in total. However, it reduces the need for more expensive and more polluting conventional generation units at moments of peak load or large imbalance. This leads to both monetary savings for the system and reduced CO2 emissions, which in the framework of the ETS not only has an environmental but also an economic value.

The quantification of these system benefits is detailed in previous sections of this document. Please note that the benefits are determined for flexibility at the level of a specific smart appliances flexibility group. In the optimisation, the assumption is made that the marginal price of flexibility is zero, to allow a maximal use of flexibility. This means that the analysis is a representation of the maximum potential that flexibility might have in the current and future energy system.

In a second step, in order to determine the viability of the business cases of the use of flexibility of smart appliances, one should also analyse the cost side to enable this flexibility to participate in the market. It is obvious that the flexibility of smart appliances will only be used in a real market situation if these costs are lower compared to the benefits. The quantified benefits can therefore be seen as an upper bound.

The benefits calculated are the total benefits for the system which means that the benefits will need to be compared with the total costs of the entire value chain of smart appliances, from producer until the end-user. As the benefits of the flexibility are supposed to be passed on to the end consumer, the other partners in the value chain will require a share of the value of flexibility via the price they will charge to the end consumer for the production of the smart appliance or the delivery of certain services enabling the flexibility of smart appliances to participate in the market. It will depend on elements such as market power, subsidy systems, sector rules, EU and Member State regulations, how the system value of flexibility will be divided across the value chain and, as a result, what will be the final benefit awarded to the end consumer, compared to a situation where the end consumer is not investing in a smart appliance.

The costs and benefits for the energy system can be summarized as follows.

- The flexibility provided by smart appliances can support the energy system in many ways:
    - It can optimize the planning in day-ahead (day-ahead use case) by replacing expensive gas and coal units during moments of peak consumption. This optimization results in a decrease in costs for the system and a reduction in CO_2 emissions.
    - It can support the system in real-time (imbalance use case) in case production is not sufficient to cover the demand. Similar to the day-ahead use case, flexibility from smart appliances can be used to avoid the activation of gas or coal power plants by energy producers or network operators on the one hand or the possibility of load

shedding on the other hand. This results again in a decrease in costs for the system and a reduction in CO_2.

- It can support the system in real-time in case there is too much production which could not be stopped in an economic efficient way (e.g. in a situation where high amount of wind and solar energy are produced) or alternatively, in case demand is much lower compared to the initial forecast. The use of flexibility from smart appliances can in this case prevent the curtailment of wind and solar energy in the system. As a result, the use of smart appliances allows an increase in hosting capacity of renewable energy.

- Another important element is the fact that home battery systems, in combination with solar panels are not only supporting the system, but are also increasing the share of self-consumption. This has additional benefits, such as a potential reduction in grid tariffs as there is less need to increase the capacity of the distribution grid,…

- The benefits the flexibility of smart appliances have a clear value for the energy system. This value has to be compared with the cost or minimum remuneration owners of smart appliances require offering their flexibility to the market. The cost differs dependent on the characteristics of the flexibility (shifting potential, average shifting period) but also on the cost of the smart appliance (purchase, maintenance, and reduced life-time of the smart appliance if used in a more flexible way). In addition, possible loss of comfort could also require an additional compensation on behalf of the owners of flexibility.

- Within the scope of this preparatory study, the benefits of the flexibility from smart appliances are evaluated for the day-ahead case and imbalance use case. There are additional use cases, such as support for grid congestion (on the TSO and DSO grid) that are not detailed in this study due to a lack of existing data. Today, these use cases are considered rather immature but they are expected to become more promising in the coming years. As explained before, the value of flexibility for additional use cases, such as congestion management, is in the same order of magnitude as for the use cases detailed in the context of this study. Worth noting is that for the use cases supporting DSOs, the value is also very location dependent, meaning that in some grids, the value will be high, and in other grids, there will be no value for services that support the DSO. This is in contrast to the day-ahead and imbalance use case where the value is independent from the location of the flexible resource.

6.2.10. EVALUATION OF THE COSTS AND BENEFITS FOR THE END-USER

6.2.10.1. Financial benefits for the end-user

As indicated in Table 57, the modelling results show that the theoretical potential monetary benefit of DSF per end-consumer appliance varies strongly between appliances. When committed in the day-ahead or real-time electricity markets and according to the BAU scenario, the value is estimated to be up to 120€/year/m² in 2020 (for tertiary cooling with thermal storage) and up to 530 €/year in 2030 (for residential heating with thermal storage). For residential energy storage systems the values are even higher. Depending on the combination of appliances used, this can add up to a considerable financial benefit.
When committed in the imbalance markets, the value is the same order of magnitude. Note that this calculated value is the result of a theoretical exercise, as in reality the financial benefits will depend

on factors such as the market business models, the degree to which the benefits are transferred through the value chain to the end-user, the availability of other flexibility types (e.g. industrial Demand Response, Demand Response from electric vehicles), etc.

DSF can also be used for other applications, such as grid congestion management or other ancillary reserves, the value of which may be higher than these figures. The added value for these cases is country, region or even district dependent. E.g., in districts in which all houses are equipped with photovoltaic panels and heat pumps, the value of DSF for grid congestion management could be larger than the value for day-ahead or imbalance markets, dependent on the local grid situation. An example of where such situations are emerging is the 'Stroomversnelling' project[333] in the Netherlands, which has the ambition to mass-renovate entire districts totalling 111.000 renovates buildings by the end of 2020 and where the mass installed photovoltaic panels and heatpumps have already necessitated local grid re-enforcements.

6.2.10.2. Additional investment and operational costs

Cost elements that need to be considered from an end consumer perspective are the initial investment costs on the one hand and the recurrent operational costs on the other hand which can be specifically attributed to the DSF functionality of the appliance.

The operational cost consists of the operating cost of the communication infrastructure and the costs related to increases in energy consumption. The latter is discussed separately below. The in-house communication infrastructure is mostly shared with other devices and applications. The operational cost that can be attributed to the smart appliances is therefore case dependent, but is assumed to be very low or negligible compared to the investment costs.

Analysis of publicly available information and contacts with industry have made it clear that it is very difficult to derive generalised estimations of the additional investment costs that can only be attributed to the DSF feature specifically subject to this Lot 33 Preparatory Study. Below, a summary is given of the findings elaborated in Task 4.

When looking at the market, it seems that some premium segment household appliances (periodical, continuous and behavioural) currently available on the market are already network connected and dispose of sufficient computational power as a basic requirement to allow DSF. These appliances include washing machines, tumble dryers, dishwashers, cooling appliances, hobs and ovens, range hoods and water heaters. For these appliances, additional costs to allow DSF mainly relate to software development, testing and documentation. In case the appliance is not yet network connected, features also need to be added in the form of additional computational power, a printed circuit board, wires and a wireless connectivity module.
Additional costs of the necessary adaptations specifically attributed to the DSF feature will mainly depend on the amount of products in the series of appliances produced. Assuming larger product series in a context of a future smart grid market, cost levels at manufacturer's level including testing and documentation are estimated as follows:

- A networked appliance only needing software modifications, testing, documentation etc.: 5-10€
- A non-networked appliance also needing a network connectivity module etc.: 15-20€

These additional manufacturing costs make abstraction of R&D costs and are exclusive of mark ups for distribution and retail level.

[333] http://www.stroomversnelling.net

The Task 4 report has also identified the technical adaptations required to enable DSF including the involved costs for the HVAC appliance category which represents an important share of the total consumed energy in the EU. Heating and cooling appliances involved are the following: electric radiators, thermal storage radiators, electric boilers and circulators, heat pumps and air conditioners. The necessary modifications and involved costs can be divided according to the so-called *joule effect appliances* (radiators, thermal storage radiators and boilers and circulators) on the one hand and the *thermodynamic appliances* (heat pumps and air conditioning) on the other hand.

For the joule effect appliances, the link between the aggregator and the appliance can be made either with an electronic thermostat capable of receiving and exchanging signals with the grid (in this case only software adaptability is required) or via an adaptor (requiring hardware and software modifications). As assessed in Task 4, the following costs are estimated for the changes of the joule effect appliances:

- A networked joule effect only needing software modifications (with an electronic thermostat i.e.), testing, documentation etc.: 5-10€
- A non-networked appliance also needing a network connectivity module etc.: 10-15€

In the context of this study, thermodynamic appliances involve a vapor compression cycle with the input of energy (in this case electricity) being consumed by the compressor in order to exchange heat between outdoors and indoors. Input from industry indicated that adding DR to a heating device using a vapor-compression cycle would raise the retail price approximately with 100€-200€ including software adaptation and development, installation costs, intervention etc. According to the authors of this Task report, this should rather be considered as the high end of the range of additional costs. These costs are assessed to include research & development costs and costs associated with the first appliances being produced in small series in a short term perspective, knowing that purchases prices of adaptors and electronic thermostat are in the range of respectively 10€ and 2€ per piece.

Apart from the benefits related to the use of flexibility from an energy system perspective, other benefits and costs are relevant from an end-user perspective, these are addressed in the following sections.

6.2.10.3. Positive/negative impact on the energy consumption

The use of the DSF may result in operating points that deviate from the most energy efficient operation point, e.g., by cooling deeper or heating higher. However, the assumptions underlying the estimates of the value of flexibility in this study were chosen in such a way that this surplus consumption is considered to be negligible.

Therefore it should be clear that more flexibility would potentially be available if less efficient operating point are permitted. In this case, the end-user should be compensated for this surplus energy consumption with an acceptable margin that still lies within the surplus added value of providing the extra flexibility. From a system perspective, this can be interesting provided that such a case allows for increased share of RES, leading to reduced CO_2 emissions despite the surplus energy consumption.

If the appliance is equipped with extra DSF specific electronics, then the operation of these may cause a small to negligible surplus electricity consumption, as discussed in Task 4. On the other hand, the functionality required for DSF support also offers opportunities for improved energy efficiency, as smart appliances allow a detailed view of the energy consumption of those appliances. A number of studies [Darby 2006; Fischer 2008; Ehrhardt-Martinez 2010; Faruqui 2010; Stromback 2011: Lewis 2014; Van Elburg 2014] have assessed the effectiveness of energy use feedback (broadly defined, taking into account multiple feedback channels ranging from awareness campaigns to dedicated in-home displays showing energy consumption in real time), mostly in terms of achieving energy savings. These studies show consistently that there is considerable case-to-case variation of reported energy savings, typically in the range of 0 - 20%[1], with usual savings between some 5 and 12% [Fischer 2008]. Variation may be explained by a variety of factors other than the feedback design, including the climate conditions, the length of pilot, the number of participants and the level of education provided [see Stromback 2011 for an overview]. Studies specifically addressing smart meters have demonstrated that providing detailed electricity consumption information to end consumers, in the combination with advice on how to reduce energy consumption results in significant electricity consumption savings of typically 3% and up to 8% per household, depending on the quality of both the information presentation and the advice on energy saving measures[334,335].

Secondly, the measurement and control functionality, required for DSF functionality, can also be used to analyse and optimize the operation of the smart appliance from an energy efficiency point of view[336]. Smart appliances also allow a more user-friendly operation (e.g. through use of apps as opposed to manuals) which leads the end-user to the optimal operational setting under the given circumstances. Even though quantitative evidence is not yet available, the operational mode which is advised by the smart setting is expected to be more energy efficient compared to the setting the end-user would choose manually. The degree of increased energy efficiency will depend on various factors such as the specific smart appliance (e.g. more potential for a dishwasher compared to a washing machine), risk aversion from the end-user (e.g. preference for washing at higher temperature), potential rebound effects (e.g. end-user is more confident to use the appliances), etc.

6.2.10.4. Impact on comfort

Generally, one of the key arguments convincing consumers towards home automation and communication-enabled appliances is the increased comfort and ease of use. The functionality and infrastructure required for the support of DSF, and shared with IoT applications in general, also offers opportunities in this area. Examples are improved user interfaces, possibly through apps, as for instance demonstrated in the Smart Domo Grid project[337], preventive maintenance, etc.

As discussed in detail in Task 3, the additional impact of supporting demand response flexibility is strongly device dependent. The results of the analysis done in Task 3 regarding the impact on the comfort of the end-consumer is summarised below for each appliance type.

For periodical appliances like washing machines, dishwashers, tumble dryers and washer-dryers consumers may feel uncomfortable operating their appliances unattended because of safety aspects (e.g. fear of flooding or fire). These concerns could be addressed by improving safety features of the appliances and by offering relevant insurances. Quite a few appliances available on the market are

[1] Reported ranges: 0-15% [Darby 2006], 1-20% [Fischer 2008], 4-12% [Ehrhardt-Martinez 2010], 3-13% [Faruqui 2010], 2-12% [Stromback 2011], 3-7% [Van Elburg 2014].

[334] Eandis, Infrax, "*POC II Smart Metering, energie-efficiëntie, resultaat verbruik*"

[335] UK Department of Energy & Climate Change, March 2015, "*Smart Metering Early Learning Project: Synthesis report*"

[336] See, e.g., the 'smart control' functionality as defined in the Ecodesign requirements for water heaters and hot water storage tanks, set via regulation No 814/2013 of 2 August 2013: 'smart control' means a device that automatically adapts the water heating process to individual usage conditions with the aim of reducing energy consumption.

[337] http://ses.jrc.ec.europa.eu/smart-domo-grid

already equipped with safety features like aqua stop valves, which protect water damages by cutting off water supply immediately in case of emergency. The end-consumer's comfort may also be compromised by noise during operation of appliances at night. Innovative technologies like frictionless magnetic motors or low-vibration components, which are already offered on the market, may help to overcome this problem in future. In view of washing machines, tumble dryers and washer-dryers, potential further impacts on comfort are related to textile damages including fading of colours, mould and wrinkles if the drying process is not started immediately after the washing process is finished. Such textile damages can be avoided by means of comfort settings e.g. defining a maximum length of power interruptions or prompting the drum to tumble in certain intervals after the washing process is finished.

In the case of cooling appliances like refrigerators and freezers (residential and commercial), there is no impact on consumer's comfort as far as food quality and safety is not compromised and the appliance works reliably. These appliances operate fully automatic and therefore consumers will hardly notice smart operation. The possibility to monitor storage temperatures might easily help to overcome concerns in view of food safety and quality.

In view of electric storage water heaters, a lack of hot water may compromise consumer's comfort, especially in case of appliances with low storage capacities. As far as devices with large storage capacities are concerned or comfort settings are induced (e.g. defining a minimum state of charge), comfort losses are small or non-existent.

For all behavioural appliances, DSF would have significant impacts on consumer's comfort, as their operation requires an active involvement of the consumer and the latter wants the service being available directly upon request.

In case of HVAC appliances, impacts on consumer's comfort are related to temperatures exceeding a comfortable range. This range is defined in the EN 15251 standard, with the inside temperature not falling below 18 °C (19 °C for tertiary buildings) in winter and not exceeding 27 °C in summer, with a maximum variation of 2 °C/h. The same standard gives guidance regarding standard air flow rates by person and admissible pollutant concentration in buildings. As far as these permissible values are not exceeded, impacts on comfort are assumed to be low.

Regarding battery chargers, consumer's comfort may be significantly compromised if the state of charge is not sufficient on next usage. Reliable predictions are necessary to overcome these concerns.

In case of energy storage systems, there is no negative impact on consumer's comfort. In contrast, as a benefit they may provide backup power when the grid is not available.

The negative comfort impact by DSF enabled lighting is naturally a serious constraint as light is used when there is a need. Comfort impacts also include safety issues for both, residential and commercial areas. For street lighting, the comfort impacts may not be that significant, especially if they are limited in time.

6.2.10.5. Risk of unequal distribution of costs and benefits

The extra functionality of smart appliances implies a surplus cost. The distribution and size of this surplus cost depends strongly on the choice for a mandatory or non-mandatory approach. In case of a mandatory approach, the extra cost per appliance is the lowest due to the scale advantage. However, mandatory measures also imply that the costs are socialized and distributed across all appliance owners, including those owners that do not use and receive added value from the demand response flexibility. The latter is avoided with a non-mandatory approach. However, in this case the surplus cost of a smart appliance will be higher due to the loss of the scale advantage. There is then also the risk that smart appliance ownership for less fortunate people is hindered, and that they share less in the added value of demand response.

Most smart appliances, as envisioned today, depend on internet access. This threatens to exclude those people without internet access from sharing in the added value of smart appliances. One method to circumvent this, is to stimulate LPWAN support by smart appliances. Another is to support the use of the smart meter as a communication link.

The distribution of costs and benefits depends strongly on the energy market organisation. If consumers in a certain region or country have no or less access to DR programs, then they can also share less in the added value. A consumer right for access to variable tariffs or other DR mechanisms can alleviate this, as are actions to organize the energy market so that DR is supported or other governmental support schemes for demand response.

The added value of DSF is mostly created at the level of the BRP, TSO, DSO and/or aggregator. A fair share of this added value must flow from these parties to the consumer. Policy makers and energy regulators must be wary of and ensure that the consumer share in the benefits is proportional, and that the distribution of those benefits is fair, and does not unfairly favour specific groups of consumers, e.g., consumers more likely to switch supplier, higher potential (and higher income) households, etc.

6.2.10.6. Risk of vendor lock-in

Unlocking demand side flexibility requires smart appliances to cooperate with components outside of the appliance, e.g., an energy gateway, cloud systems, etc. This creates risks for vendor lock-ins, both to the vendor or manufacturer of the appliances, and to the energy retailers. It must be possible to use and interchange any smart appliance of any brand/vendor in any demand response program. The use and support of open standards is essential to achieve this. Also the energy market design has an impact on this matter, more specifically in the links between demand response programs and/or aggregators on the one hand and the energy retailers on the other.

6.2.11. EVALUATION OF THE COSTS AND BENEFITS FOR INDUSTRY

Based on the limited available data on additional costs (see Task 4 and previous section), it has not been possible to make an analysis of the impacts on industry regarding required investment levels and the derived impacts on the sectors‘ profitability, competitiveness and employment. The market trends/forecasts described in Task 2 clearly showed that digital communication functionality will be a common (commodity) function in most appliances sold from 2020 onwards. Manufacturers will most likely include digital communication functionality in all or (at least) in special product series for all product categories in the scope of this Preparatory Study, leading to ‘connected’ (communication-enabled) and ‘app-enabled’[338] appliances.

However, this tendency does not imply that these appliances will be interoperable or will provide DSF functionality, given the fact that in 2015 most of the communication-enabled appliances are not yet part of a DR program - except for smart thermostats and energy management systems (as detailed in Task 2).

[338] Most of these ‘smart‘ appliances or devices come with a smartphone or tablet app, which is indicated as ‘app-enabled’.

It is clear that the trend towards connected devices will have a significant impact on the business models, the roles, the sales channels and service channels in this market. Instead of a one-time contact (sales) with the customer, the manufacturer/vendor/service provider will in the IoT scenario have a permanent link with the customer for the entire lifetime of the product. Adding the DSF functionality will bring more opportunities for improving existing services and/or extending to new services valorising the benefits to the energy system.

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ANNEX 1 ANALYSIS PER APPLIANCE CATEGORY

HOUSEHOLD APPLIANCES

ELECTRICITY CONSUMPTION, MOST IMPORTANT PRODUCTS

Household appliances category contains the main appliances destined for private use: dishwashers, washing machines, tumble dryers, washer-dryers, refrigerators, freezers, water heaters, hobs, ovens, range hoods and vacuum cleaners.
In the following table, energy consumption data of the appliances in this category is shown to provide a first overview in view of DR potentials.

Table 69 : Total and household appliances electricity consumption in Europe (Bertoldi, 2012; Kemna, 2014)

	2010	2010
	TWh	**% total**
Electricity consumption EU27	2836	100%
Residential	842,5	ca. 30%
Dishwashers	25.3	0.9 %
Washing and drying	60.7	2.1 %
Refrigerators	82.0	2.9 %
Freezers	40.0	1.4 %
Water heaters	73.0	2.6 %
Hobs	40.1	1.4 %
Ovens	23.0	0.8 %
Range hoods	12.3	0.4 %
Vacuum cleaners	25.3	0.9 %

According to their main characteristics, all appliances mentioned above were divided into three categories: periodical appliances, permanent appliances and behavioural appliances.

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PERIODICAL APPLIANCES

DESCRIPTION

Periodical appliances are appliances that periodically execute a user initiated cycle, such as dishwashers, washing machines, tumble dryers (electric vented, electric condenser) and washer-dryers destined for private use. There is no interaction with the user while running and often the user does not require the programme to be finished as soon as possible.

INSTALLED BASE (EU27)

Dishwashers: in 2010, there were 82.799.000 appliances in stock. According to estimations, the number increases up to 98,345,000 in 2015, 115,036,000 in 2020, 131,797,000 in 2025 and 148,553,000 in 2030. (Kemna, 2014)
Washing machines: in 2010, there were 185,828,000 appliances in stock. According to estimations, the number increases up to 196,821,000 in 2015, 200,805,000 in 2020, 202,648,000 in 2025 and 204,744,000 in 2030. (Kemna, 2014)
Tumble dryers: in 2010, there were 62,723,000 appliances in stock. According to estimations, the number increases up to 68,018,000 in 2015, 71,801,000 in 2020, 75,767,000 in 2025 and 77,778,000 in 2030. (Kemna, 2014)
Washer-dryers: in 2012, sales of washer-dryers in the EU were above 700,000 units (about 4 % of the washing machine market) and the market is expected to grow. However, there is no information on installed base. (Kemna, 2014)

SHIFTING OR CAPACITY MODULATING POTENTIAL

SHIFTING OR CAPACITY MODULATING POSSIBILITY

There are three options to change the electricity consumption profile of periodical appliances:

1. For dishwashers, washing machines and washer-dryer, **start-time delay** or pre-select functions are already available on the market. This is the option for the user to manually shift the operation of the selected programme to a later moment in time. The power demand curve on activation of the appliance remains the same. Overall, 39 % of dishwashers and 32 % of washing machines are equipped with this option, but differently in various countries. The option allows anticipating or postponing power demand at any time. An average delay of 3 hours can be expected, the estimated maximum is about 19 hours for dishwashers and 9 hours for washing machines and tumble dryers. (Stamminger, 2008) Due to its manual nature, the start-time delay function is outside the scope of this study.
2. Second option is **remote activation**. The user configures a deadline in function of when the selected programmemust be finished at the latest. Based on DR control signals or power grid measurements and respecting the time window set by the user, the appliance is automatically activated at the optimal time. The power demand curve on activation of the appliance remains the same. Figures on the average length of the delay window vary from 3 hours (Stamminger, 2008) up to 8.5 h, 7.3 h and 8.1 h for dishwashers, washing machines and tumble dryers, respectively (Linear, 2014). One can assume that both user motivation and user remuneration

has a large impact on the average delay window length. Pilots demonstrate a large user-dependent spread on the length of the window, ranging from 1 h up to 9 h for dishwashers and washing machines (Stamminger, 2008) or 24 h (Linear, 2015). Although user questionnaires indicated that the user acceptance with regard to delaying tumble dryers may be low, and higher for washer-dryers (Stamminger, 2008), pilots showed that the share of 'smart' configurations for washing machines (29 %) and tumble dryers (31 %) is about equal. User acceptance for dishwashers is the highest: 56 % of smart configurations (Linear, 2014). Most smart configurations take place during the evening, most explicitly so for dishwashers. Hence most flexibility in terms of shiftable energy is during the night. There is a higher chance of day-time smart configurations in the weekends.

3. Third and most advanced option is to not only shift the execution of the program, but to also **alter the electricity consumption pattern** during programmeexecution, e.g., pause in between the different phases, interrupt the heating phase, use lower temperatures, etc. It is estimated that about 20 % of dishwashers, 10 % of washing machines and 30 % of tumble dryers may be operated in this mode. (Stamminger, 2008)

For appliances in this category, flexibility is typically situated in the afternoon and especially in the evening. The evening flexibility peak is most pronounced for the dishwashers. There is more flexibility in the weekends than in during weekdays.
For dishwashers and washing machines, there are almost no seasonal effects. However, tumble dryers are predominately used in winter season.

SHIFTING OR CAPACITY MODULATING POTENTIAL PER APPLIANCE

Data on energy shifting or power modulating potential per appliance are scarce. The following data are derived from a Swedish study on DSM-potential in Swedish households. In this study, the energy shifting potential of dishwasher in Sweden is expected to be between 0.6 - 1.7 GWh/day depending on the day of the week. For washing machines and tumble dryers, expectations are between 0 - 1.9 GWh/day and 0 - 1.3 GWh/day, respectively, depending on the day of the week and the season. By absolute numbers, the peak reduction in view of dishwashing and laundry is between 150 MW to 300 MW and remains the same all over the year. Expressed as a percentage, the peak load in Sweden could be reduced by 1.1 – 2.3 %. (Puranik, 2014)
Within the scope of the Smart A project, scenarios were simulated for various regions representative for different parts of Europe to estimate potential for load shifting. In all simulation scenarios, the average energy shifting potential of a washing machine in an average European household in 2015 amounts to about 24 Wh/ day per household. The potential of tumble dryers range from 40 to 125 Wh/ day per household depending on penetration rates and consumer's acceptance in the respective regions. For dishwashers, an energy shifting potential of 62 Wh/ day was estimated per household. For scenarios where the smart appliance react to locally measured grid parameters, such as the frequency, a 10 % shift (anticipating or postponing) of operation at any time is estimated. (Stamminger, 2008)
Within the Linear project, the flexibility offered by dishwashers, tumble dryers and washing machines was extrapolated to calculate the Belgian potential (4.6 million households). This indicated that around 00:00 in the weekend a maximum increase of 2 GW during 30 minutes can be realised in Belgium. During the week this maximum drops to 1.4 GW. In the forenoon and early evening during the week, the maximum increase drops to 800 MW. Flexibility showed asymmetric properties: more surplus power can be realised at a certain moment by activating waiting appliances than power can be reduced by shifting appliances away from where they would normally have run. The 4 hour evening peak can be reduced by 200 MW. (Linear, 2014)
Reducing or increasing the demand at a certain time creates rebound. The total energy consumption remains the same, even if it is shifted. Energy consumed extra or less at a certain point in time must

be compensated for at another time. In the case of short term interruptions, heat may be lost during the pause resulting in an additional energy consumption. (Stamminger, 2008; Linear, 2014)

TOTAL SHIFTING POTENTIAL OF APPLIANCE CATEGORY

For 2025, the following load shifting potentials can be calculated based on data from Smart A project (Stamminger, 2008): By assuming 202,648,000 washing machines in stock in 2025 and an average shifting potential of washing machines in an average European household of 24 Wh, the energy shifting potential of all washing machines in Europe is about 4.86 GWh. For tumble dryers, it is between 3.03 and 9.47 GWh and for dishwashers, it amounts to 8.17 GWh.

COMFORT AND USER IMPACT

Start-time delay: in the case of dishwashers and washing machines, there is almost no comfort or user impact. Users maintain the control whether or not to react to the incoming signal. In view of tumble dryers, the consumer's acceptance is expected to be low because it is likely that the drying process cannot start immediately after washing and wet clothes remain inside the machine. This was confirmed in the Linear pilot, where extra persuasion was required for the smart use of tumble dryers. This problem doesn't persist in case of washer dryers, if drying capacity fits washing capacity. (Stamminger, 2008; Linear, 2014)

Remote activation: The impact is the same as for start-time delay, except for concerns about safety (especially in periods of absence) and noise (during the night)**.** (Stamminger, 2008; Linear, 2014)

Altered consumption pattern: With regard to washing machines, stops of the machine and prolongation of washing and rinsing time can occur. Also damages of laundry, e.g. fading of colours, are possible. In the case of dishwashers and tumble dryers, short-term interruptions are hard to notice, almost no comfort or user impacts are expected. However, the tumble dryer should continue tumbling during interruptions exceeding 5 minutes to avoid textile damages. For all three appliances, interruptions during heating phases or phases at high temperatures may increase total energy consumption. (Stamminger, 2008)

GAPS AND/OR PRE-CONDITIONS FOR THE POTENTIAL TO BE REALISED

Start-time delay function is already available on the market and in almost 40 % of appliances in stock. By using this option, additional energy is needed in start-time delay mode (>0-1 W). The same additional energy consumption (> 0-1 W), occurs for other delayed start methods.

All gaps and interoperability issues as listed in the main text are valid: the smart appliance needs to be equipped with extra communication, measurement and/or control functionality, which depends on the communication and control architectures, the selected communication carrier, the communication standards, etc.

As operation may occur in periods of absence or during the night, safety of appliances should be increased (e.g. by measures slowing down or stopping fire spread inside the appliance, overheat protection, Aqua stop) and noise level decreased to address concerns of consumers.
Additional costs for consumers should be low to guarantee amortization within a reasonable period of time.

FUNCTIONALITIES SUPPORTING ENERGY EFFICIENCY

As all three appliances in this category have options to operate at higher temperatures, they could be connected to hot water supply or use the heat produced by CHP, solar plants or district heating. Power consumption for appliance-internal electric-resistance heating can be reduced by 50 % (hot water supply) up to (in principle) 100 % (all other cases). (Stamminger, 2008)
A further possibility is to transfer heat from one process to another (e.g. by using tanks or phase change material), which results in a 50 % reduction in heating power. (Stamminger, 2008)
Information on the energy consumption of the appliances may help the user in selecting the most energy efficient program.

CONCLUSION

With regard to dishwashers, washing machines washer dryers and tumble dryers, three different levels of energy shifting or power modulating possibilities could be identified. The complexity of technical adjustments increases from the first to the third level. Appliances in this category offer a high flexibility in energy shifting operation.

Consumer's acceptance of shifted operation is high despite some concerns about safety during absence periods and noise during the night. In view of tumble dryers, the consumer's acceptance of shifted operation is expected to be lower because it is likely that the drying process cannot start immediately after washing and wet clothes remain inside the machine. Short-term interruptions (e.g. interruption or delay in heating phase) can be realised for all three appliances in this category. In this way, power demand curve of a single appliance can be changed, instead of merely shifted.

The total energy consumption of dishwashers, washing machines, washer dryers and tumble dryers is relatively small in comparison to other household appliances (e.g. refrigerators or water heaters), as the operation time and number of operation cycles is limited. However, the higher power during operation, the larger delay windows (higher flexibility) and the high market penetration in Europe, especially in the case of washing machines and dishwashers, results in a significant DR potential.

By taking into account all households in Europe, an energy shifting potential of washing machines of about 4.86 GWh was calculated. For tumble dryers, it is between 3.03 and 9.47 GWh and for dishwashers, it amounts to 8.17 GWh.

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ENERGY STORING APPLIANCES

DESCRIPTION

Energy storing appliances are appliances destined for private use that provide a capacity to store energy in a form ready to be delivered to the user without any further transformation , such as refrigerators, freezers and water heaters (storage). These appliances require no interaction with the user after initial set up, although user actions can impact the appliance's operation.

INSTALLED BASE (EU27)

Refrigerators and freezers: in 2010, there were 297,800,000 appliances in stock. According to estimations, the number increases up to 303,200,000 in 2015, 308,000,000 in 2020, 312,800,000 in 2025 and 317,600,000 in 2030. (Kemna, 2014)
Water heaters[339]: in 2010, there were 157,293,000 appliances in stock. According to estimations, the number increases up to 161,740,000 in 2015, 165,192,000 in 2020, 168,688,000 in 2025 and 172,268,000 in 2030. (Kemna, 2014)

SHIFTING OR CAPACITY MODULATING POTENTIAL

SHIFTING OR CAPACITY MODULATING POSSIBILITY

There are two options to change the electricity consumption profile of energy storing appliances:

1. For refrigerators, freezers and water heaters, **remote activation** is a possible option to harmonise the available power on the grid with demand. Based on DR control signals or power grid measurements, start of the compressor or the water heater may be delayed. Storage water heaters may also be called to anticipate their operations for storing energy in anticipation of future use in the coming hours In terms of cooling appliances, temperature inside the compartment must determine time of delay for food safety reasons. The power demand curve on activation of water heaters remains the same. In view of refrigerators and freezers, operation time may be prolonged. It is estimated that this strategy allows shifting 5 % of individual operations of refrigerators and freezers and 75 % of operations of water heaters by seconds or minutes. (Stamminger, 2008)
2. Second and most advanced option is to **alter electricity consumption pattern** during operation time, for cooling appliances e.g. interruption of cooling process, changes in temperature setting, prolongation of cooling process by reducing motor speed, enlargement of temperature hysteresis, for water heaters e.g. interruption of heating phase, reducing the desired water temperature. It is estimated that this strategy allows shifting 5 % of all individual operations of refrigerators and freezers as well as 75 % of all operations of water heaters by seconds or minutes. (Stamminger, 2008)

339 The numbers for water heaters include: electric storage and instantaneous water heaters, gas-and oil fired storage and instantaneous water heaters as well as solar-assisted water heaters.

For appliances in this category, flexibility depends on the thermal storage capacity. In first instance, it may be considered as evenly distributed throughout the day and throughout the week. For refrigerators and freezers, seasonal effects are only weak. Water heater loads are highly seasonal with highest potential occurring in winter. This can be explained by the fact that both, differences in water temperature and hot water consumption are higher in winter season. (Stamminger, 2008, Puranik, 2014)

SHIFTING OR CAPACITY MODULATING POTENTIAL PER APPLIANCE

Data on shifting or capacity modulating potential per appliance are scarce. The following data are derived from a Swedish study on DSM-potential in Swedish households. In this study, the energy shifting potential of water heaters in Sweden is expected to be between 8 - 9 GWh/day in winter, 3.3 - 5 GWh/day in spring, 2.5 - 5 GWh/day in summer and 3 - 5 GWh/day in autumn. The maximum peak load reduction observed in winter, spring, summer and autumn is 0.95 GW, 0.872 GW, 0.69 GW and 0.9 GW, respectively. (Puranik, 2014)
Within the scope of the Smart A project, scenarios were simulated for various regions representative for different parts of Europe to estimate potential for energy shifting. In all simulation scenarios, the potential for short term interruptions of refrigerators amounts to about 8 Wh/ day per household in UK, but might be lower in all other parts of Europe. (Stamminger, 2008)
Reducing or increasing the demand at a certain time creates rebound. The total energy consumption remains the same, even if it is shifted. Energy consumed extra or less at a certain point in time must be compensated for at another time. (Stamminger, 2008; Linear, 2014)

TOTAL SHIFTING POTENTIAL OF APPLIANCE CATEGORY

Assuming a potential for short-term interruptions of 5 Wh per household in Europe, a shifting potential of 1.56 GWh for refrigerators and freezers in 2025 can be calculated.

COMFORT AND USER IMPACT

Refrigerators and freezers: With regard to refrigerators and freezers, smart operation may in principle not affect food safety and quality negatively. For this reason, temperature inside the cooling compartments has to be kept constant within narrow specific ranges to prevent microbial growth. Whereas it is possible to store energy by cooling to lower than normal storage temperatures in the case of freezers, this possibility is limited in the case of refrigerators because of the risk of freezing sensitive food and loosing food quality. If no influence on food quality occurs, high consumer acceptance can be assumed in view of remote activation and altered consumption pattern. (Stamminger, 2008)
Storage of energy by cooling down freezers to lower than normal storage temperatures results in surplus energy consumption due to a larger temperature difference and associated a lower coefficient of performance.
Water heater: Shifts in operation of water heaters may cause shortages or even interruptions of hot water supply, especially in the case of water heaters with small storage capacities. Because of that, shifts in operation are improbable for these types of appliances. In terms of devices with large storage capacities, shifts in operation are possible without comfort or user impact. An alteration of consumption pattern, e.g. reduction of the desired water temperature (at present about 60 °C) might be critical from a hygienic point of view as the growth of microorganisms such as *Legionella* can only be reliably prevented at higher water temperatures of about 60 °C. If there is no loss of comfort, consumers would accept remote activation and altered consumption pattern. (Stamminger, 2008)

GAPS AND/OR PRE-CONDITIONS FOR THE POTENTIAL TO BE REALISED

All gaps and interoperability issues as listed in the main text are valid: the smart appliance needs to be equipped with extra communication, measurement and/or control functionality, which depends on the communication and control architectures, the selected communication carrier, the communication standards, etc.

Additional costs for consumers should be low to guarantee amortization within a reasonable period of time.

FUNCTIONALITIES SUPPORTING ENERGY EFFICIENCY

In case of refrigerators and freezers, phase change material could be used to balance interruptions in power supply over a longer period of time. A further possibility is to implement absorber technology, which is driven by heat produced by solar collectors or CHP. (Stamminger, 2008)
Water heaters could be connected to CHP, solar plants or district heating. Electricity is only needed for basic functions of the device and the pump. (Stamminger, 2008)

CONCLUSION

With regard to refrigerators, freezers and storage water heaters, two different levels of shifting or power modulating possibilities could be identified. The technical adjustments are more complex for the second level. Appliances in this category offer a high flexibility in energy shifting operation. Consumer’s acceptance is assumed to be rather high if food safety and quality is not compromised and if there is no loss of comfort. Short-term interruptions of heating or heating processes or power modulation (e.g. changes in temperature setting or reduction in motor speed) can be realised for all appliances in this category. In this way, power demand curve can be changed instead of merely shifted.

Assuming a potential for short term interruptions of 5 Wh per household in Europe, an energy shifting potential of 1.56 GWh for refrigerators and freezers in 2025 was calculated.

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BEHAVIOURAL APPLIANCES

DESCRIPTION

Behavioural appliances are appliances where the operation is linked to its functionality and whose operation require the active involvement of consumers, e.g. electrical hobs, ovens, hoods, vacuum cleaners[340] and instantaneous water heaters destined for private use.

INSTALLED BASE

Electric hobs: in 2010, there were 133,781,000 appliances in stock. According to estimations, the number increases up to 149,114,000 in 2015, 163,566,000 in 2020, 176,468,000 in 2025 and 188,544,000 in 2030. (Kemna, 2014)
Electric ovens: in 2010, there were 191,823,000 appliances in stock. According to estimations, the number increases up to 199,332,000 in 2015, 209,502,000 in 2020, 220,505,000 in 2025 and 232,059,000 in 2030. (Kemna, 2014)
Range hoods: in 2010, there were 92,371,000 appliances in stock. According to estimations, the number increases up to 97,111,000 in 2015, 102,060,000 in 2020, 107,267,000 in 2025 and 112,741,000 in 2030. (Kemna, 2014)
Vacuum cleaners: in 2010, there were 364,226,000 appliances in stock. According to estimations, the number increases up to 388,857,000 in 2015, 419,407,000 in 2020, 487,849,000 in 2025 and 545,178,000 in 2030. (Kemna, 2014)
Instantaneous water heaters: no separate numbers are available for instantaneous water heaters (see water heaters)

SHIFTING OR CAPACITY MODULATING POTENTIAL

SHIFTING OR CAPACITY MODULATING POSSIBILITY

There are two options to change the electricity consumption profile of behavioural appliances:

1. The first possibility is that consumer receives information on availability of power e.g. via smartphone and the consumer shifts operation of hobs, ovens range hoods and vacuum cleaners to any time of the day, when a huge amount of energy is available. Due to the fact that eating times are more or less fixed times during the day, shifts of not more than 30 minutes seem to be realistic for cooking appliances (hobs, ovens and range hoods). In view of vacuum cleaners, longer shifts up to 2-3 hours are assumed to be feasible. For instantaneous water heaters, this scenario is improbable. (Stamminger, 2009) Due to its manual nature, this option is out of scope of the study.
   DR
2. Third and most advanced option is to not only shift the execution of the process, but also to alter the electricity consumption pattern during the process, for hobs and ovens e.g., prolongation of

[340] Robot vacuum cleaners can be regarded as an exception to this. However, as the flexibility of robot vacuum cleaners is in the charging of the battery, the assessment is part of the analysis of chargers.

intervals between two heating phases or interruption of heating phase, for vacuum cleaners and range hoods e.g. reducing power. For instantaneous water heaters, this scenario is improbable. From an energy point of view, interruptions are not applicable in the first few minutes after the heating phase in terms of hobs and ovens. Referring to range hoods and vacuum cleaners, interruptions are improbable as their power demand remains constant during operation and interruptions in power supply would could cut them off. The pattern of the power demand curve of a single appliance can be changed in different ways, e.g. shift in operation time or reduction of power. It is estimated that about 5 % of consumers would accept this option. (Stamminger, 2009)

SHIFTING OR CAPACITY MODULATING POTENTIAL PER APPLIANCE

If looking at the annual energy consumption of these appliances in 2010, the potential seems to be significant:

- Hobs: 300 kWh/a
- Ovens: 120 kWh/a
- Range hoods: 133 kWh/a
- Vacuum cleaners: 69 kWh/a
- Instantaneous water heaters:

However, according to literature and own estimations, the acceptance by residential end-users may be limited to about 5 % for interruptions by seconds and minutes. So acceptance appears to be the limiting key factor. (Kemna, 2014; Stamminger, 2009)

TOTAL SHIFTING POTENTIAL OF APPLIANCE CATEGORY

An estimate on the shifting potential is hard to state, since not much research has been done on this in view of appliances in this category.

COMFORT AND USER IMPACT

Concerning hobs and ovens, it has to be examined whether short term interruptions of heating phases or prolongation of the interval between two heating phases by seconds or minutes compromise the cooking process and consequently the performance. However, the consumer's acceptance is supposed to be low.

In view of range hoods and vacuum cleaners, a reduction of power will result in a lower air change rate or a loss of suction power, respectively, leading to a lower effectiveness and a highly variable background noise.

In view of instantaneous water heaters, short term interruptions in power supply would cause losses in comfort, which will not be accepted by consumers.

GAPS AND/OR PRE-CONDITIONS FOR THE POTENTIAL TO BE REALISED

All gaps and interoperability issues as listed in the main text are valid: the smart appliance needs to be equipped with extra communication, measurement and/or control functionality, which depends on the communication and control architectures, the selected communication carrier, the communication standards, etc.

The most important factor is the willingness of end-consumers to apply the smart functionalities. Business cases should be available to ensure that savings balance the additional costs and to provide sufficient incentives for end consumers to participate in this.

Functionalities supporting energy efficiency

With respect to hobs, efficiency differs significantly between different types. During operation, the induction hobs are the most efficient ones ahead of ceramic hobs. Sealed plate hobs are the least efficient ones.

Conclusion

Due to a lack of consumer acceptance, the potential is assumed to be low.

References

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(Stamminger, 2009) Stamminger, Rainer. 2009. Synergetic potential of smart appliances in renewable energy systems. Shaker Verlag, Aachen, Germany.

HEATING, VENTILATION AND AIR CONDITIONING (HVAC)

HVAC ELECTRICITY CONSUMPTION, MOST IMPORTANT PRODUCTS

HVAC category contains 4 main functions and related residential / commercial appliances: heating, cooling, ventilation and humidity control.

Smart heating, ventilation and dehumidification equipment can contribute to shift / reduce electricity load in the winter period, while cooling and dehumidification appliances may contribute in the summer.

For this first overlook of the DR potentials, it is important to have in mind orders of magnitude of total electric consumption corresponding to the different appliances.

Table 70: Total and HVAC electricity consumption in Europe from (Bertoldi, 2009) and (Bertoldi, 2012)

	2007	2007	2010	2010
	TWh	% total	TWh	% total
Electricity consumption EU27	2797	100%	2836	100%
Residential	800	29%	842,5	30%
Electric heating / boilers (2)	150	5%	152	5%
Ventilation (2)	22	1%	22	1%
Air conditioning (2)	17	1%	17	1%
		0%		
Tertiary	760	27%	834	29%
Electric heating and water heating	150	5%	160	6%
Ventilation	96	3%	104	4%
Air conditioning	21,6	1%	24	1%
Pumps	45	2%	49	2%
Residential + Tertiary				
Electric heating/boilers (1)	270	10%	280	10%
Ventilation	118	4%	126	4%
Air conditioning	38,6	1%	41	1%

(1) Tertiary electric water heating supposed to account for 20 % of tertiary space and water heating (French case) is not accounted[341]

(2) Residential split not available in 2010 - shares of 2007 are supposed to remain constant in 2010

Regarding humidity control in the residential sector, (Rivière, 2007) gives an idea of the consumption of dehumidifiers (consumption of products sold in 2006 : 0.03 TWh / year). It is also stated that humidifiers may consume as much energy as dehumidifiers although there is no figure. The humidity function probably consumes less than 1 TWh of electricity and respective appliances are mainly

[341] In (Bertoldi, 2009), the electricity consumption of electric heating and water heating is not disagregated. Based on French statistics, 20 % of the total figure (150 TWh in 2009) is attributed to water heating to make an estimate of tertiary electric heating.

portable products. So their potential for DR is considered as very limited and consequently these products are not further analysed in this study.

In contrast, the focus of the following analysis is lead on electric heating (including, direct joule heating, electric and heat pump boilers as well as circulation pumps), electric air conditioning and ventilation.

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(Rivière, 2007) P. Rivière, et al., Introduction to Preparatory Study on the Environmental Performance of Residential Room Conditioning Appliances (Airco and Ventilation), 2007

HVAC/ELECTRIC HEATING

DESCRIPTION

Electric heating covers direct joule effect electric radiators (with or without built-in heat storage capability), electric and hybrid (gas or fuel + electric) heat pumps. Electricity consumption in Europe (EU27) is assumed to be around 150 TWh for the residential sector and 130 TWh for tertiary sector in 2010.

(BIOIS, 2012) describes the different types of electric radiators installed in Europe. Following (Stamminger, 2008), electric heating appliance categories are separated depending on the thermal inertia they can activate, which then will condition the load shifting potential.

No inertia: Portable - convector panel, radiators, Fan heaters, Radiant panel heaters, Ceramic heaters, Visibly glowing radiant heaters; Fix - Convector panel heaters, Radiators, Fan heaters, Radiant panel heaters, Visibly glowing radiant heaters, Towel heaters for bathrooms (with or without fans)

With inertia: Underfloor heating (thin film, cable), Storage heaters (static - heat release is ensured by natural convection and radiative heat transfer), Storage heaters (dynamic - heat release is ensured by a thermostat controlled fan). Storage heaters are typically charged during off-peak conditions (Stamminger, 2008) so that they have a shifting potential of several hours (typically half a day). These are more easily controlled than underfloor heating for which control of the ground temperature to ensure occupant comfort is an issue. The inertia of underfloor heating systems is in fact dependent upon the specific building soil installation and not of the heating product per se.

Regarding electric heat pumps, these are air based (air is the indoor heating vector as for reversible split air conditioners) or water based. Water based heat pumps are further broken down depending on the heating source (air, water, geothermal energy). Some of the water-based heat pumps may have built-in system inertias, through water storage (to ease water temperature control) and for underfloor heating (part of the building mass can be activated via the heating system - as for underfloor electric heating). In practice, the water inertia is generally low when the heat pump is used at full capacity (typically 3 to 10 minutes) so that their main load shifting potential is the one of the building. Thus the only specific category with higher shifting potential is the floor heating category. However, heat pump floor applications are not dominant (because of higher costs and the fact that they can only be installed in new or largely retrofitted buildings). Consequently, all heat pumps are added in the "no inertia" electric heating category hereafter.

It is interesting to notice that hybrid heat pumps (products that combine a gas or liquid fuel boiler and an electric heat pump) can shift from electricity to gas when required and may shift almost completely their energy consumption to gas if it is required. However, the market for such hybrid products is still very small as these products are just entering the market.

We thus distinguish three main types of electric heating appliances to differentiate potential analysis: electric heating (joule effect or heat pump), electric with inertia (underfloor heating with static and dynamic storages) and boiler circulators.

INSTALLED BASE

Joule heating

From the EuP DG ENER Lot 20 study (BIOIS, 2012), it is possible to extract the estimated stock of installed electric heating appliances in Europe and European consumption in 2010. Individual data for electric appliances are not available in the policy scenario analysis. Probably this population of electric heaters is no longer increasing anymore, due to the effect of the national building regulations.

Table 71: Electric heater units, power installed and consumption, Source: (BIOIS, 2012)

Electric heating type	EU-27 stock (in 1000 units)	TOTAL (GW) Installed capacity	Hours	Energy (TWh)
NO INERTIA, PORTABLE	61,400	63	324	20
NO INERTIA FIX	159,200	166	1,130	188
WITH INERTIA	13,800	37	1,324	49
TOTAL	**234,400**	**266**		**257**

Probably most inertia storage heaters are in the residential sector, while for units without inertia it is not clear. Indeed, according to (Bertoldi, 2009), the total residential and tertiary electric space heating consumption was close to 270 TWh in 2007. It probably means that both residential and tertiary electric radiators are included in the figures above.

Electric boilers
Electric boilers are simply water storage electric heating boilers similar to hot water electric storages for which the electric element is larger in order to be able to supply the heating needs of a dwelling. According to (VHK, 2007), the stock of units was around 1.1 million in 2004, with average size between 4 and 15 kW[342] or about 10 GW installed capacity / power (keeping a median 10 KW value per unit).

Electric heat pumps
(EHPA, 2014) gives an estimate of the market and stock for heat pumps in Europe. The total stock of heat pumps is estimated to 4.5 million units in 2010 and 6.7 million units in 2013. With an average of about 30 kW output (according to EHPA, 2014) and assuming a base temperature of - 7°C, this capacity reaches about 18 kW and the COP of approx. 2 (assuming most heat pumps are of the air source type), it leads to about 9 kW electric peak load per unit, resulting in 40 GW (at peak conditions i.e. for - 7 °C outside) for the total stock of heat pumps in 2010 and already about 60 GW in 2013. This is probably a conservative low-end figure because only a minor part of reversible air conditioners is taken into account as being really used as a heat pump. But at the same time, the share of non-residential units is not known.

Boiler circulators
There were about 103 million circulators installed in Europe in 2005 (VHK, 2007), serving all directly the boiler systems. Their energy consumption was estimated to be around 50 TWh/a (Stamminger, 2008). This total energy consumption is thought to decrease by at least a half by 2025, as the stock of boiler will have been replaced and newer boilers use circulators whose consumption can be 4 times less than for older boilers as consequence of the respective EU regulation. For most old circulators in the stock, the flow rate is constant during all the heating season, whereas in newer installations, circulators only work when there is a heat demand. With variable flow technology being the new standard, the power drawn by the circulator will more and more depend on the actual heat load as well as the outdoor temperature.
For an average heating season of 9 months, assuming a constant power drawn over 9 months (c.a. 6500 hours), the total power installed is close to 7.5 GW (equals to 50 TWh / 6500 h) for the residential sector.

Total installed base of electric heating (estimation from market research) in EU27

[342] http://www.boilerguide.co.uk/articles/electric-boilers

In 2010, the total installed base of electric heating systems is is assumed to be close to 325 GW in Europe. A summary table for the whole group of electric heating systems is presented below. This figure probably contains a large part of the tertiary electric heating installations for joule heating and for electric heat pump.

Table 72: Electric heating units, installed power, summary table

	Million units	GW	GW Probable trend after 2014
Electric heating, without built-in inertia (2)	**226.2**	**279**	Decreasing
Joule fix residential + tertiary () 2010	159.2	166	Decreasing
Joule portable (residential + tertiary) 2010	61.4	63	Decreasing
Elec. Boiler (residential) 2005	1.1	10	Decreasing
Elec. Heat pump (residential + tertiary) 2010 (1)	4.5	40	Strong increase
Electric heating, with built-in inertia	**13.8**	**37**	Decreasing
Circulation pump	**103**	**7.5**	Strong decrease

(1) At -7°C full capacity
(2) Probably contains also part of tertiary building heating systems

<u>Total installed base of electric heating (estimation from the grid)</u>
This is an interesting figure that is worth being compared with what is seen at the electricity grid level. RTE[343] is in charge of ensuring matching consumption and generation of electricity and releases information about the temperature sensitivity of electricity consumption in France every year.
Figure 4 below shows the correlation between average daily outdoor temperature (weighted average temperature over 30 cities in France[344]) and daily national energy consumption. The derivative of the heating slope is evaluated to be 2400 MW / °C (RTE, 2013). It means that below a certain threshold of around 15 °C, each decrease of 1 °C will increase the national electricity load by 2400 MW / °C. In 2012, the peak day in France occurred on February 8 with a daily average required power of about 93 GW. This is coherent with calculations based on the average daily temperature of about -4 °C, leading to an average load of 93.5 GW (1150/24 + (15-(-4))*2400 = 93.5 GW) (See below).

[343] RTE (Réseau de transport d'électricité) - French electricity transmission system operator.
[344] Please note: To make this correlation, RTE filters the effect of nebulosity during the day, i.e. the load reduction due to solar radiation is not accounted for, although it has most likely only little impact during the coldest days of the year.

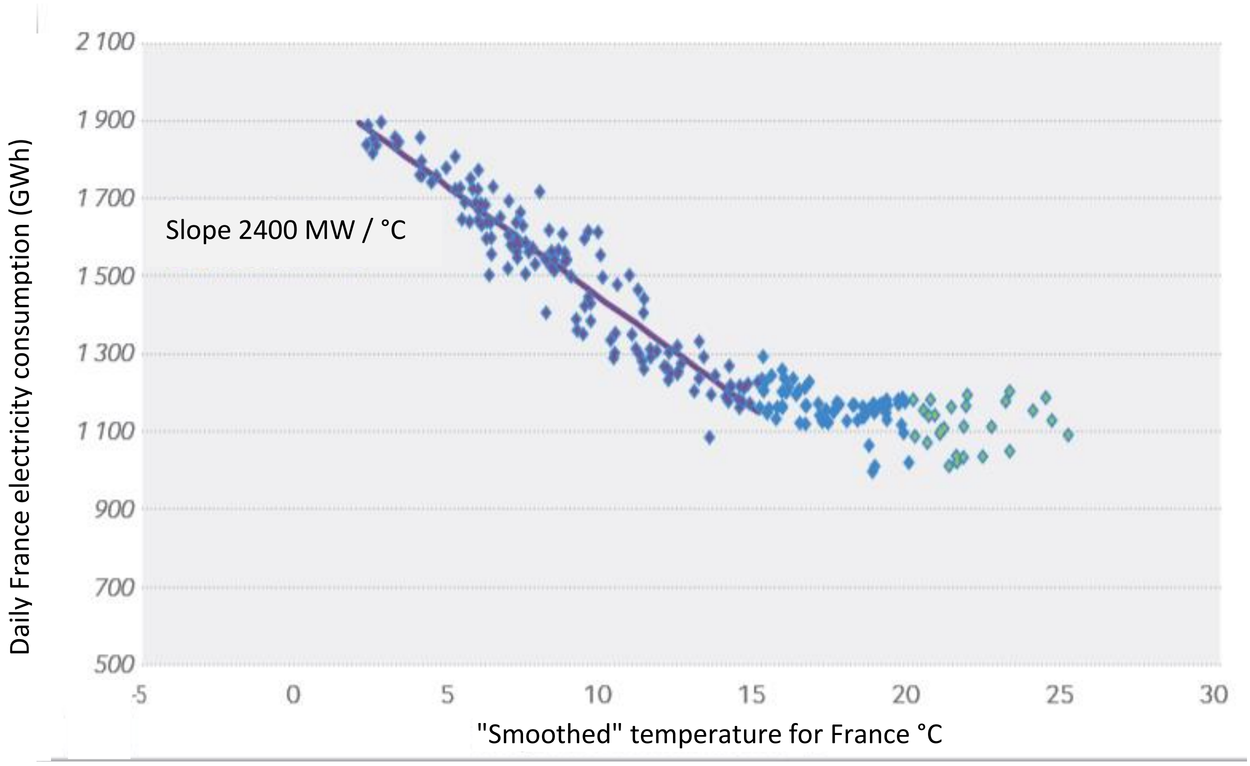

Figure 70: Temperature sensitivity of electricity consumption in France in 2013 - daily average electricity consumption VS smoother average France temperature and slope, from (RTE, 2013)

On the Figure below, the same slope is indicated for several EU countries and at EU level. It can be seen that France alone accounts for close to 50 % of the total temperature sensitivity of the EU electricity consumption as consequence of the widespread usage of electric heating systems.

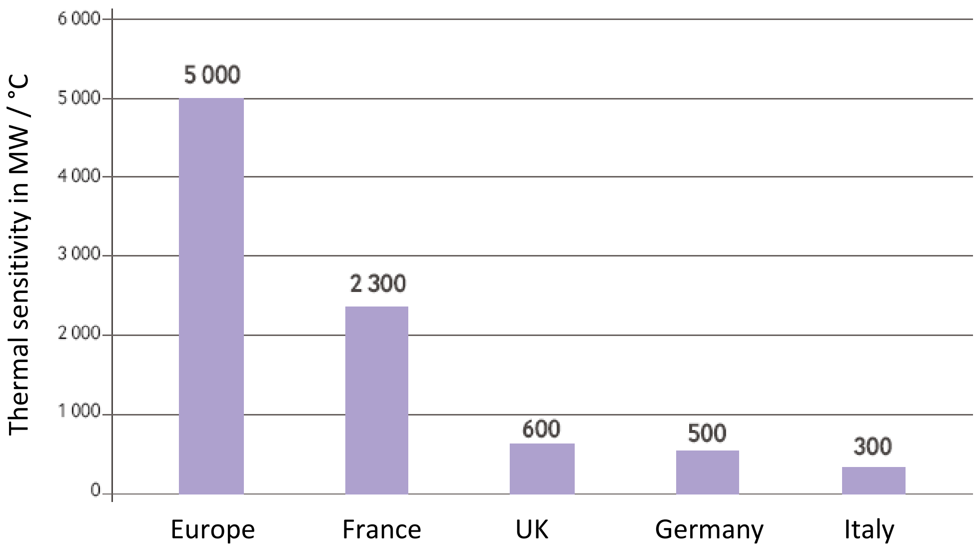

Figure 71: Temperature sensitivity of electricity consumption in France and other countries in Europe in 2012, from (RTE, 2012)

Assuming the same threshold temperatures apply for Europe and that EU average on February 8 was close to - 4 °C like in France, it gives a total electric heating contribution of around 5 * 19 or 95 GW. This is only to give an order of magnitudes.
But this estimation is noticeably much less than could be inferred from the market data, which indicated a total installed stock power close to 325 GW for electric heating. There may be many reasons for this important difference:

- Circulation pump consumption profile is probably not temperature sensitive nowadays (as most circulators are still with constant flow) so that the signal from the grid is underestimated by about 10 GW.
- Probably, some of the heaters are not in use (the case of many portable heaters probably, heating systems in secondary houses, secondary or backup systems).
- It is likely that many installations are oversized by 20 to 50 % because of local design habits.
- Others may be operated at peak conditions all year long (probably the case of some fan heaters in the industry) and thus their consumption is not sensible to the outdoor temperature.

Although this is a very rough estimation, it is most likely that the maximum electric demand in winter peak conditions for an typical meteorological year is close to 100 GW despite an apparently much larger installed base.

SHIFTING OR CAPACITY MODULATING POTENTIAL

All electric heating appliances (except boiler circulators) include thermostatic control.
Portable electric appliances have generally no planned connection to a central controller and are operated manually (switch on-off, temperature setting and fan speed for fan heaters).
Newer installations of fixed joule heating now have multiple standard control modes (4 or 6 modes) enabling a central controller to send standardised orders to reduce consumption over a period of time chosen by the end-user (Typically: Comfort - heating at locally adjusted set point, Eco - locally set point temperature minus 1 or 2 °C, night or absence setback, anti-freezing set point, stop). The physical link between the radiator and the controller is called in France "pilot wire" and has become a national industry standard for some years. However, concerning the total stock, this control approach is only applied to a small portion of the installed systems.
Generally, current electric heating controllers cannot exchange information with the grid. Only for very specific DR programs, such connections are made (for instance, the firm Voltalis in France installs a box in the fuse box on the electric heating cable to enable consumption measurement and control of the electric heating). In France, this type of DR programmerepresented less than 100 MW in February 2013 (RTE, 2013).

More recently, smart heating thermostat have been offered to customers by energy providers. Smart thermostats are two way (internet) communication devices, which monitor a combination of several variables in the houses (like air temperature possibly by zone, occupation possibly by zone, user comfort habits and satisfaction), and can also include GPS position tracking of the dwelling's tenants, price tables or signals, and weather previsions, in order to help customers to reduce their heating bills by improving the control of the heating system. These systems are only beginning to spread and in Europe, most solutions are reserved for traditional boiler systems (dominant type in Europe). Nevertheless, solutions do exist for electric heating which could be a support to realise DR potential.[345]
Heat pumps generally require more sophisticated controllers than electric radiators, which in turn enable to include more functions. Recently web based applications enabling the distant monitoring

[345] http://www.theguardian.com/environment/2015/jan/27/smart-thermostats-reviewed-which-can-save-you-most

and parameterization of heat pumps have reached the market. This option is presently used by the end-user itself. The German Smart Home Ready label[346] has gained popularity for heat pumps, since its introduction in 2013, and could help to standardise communication orders.
Note that smart thermostats are also proposed for heat pumps.

Regarding heat storage, as they are conceived to benefit from night tariffs, these are most probably linked to the grid operator at the fuse box level so that their charging may be operated distantly.
There are three different types of flexibility involved for heating:

a) Inertia of the building (this includes all types of electric heating without storage and boiler circulation pump),
b) Inertia built in the heating system (electric storage radiators and electric boilers)
c) Energy source shift during peak times for hybrid gas or fuel electric heat pumps. This potential is extremely high as the electricity consumption can be shifted at any time, but the market for such hybrid heat pumps is just at its beginning (still negligible in 2014).

SHIFTING OR CAPACITY MODULATING POSSIBILITY

This varies depending on the type of inertia involved:
a) Shifting potential is limited by the comfort of the occupants. (Da Silva, 2011) suggests that the heating load can be typically shifted by 1 hour per day for old buildings and by up to 2 hours for new buildings (figures are for France and new buildings are the ones built after 2005, equalling about 15 % of the French building stock) in order to remain in the EN 15251 (CEN, 2007) standard comfort zone. But even in those new buildings, during the coldest days of the year, it is likely that occupants feel uncomfortable because of the too high variation of the indoor air temperature (more than 2 K / h). The situation can be improved if heat pre-charging of the building is allowed, which is less energy efficient but enables to gain acceptance from the end-user point of view. The potential could amount to about two hours, but this requires two-way communication with the indoor thermostat, which is commonly not available today.
b1) Basically, the heating storage is built to enable the electricity to be consumed mainly during the night, while heating is supplied night and day. For a typical day (in Germany), the heating energy which can be shifted from day to night represents close to half of the daily energy consumed by one unit (Stamminger,2008).
b2) For heating electric boilers, they can be flow boilers[347] (instantaneous) or storage boilers[348] with inertia ranging from 1 hour to 4 hour of shifting potential under peak conditions and up 4 hours and 12 hours at 30 % load. 20 L / kW or about 1 hour inertia in peak conditions are assumed.
c) All the energy consumed by the unit can be almost completely supplied by gas or fuel (but in that case, it would not make sense for the end-user to have bought a hybrid heat pump).

SHIFTING OR CAPACITY MODULATING POTENTIAL PER APPLIANCE

This varies depending on the type of inertia involved:
a) 1 hour with simple stop of the heating radiators or about 4 % (1/24), 2 hours (with two way communication enabling pre-charging of the building and other optimised strategies) or about 8 % (2 /24) - 8 % are kept to establish the total potential
b1) About 50 % the consumption of the storage unit
b2) As a) plus 20 L / kW water inertia
c) 100 %

[346] Described in more details in Annex 2 on page 119.
[347] See for instance http://www.heatraesadia.com/docs/Amptec_-_Issue_9.pdf
[348] See for instance http://www.thermaflowheating.co.uk/our-brochure/

TOTAL SHIFTING POTENTIAL OF APPLIANCE CATEGORY

The total shifting potential is summarised in the Table 6 below. Electric radiators and storage installed capacities, and heat pump average performance curves have been adjusted so that the total electricity consumption is in line with Bertoldi (2009 and 2012) and RTE peak power observations.
It is important to notice that residential and tertiary units are certainly included in the estimate below.

End use sectors (residential and tertiary) might have different flexibility limitations other than occupants' comfort. While for residential units, the main constraint is acceptance from the end-user to allow a third party control the HVAC system of his/her dwelling, for tertiary buildings there might be other type of constraints. These limitations regarding mainly temperature regulations, might be related to security reasons in tertiary buildings like hospitals, laboratories, agro-industrial sites.

Table 73: Electric heating function in Europe, Estimation of energy consumption for Europe in 2010, of total shifting potential and of peak power

	Monthly avg. Temp.	Circulation pumps	Storage	Elec fix radiators	Elec boiler	Elec HP	Total energy	Power (wo pump)	Total shift potential	Storage share	Elec fix radiators share	Elec boiler share	Elec HP share
		cons	cons	cons	cons	cons	cons	Power	cons				
MONTH	°C	TWh	TWh	TWh	TWh	TWh	TWh	GW	TWh	%	%	%	%
JAN	2,2	5,5	4,2	27,9	3,7	7,3	48,7	59,0	5,6	38%	40%	11%	11%
FEB	3,1	5,5	3,9	26,0	3,5	6,6	45,6	54,8	5,2	38%	40%	12%	10%
MAR	5,2	5,5	3,2	21,4	2,9	5,1	38,0	44,5	4,3	38%	40%	13%	9%
APR	8,7	5,5	2,1	13,7	1,8	2,9	26,0	28,0	2,9	36%	38%	17%	8%
MAY	13,8	5,5	0,4	2,6	0,3	0,5	9,3	5,2	0,8	24%	26%	45%	5%
SEP	14,4	5,5	0,2	1,3	0,2	0,2	7,4	2,6	0,6	17%	18%	61%	3%
OCT	10,5	5,5	1,5	9,8	1,3	2,0	20,0	19,9	2,1	35%	37%	21%	8%
NOV	6,2	5,5	2,9	19,3	2,6	4,5	34,7	40,0	3,9	37%	39%	14%	9%
DEC	2,8	5,5	4,0	26,6	3,6	6,8	46,4	56,0	5,3	38%	40%	12%	10%
Peak conditions	-4	5,5	6,3	41,4	5,5	13,8	72,5	**91,6**	8,3				
ANNUAL ENERGY (TWh)		49,2	23	148,5	4,4	36,1	**276,2**		**30,7**	37%	39%	15%	9%
Installed base correction factor for radiators and storage units:						0,45							
Correction made in coherence with Bertoldi 2009 and 2012 reports and RTE observations													
Inertia of electric boiler in L / kW :			20										

In case the electric boilers do not supply water inertia, their share is reduced to standard building inertia and the total potential to shift energy is close to 27 TWh.

COMFORT AND USER IMPACT

Comfort is the limiting factor, as temperature will drop in the house when the heating system is stopped. Strategies can be adapted (heat pre-charging of the building structure, ventilation can be stopped) but this requires two-way communication. Another limiting factor is the speed of air temperature change in the house. More than 2 K / h is outside the comfort range of the EN 15251 standard. This may be mitigated by modulating the system control orders (e.g. not full stop, but only 50 % of the capacity supplied over a longer period).

GAPS AND/OR PRE-CONDITIONS FOR THE POTENTIAL TO BE REALISED

Several smart grid and DR experiments are on-going in France. They will help to characterise the user acceptance regarding the comfort degradation due to heating power modulation and the need for two way communication in order to satisfy comfort as well as to ensure the durability of any DR programme based upon electric heating.

FUNCTIONALITIES SUPPORTING ENERGY EFFICIENCY

For electric heat pumps, more and more complex CPUs are integrated in the products in order to achieve the control of the units (in the tertiary sector, large VRF[349] units may control up to 50 indoor units in addition to the one of the heating generator). For maintenance purpose, interfaces are generally available for more than 10 years for more advanced brands, in order to ensure optimal and energy efficient operation.
It is believed that for most other electric heating units, there are no supporting energy efficiency features.

CONCLUSION

Flexibility potential:

- **Peak power: up to about 95 GW (2010)**
- **Energy consumption: about 280 TWh/a**
- **Potential energy to be shifted: about 30 TWh/a, about 100 GWh/day in the coldest winter months**

The flexibility potential is divided at about 50/50 between built-in system inertia (storage radiators, electric boilers) and building thermal mass inertia. Regarding the use of building thermal mass, several smart grid and DR experiments are on-going in France. They will help to characterise the user acceptance regarding the comfort degradation due to heating power modulation and the need for two way communication in order to satisfy comfort as well as to ensure the durability of any DR program based upon electric heating.

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HVAC/VENTILATION

Description

Ventilation includes energy using products whose main function is to renew the air of occupied buildings.

Ventilation products are:

- In the residential sector, local and central extraction fans and local and central heat recovery ventilation units (noticed below as RVU for "Residential Ventilation Units")
- In the tertiary sector, central extractors and air handling units (noticed below as NRVU for "Non-Residential Ventilation Units")

Installed base

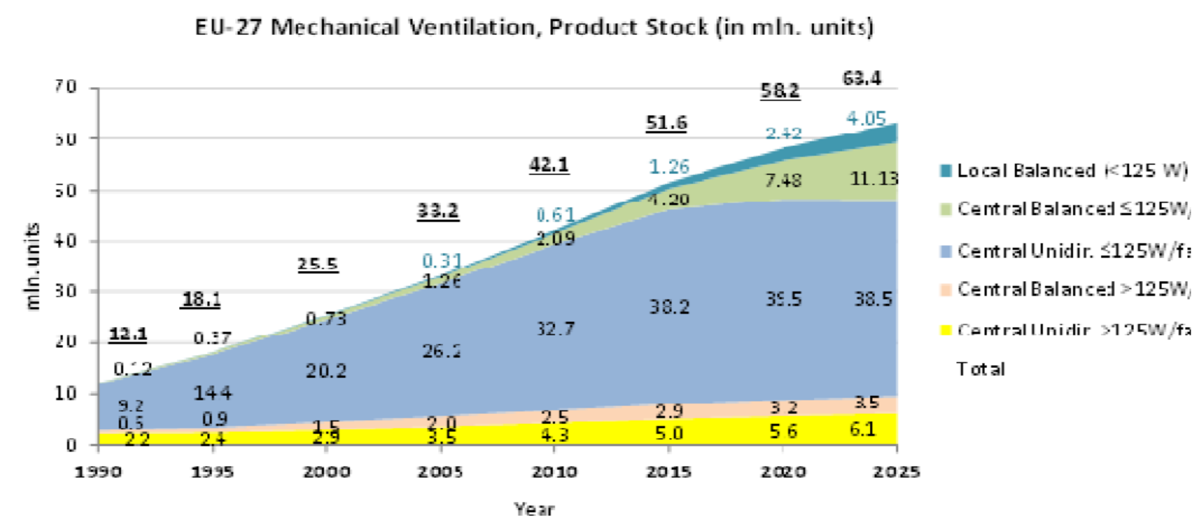


Figure 72: Stock of ventilation units in the EU 1990-2010 and projections 2010-2025 (BAU, source: preparatory studies), from (EU, 2014)

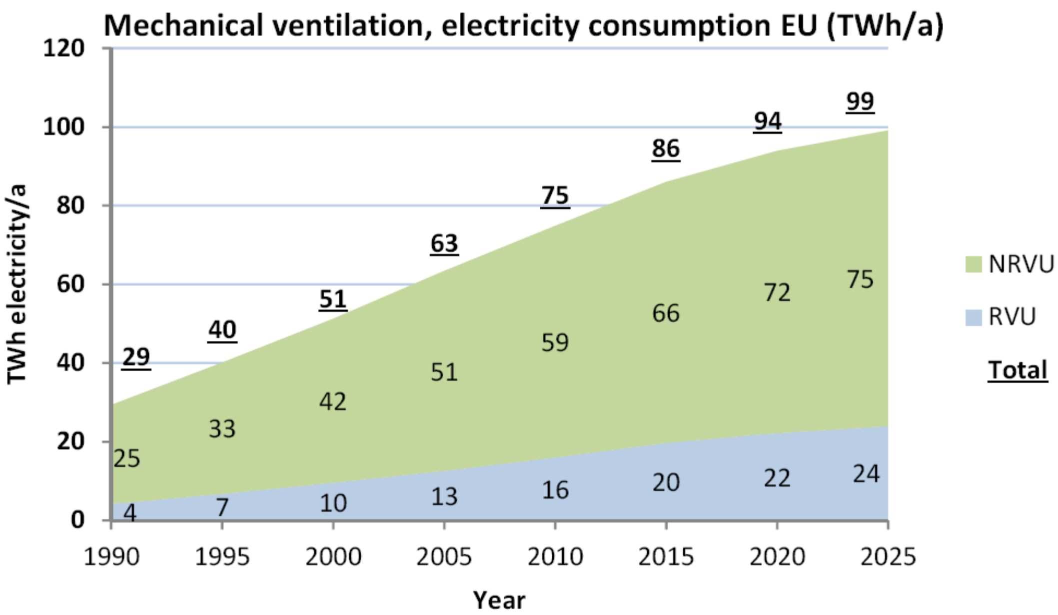
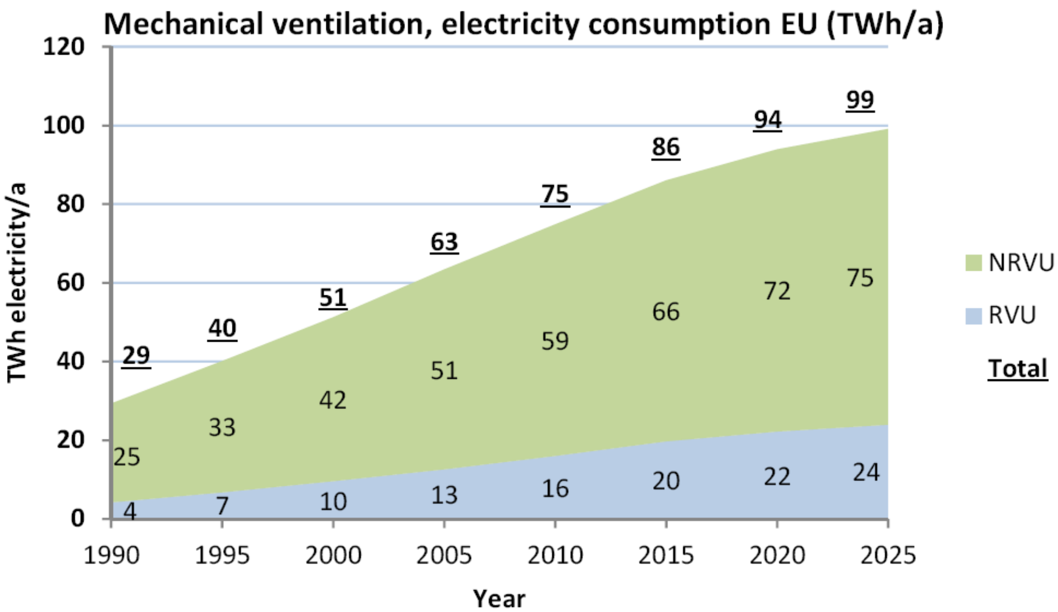


Figure 73: Mechanical ventilation, EU electricity consumption 1990-2010 and projections 2010-2025 (BaU) in TWh electricity per year (EU, 2014)

Please note that in comparison with figures in (Bertoldi, 2009), the presented electricity consumption is much lower (in 2007, 67.5 TWh/a on



versus 118 TWh/a in (Bertoldi, 2009)). But in total, the sum of air conditioning consumption estimated in preparatory studies[350] and of ventilation in (Eu, 2014) is quite close to (Bertoldi, 2009) estimates.
This consumption represents a near constant electric load of 1.8 GW for the residential sector. In the non-residential sector, ventilation is controlled at night and during weekends. The load is thus probably closer to 10 GW during the day (6.7 GW on average over 24 hours). These figures are expected to increase by 50 % between 2010 and 2025.

[350] Air conditioning preparatory studies : Central air conditioning systems (Rivière, 2012) and room air conditioners (Rivière, 2009).

SHIFTING OR CAPACITY MODULATING POTENTIAL

Presently, in the residential sector, ventilation is mainly constituted of one or few local exhaust fans (in wet rooms) or of a central extractor. Balanced (with heat recovery) ventilation units are growing but still represent a very limited share of market and stock.

All these systems operate continuously and may be controlled by the end-user. Some central extraction units are equipped with two speeds (case in France) with manual control (which can be either adjusted by wired or radio frequency control). Best available technologies (BAT) include demand controlled ventilation (based on CO_2 or other presence sensors), balanced heat recovery ventilation, as well as EC (electronically commutated) motors (having the ability to adapt the motor frequency to adjust the flow), which still represent very low market shares.

In the non-residential sector, ventilation works on the same principle with larger and more sophisticated units.

Air handling units allow more air treatment functions, which require also more sensors for control. Local sensors can communicate with the products through radiofrequency and it is now common to see manufacturers offering web interfaces for their products, for maintenance as well as energy consumption and performance measurement. The share of end-users buying these options is not known.

As a conclusion, some degree of smartness already penetrated the non-residential sector, but probably a small part only, while the residential sector is probably fully "non smart" technology.

SHIFTING OR CAPACITY MODULATING POSSIBILITY

Electric energy can be shifted directly, i.e. by stopping or modulating the fan electric power.

But when the ventilation system is specifically installed in a building that is heated or cooled by an electric generator, reducing the air renewal flow rate will also reduce the total heating / cooling load. Please note that the thermal energy saved by reducing the ventilation is much higher than the electricity consumption of the fan itself (typical rate: 4 or 5 to 1). In low energy dwellings, the share of the heating load due to air renewal may well reach 50 % but in general for a standard building in the stock, it is supposed to lie between 20 and 40 %). Please also note that some authors, e.g. (Da Silva, 2011), have proposed to increase the comfort during heating DR programmes by stopping completely the ventilation, i.e. coupling heating and ventilation in order to propose optimised DR strategies for buildings using electric heating. Note that this also applies for cooling. In this document, this contribution is included in the parts dedicated to heating / cooling and thus, only the electric consumption shifting potential from ventilation is considered.

For RVU, the electric power of the fan is generally constant (single speed unit). Central extractors have developed towards two speed models due to the national building codes (typically, the fans operate at 40 % except during 1 or 2 hours a day when operating at 100 % to remove humidity from showers or cooking). Control is mainly manual but can be automated when associated with a humidity control (popular in France). Balanced ventilation are operated all year long at constant flow.

For NRVUs, air handling units have more control options:

a) Clock control (on/off flow)
b) Air flow adjustment using dampers (creating more or less pressure drop and thus changing the total flow rate) (note: this type of control does not cut power consumption, but only adjust flow rate by flow resistance)
c) Multi-speed or variable speed control

SHIFTING OR CAPACITY MODULATING POTENTIAL PER APPLIANCE

For residential ventilation, the DR potential is probably too diffuse and challenging to be really economical (30 W or less per fan for central extraction unit). It is probably only interesting because of its indirect effect on thermal loads.

For non-residential ventilation, these products are included in DR programmes in the USA (LBNL, 2013). For systems with variable speed control or with several speeds / air handling units, there is a potential to reduce flow rates for DR programmes. The ventilation system is designed for peak conditions but without advanced demand control installed, the ventilation is mostly programmed by clock with fan power reduction at night (and possibly during lunch time), when the building is empty. The shifting potential then depends on the occupancy of the building. (LBNL, 2013) classifies commercial ventilation as suitable for "energy" DR programmes, i.e. around 50 % of the electric load can be shifted in time for more than 1 hour up to two times per day (or in total the full power more than 1 hour per day). But in the following report (NREL, 2013), the same authors eventually limit commercial ventilation to shorter-term grid services with a maximum of one-hour shift. Thus 1 hour is assumed, based on the US literature.
However, this potential is thought to be not sustainable, at least as building operations become more and more efficient. Indeed, the minimal ventilation consumption corresponds to a building operated with variable speed fan motors and demand controlled ventilation with CO_2 concentration sensors. The EN15251 standard specifies the maximum allowed CO_2 concentration in the air, which in turn defines the minimum ventilation flow rate. Hence, for an optimal building from the point of view of ventilation, it should be operated close to that minimum level with no possibility to go below.
With the limit being a maximum CO_2 concentration, there still could be a shifting potential if associated with a pre-period with higher than necessary ventilation levels. However, this probably leads to potentials of a few minutes only.

Total shifting potential of appliance category

About 10 GWh/day today but probably decreasing drastically with the increasingly intelligent and more energy efficient ventilation systems.

Comfort and user impact

The standard EN 15251 regarding comfort criteria in buildings defines required air renewal flow rates to reach acceptable levels of concentration for indoor pollutants. Assuming a perfect demand controlled ventilation system, limiting the air flow renewal exactly to the quantities to maintain the required levels of indoor pollutants with variable speed adjustment of the fan, there would be no place for DR programmes.

Gaps and/or pre-conditions for the potential to be realised

Installation of sensors and variable speed control for the fans, in order to comply with comfort criteria and to make sure for the building manager that comfort rules are respected despite lower air renewal flow rates.

Functionalities supporting energy efficiency

Distant maintenance and parameterization, energy and efficiency metering.

Conclusion

Maturity and low potential probably exclude residential ventilation, because power per unit is very low.
Flexibility potential:

- The peak power of non-residential ventilation is relatively low, about 10 GW.

- With 59 TWh in 2010 energy consumption of non-residential ventilation is relatively important because units operate all year long during working hours.
- Units may probably shift about 10 GWh/day during working hours in the week.

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HVAC/AIR CONDITIONING

DESCRIPTION

All cooling systems for comfort cooling:

- Residential air conditioners, mainly split and multi-split systems, but also portable air conditioners
- Non-residential air conditioning systems, i.e. chillers, large split, multi-split and VRF[351] systems, rooftop air conditioners and cooling systems of air handling units

INSTALLED BASE

Table 74: European stock of European air conditioning systems in GW of cooling capacity, source (Rivière, 2007) and (Rivière, 2012)

Peak power GW	1990	1995	2000	2005	2010	2015	2020	2025
Air conditioners < 12 kW (w/o portable)	8,8	21,2	37,9	61,8	85,7	89,3	99,6	108,1
Air conditioners > 12 kW	5,2	11,9	22,9	33,0	39,5	42,6	46,2	51,0
Chillers	31,1	40,0	49,2	61,2	72,8	81,9	90,1	97,3
Total	**45,1**	**73,1**	**110,1**	**156,0**	**198,0**	**213,8**	**235,9**	**256,4**

Energy consumption TWh	1990	1995	2000	2005	2010	2015	2020	2025
Air conditioners < 12 kW (w/o portable)	3,1	7,6	13,3	20,0	25,9	24,8	27,6	30,3
Air conditioners > 12 kW	2,2	5,3	10,2	15,6	19,7	20,8	21,9	23,8
Chillers	14,3	17,3	21,7	27,3	32,9	37,3	40,5	42,3
Total	**19,7**	**30,2**	**45,2**	**62,8**	**78,5**	**82,9**	**89,9**	**96,3**

Portable air conditioners are not considered in this evaluation of the air conditioning potential for DR. Please note that post 2005 figures for lower than 12 kW units and 2010 figures for other figures for larger air conditioners and chillers are BAU scenarios.
(Bertoldi, 2009) shows lower estimates for tertiary air conditioning: in 2007, it is estimated to 21.6 TWh versus 42.5 TWh in (Rivière, 2012) but residential figures are matching. In addition, the sum of tertiary air conditioning and ventilation are relatively close in both (Bertoldi, 2009), and in (VHK, 2012) and (Rivière, 2012).
Please note that as opposed to the heating load, there is little information regarding the impact on the European grid so that is difficult to make a reality check of these figures.

[351] VRF - Variable refrigerant flow system. Split system air conditioner with several indoor units connected on a refrigerant loop with individualized controls per room.

SHIFTING OR CAPACITY MODULATING POTENTIAL

Air conditioning units are typically equipped with sophisticated controllers. For most units, except small split units using a remote control, a central controller is generally installed with the unit. Controls of air conditioning units may be proprietary of the brand of the unit or bought to a specialised OEM. The same is true for the central controller. It is then thought that protocols of information and parameterisation data exchange are standardised and can be used to give indirect operation order to the unit (by shifting set point or thermostat). To get smarter, air conditioners may require slight adaptation however. Australia has for instance adopted a standard (AS 4755, 2008) for air conditioners to be equipped with specific DR signals (Defined modes: Stopped, working at 50 % or 75 % of their demand) in order to ease the interaction with a standardised DR enabling device which can be operated by external agents (typically agregators). The price of such a modification for air conditioners is estimated to 10 $(AUD).
However, the units sold in Europe do not have this functionality so far and are not directly “smart” even if the Australian example shows that it does not require a large adaptation.
Although smart thermostats are offered in Europe mainly for heating, they could also provide internet communication and control functionality for cooling appliances, thus helping to make a larger share of the installed based of air conditioners smart.

SHIFTING OR CAPACITY MODULATING POSSIBILITY

As for heating, electric cooling shifting potential mainly relies on the building thermal capacity to maintain indoor air temperature within acceptable limits when the cooling power is reduced or cut. As for heating, alternative strategies such as pre-charging of the building mass is feasible in case of two-way communication. All new equipment sold from 2012 onwards are equipped with multi-stage compression circuit or variable speed drive to control the cooling capacity output.
(Reddy et al., 1991) proposed a simplified formula to evaluate the time an air conditioning system could be stopped in a building without leading to temperature variations of more than 2 °C. His results show that for most buildings, air conditioning can be stopped for at least one hour a day. Recent evaluation of DR capability in the USA (NREL, 2013) have evaluated that between 20 and 70 % of the load can be shifted of at least one hour twice a day in the residential sector and between 40 and 50% in the commercial sector. Thus, 2 hours a day are assumed to make a first estimate of the potentials.

SHIFTING OR CAPACITY MODULATING POTENTIAL PER APPLIANCE

(Stamminger, 2008) states that for residential air conditioners, the acceptance by residential end-users may be limited to about 10 % of dwellings and for air conditioning stopped from 15 to 60 minutes per day. So acceptance appears to be a limiting factor. More sophisticated options than curtailment, like pre-charging of the building could probably improve this low acceptation level.

TOTAL SHIFTING POTENTIAL OF APPLIANCE CATEGORY

The total potential is thus assumed to be in a magnitude of 160 GW over one hour over the cooling season during week days (but also week-ends for residential units). In practice however, this could only be reached if all the appliances would operate at about 35 °C, which is most probably not the standard case in Europe, meaning that 130 GW (for about 30 °C average temperature) is probably a maximum. On average over the summer, the required daily peak load would be most likely only the half or about 65 GW. The main load occurs during the day, at noon in the commercial sector and in the afternoon for residential air conditioners.
Shifting potential in terms of energy can then be estimated to: 4 (months) * 65 GW * 30.5 (day/month) * 1 h = 7.9 TWh/a or 65 GWh per day on average during the summer period (June to September). Please note that as for heating, this figure will vary with outdoor temperature and the potential will be only available during daytime.

Comfort and user impact

The rationale is the same as for heating. Comfort is the main limiting factor of the shifting or curtailment potential.

Gaps and/or pre-conditions for the potential to be realised

The full potential requires comfort acceptance. And this could be achieved by two-way communication used to minimise the impact of DR on the user comfort. The level of acceptability for residential cooling DR programmes has been estimated to only 10 % in Germany (Stamminger, 2008) and between 10 and 40 % in the USA (LBNL, 2013).

Functionalities supporting energy efficiency

The same trends as for heat pumps can be observed : more and more complex CPUs integrated in the products in order to achieve the control of the units ; in addition, for maintenance purpose, interfaces are generally available for more than 10 years for more advanced brands, in order to ensure optimal operation and thus energy efficient operations.

Conclusion

It is believed that about 15 % of all electric cooling appliances are equipped grid communication and control.
Flexibility potential :

- Peak power : up to about 200 GW (2010) but probably not more than 160 GW even in case of extreme events.
- Energy consumption : about 80 TWh in 2010
- Potential energy to be shifted : about 65 GWh/d in the summer and about 8 TWh/a in total

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LIGHTING

DESCRIPTION

This category comprises lighting in residential and commercial indoor areas and public street lighting.

INSTALLED BASE (EU 27)

The estimated stock year 2013 based on the Ecodesign Preparatory Study on Light Sources (ENER Lot 8/9/19 (VITO, 2015):

- LFL: Linear fluorescent lamp: 2209 million units
- CFL: Compact fluorescent light: 4406 million units
- Tungsten: 2569 million units
- GLS: General lighting service ('incandescent'): 561 million units
- HID: High intensity discharge lamp: 84 million units
- LED: Light emitting diode: 144 million units

Separately, the estimated number of street lighting luminaires in EU-25 is about 60 million (2004 figures) (VITO, 2007).

Total calculated energy consumption year 2013 calculated on the basis of (Kemna, 2014):

- LFL: Linear fluorescent lamps: 126 TWh/year
- CFL: Compact fluorescent light: 33 TWh/year
- Tungsten: 57 TWh/year
- GLS: General lighting service ('incandescent'): 13 TWh/year
- HID: High intensity discharge lamp: 48 TWh/year
- LED: Light emitting diode: 1 TWh/year
- Total: 279 TWh/year

Total energy consumption (2020) of street lighting is 35 TWh/year (VITO, 2007).

SHIFTING OR CAPACITY MODULATING POTENTIAL

SHIFTING OR CAPACITY MODULATING POSSIBILITY

There are the following possibilities to shift or modulate capacities:
For advanced LED light bulbs: There are already LED light bulbs on the market, which can be controlled by a smart phone over Wi-Fi – in some cases combined with a special hub for the bulbs. This can be further developed into a DR enabled system controlled by signals from the power supply system. For LED systems there will be no technical problems in dimming and switching off the light.
For CFLs: It is also possible to build in DR enabling, but in a less extent dimming compared to LEDs.

Generally, for all light bulbs (LED, CFL, Tungsten, GLS) it is technical possible to mount an extra DR module for switching on and off the bulbs.
For luminaires and lighting systems in commercial areas (mainly LFL): There are already advanced systems on the market, which can be controlled by local conditions in the lighted area through presence sensors and solar radiation sensors combined with the time of day. This can be further developed into a system controlled by signals from the power supply system.
Street lighting: Street lighting systems are already highly controlled from outside and it is possible to combine this with a DR module.
Many light technologies can be dimmed (tungsten, halogen, fluorescent, LED etc.) resulting in reduction in power load and energy consumption. Lighting including street lighting is naturally mostly switched on in periods with no solar radiation apart from indoor areas with no or few windows such as basements, commercial centres etc. meaning that the energy consumption is higher in evenings and during nights, though also depending on time of year and geographical location within EU. For offices and some other commercial area, the energy consumption is reduced during weekends. The energy consumption is higher during these periods, which would be a basis for the flexibility potential.

SHIFTING OR CAPACITY MODULATING POTENTIAL PER APPLIANCE

Data on shifting or capacity modulating potential per appliance in a smart grid perspective are scarce. Instead, we have assessed the potential from available data on stock, lumen output, operating hours, and efficiency (Kemna, 2014) combined with more details on street lighting (VITO, 2007).
Based on average data on lumen/unit and lumen/watt, the average wattage for each unit is:

- LFL: Linear fluorescent lamps: 29 watt
- CFL: Compact fluorescent light: 11 watt
- Tungsten: 50 watt
- GLS: General lighting service ('incandescent'): 51 watt
- HID: High intensity discharge lamp: 144 watt
- LED: Light emitting diode: 5 watt
- Tungsten stock: 36 watt

The technical potential for load shifting for each light bulb is of the same size assuming switching off. Modulating i.e. dimming potential is much less but naturally depends on the dimming level.

TOTAL SHIFTING POTENTIAL OF APPLIANCE CATEGORY

Based on data on the total amount of lumen for EU27 and the lighting efficiency (Kemna, 2014), we have calculated the total power draw for each type of lighting technology assuming full simultaneous power draw:

- LFL: Linear fluorescent lamps: 56 GW
- CFL: Compact fluorescent light: 36 GW
- Tungsten: 49 GW
- GLS: General lighting service ('incandescent'): 8 GW
- HID: High intensity discharge lamp: 7 GW
- LED: Light emitting diode: 29 GW
- Total: 185 GW

This figure needs to be reduced with a simultaneity factor i.e. taking into account that all lighting devices are not switched on all the time. As a rough estimate, we assume a 30 % simultaneity factor

and a 50 % comfort factor i.e. only 50 % would be possible to switch off without losing unacceptable comfort losses. The total shifting potential is therefore about 28 GW.
Of this total shifting potential, street lighting is estimated at about 5 GW (based on VITO, 2007) and residential and commercial indoor lighting is 23 GW.

If assumed maximum 5 minutes and 30 minutes of acceptable off time per day for residential and commercial indoor lighting and street lighting, respectively, then the switching potential would be about 4 GWh/day.

COMFORT AND USER IMPACT

Assuming that the use of the lighting is already well controlled, either manually or automatic, the negative comfort impact of dimming or switching off will be large; especially in the homes and commercial areas, which may include safety issues. Only very short periods of time would be accepted; we assume 5 minutes per day.

For street lighting the comfort impact may be more limited, at least for shorter periods of time. On average, we assume half an hour per day.

GAPS AND/OR PRE-CONDITIONS FOR THE POTENTIAL TO BE REALISED

There are not many technological gaps, because the technology exists.
There may be technological gaps regarding some lighting technologies, which are not suitable for dimming and/or often switching on/or, else the gaps are few and technology are already used for lighting systems on the market.
The control systems may result in standby power consumption.
The main gap is the user impact regarding comfort loss.

FUNCTIONALITIES SUPPORTING ENERGY EFFICIENCY

For lighting in homes and commercial areas, information feedback on the level of consumption; when the consumption takes places in relation to the needs and efficiency and possibilities of impacting the consumption by behaviour changes and change of bulbs and lighting systems may provide substantial energy savings.
Street lighting is typically highly controlled and professional procured, and only few savings would be possible to achieve with more information feedback.

CONCLUSION

Due to energy labelling and ecodesign measures, there is a high focus on energy efficient lighting, both regarding efficient lighting devices and regarding efficient control (presence sensors, automatic dimming according to actual needs, etc.). When lighting is an energy service, which needs to be produced simultaneous as the needs occur, all lighting load shifting would have serious user impacts.
Therefore, even though the technical potential is large, the flexibility is low, especially for homes and commercial areas, and the real potential will mainly exist for short periods of emergency load shifting.

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BATTERY OPERATED RECHARGEABLE APPLIANCES

DESCRIPTION

This factsheet covers (low power) appliances equipped with battery charging function. These include all kind of multimedia devices (phones, tablets, video cameras, etc.), power tools and other household appliances with rechargeable batteries (clocks, electric shaving, toothbrushes, etc.) on a low power level.
Not included are high power chargers for electric vehicles or in home battery storage, Uninterruptible power supplies (UPS) or industrial appliances.

INSTALLED BASE

The installed base of these appliances is very high.
For smartphones only, the sales figures (IDC[352] and Gartner[353]) worldwide have gone from 300 million in 2010 to more than 650 million in 2012 and grew above 1 billion in 2014. The estimated total installed base for smartphones only will exceed 2 billion. The situation is similar for tablets worldwide, with sales growing from 200 million in 2013 to an expected 260 million in 2016 (Gartner, January 2015)[354]. Estimates of laptop sales vary between 200 and 180 million.
For Europe (EU28), the sales of all mobile phones (smartphones and regular mobile phones) range from 227 million in 2009 to 213 million in 2013.
Sales of personal navigation devices (PNDs) in Europe peaked at 17 million units in 2008 and fell to less than 10 million units by 2012. Digital camera figures remained around 30 million till 2012. It is expected that this figure will decrease in the subsequent years in favour of smartphones with advanced integrated cameras.
Figures for other appliances are harder to find, but it is estimated that all together they represent annual sales of more than 50 million units in the EU[355].

SHIFTING OR CAPACITY MODULATING POTENTIAL

SHIFTING OR CAPACITY MODULATING POSSIBILITY

Currently, only a minority of these appliances are ready for smart charging. However a distinction needs to be made between the devices with a rather large processing power capability (most multimedia appliances) and network facilities as well as those without these features. Smart charging functionality could be added as a software application without the need to further adaptations. In the light of the comparatively 'low' selling prices of these appliances, the need for further (physical) adaptations would be also a significant financial barrier.

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SHIFTING OR CAPACITY MODULATING POTENTIAL PER APPLIANCE

When looking at the total energy consumption of these appliances:

- Smartphone: 3 to 5 kWh/year
- Tablet: 12kWh/year
- Rechargeable Power Tool: 38 kWh/year

it can be concluded that a flexibility capacity would come from the large number of appliances, rather than the individual power consumption.
Since the multimedia appliances have a high annual usage and therefore will be charging often, there will be a significant potential that can be shifted. This is less the case for other appliances like e.g. rechargeable power tools, since their usage is less predictable.
Also peak powers in the charging of these appliances are rather low, often < 50 W.

TOTAL SHIFTING POTENTIAL OF APPLIANCE CATEGORY

The overall shifting potential of this group of appliances is hard to evaluate, since not much research has been done on this topic. It can be assumed that the largest potential is situated overnight when many of these appliances are connected to the chargers, but as stated, no real figures were found to support this. Also no figures were found on the relationship between average charging times of the appliances and concrete time periods for the connection with the charger.

COMFORT AND USER IMPACT

For evaluating the comfort and user impact, 2 basic scenarios have to be considered. One that keeps the appliance on a minimum “State Of Charge” (SOC) and a second where the appliance should be fully charged at a certain point in time.
In the first scenario, the process could be implemented so that it is executed without user interaction. We could think of laptops that reside a lot in docking stations. This however implies that the appliance cannot be predicted or guaranteed to be fully charged at a certain point of time, limiting flexibility, ‘mobility’ and therefore the comfort level.
The second scenario requires the user to set the ‘be fully charged time’. This could be either done each time the appliance charges, according to defined schedules, or following other similar solutions. The comfort level is higher, but user interaction (change of habits) is required.

GAPS AND/OR PRE-CONDITIONS FOR THE POTENTIAL TO BE REALISED

As stated before some appliances could exploit the smart charging facilities just by means of a software adaptation. But for others functional hardware extensions are needed to be able to execute smart charging, i.e. not charging completely to the maximum as soon as connected.
A second important factor is the willingness of end-consumers to apply the smart charging functionality, in order to address e.g. the question: “What is the benefit for users to provide this flexibility?” Business cases should be available to provide sufficient incentives for end consumers to participate in this.

Functionalities supporting energy efficiency

For some battery types (e.g. NiMh) the efficiency is higher between certain SOC levels. The smart charging implementation could include this information. Note that this is not the case for Lithium-ion batteries which represent a large number in the installed base of the here described appliances.

Conclusion

There is a certain potential, however its capacity will depend on controlling large numbers of products. Peak powers and average consumption is rather low for these appliances, whereas numbers are very high (millions).

Limited research has been done on the potential of smart charging in the low power appliances sector, but similar techniques already were investigated for electric vehicles, which could also be applied for this.

References

- Framework Service contract ENTR/2008/006/Lot 1, Study on the Impact of the MoU on Harmonisation of Chargers for Mobile Telephones and to Assess Possible Future Options
- IDC Press Release : Worldwide Smartphone Growth Expected to Slow to 10.4% in 2015, Down From 27.5% Growth in 2014, According to IDC, August 2015, http://www.idc.com/getdoc.jsp?containerId=prUS25860315
- Gartner Press Release : Gartner Says Smartphone Sales Surpassed One Billion Units in 2014, March 2015, http://www.gartner.com/newsroom/id/2996817
- Gartner, Press Release : Gartner Says Tablet Sales Continue to Be Slow in 2015, January 2015, http://www.gartner.com/newsroom/id/2954317

RESIDENTIAL ENERGY STORAGE SYSTEMS

DESCRIPTION

This category represents larger battery storage systems. They fall into the 2 main categories (1) ”backup systems” like Uninterruptible Power Supply systems (UPS) as well as (2) “Battery Energy Storage Systems”, which are mainly designed for load levelling and peak power compensation.

INSTALLED BASE

UPS:

The total installed base for 2011 was calculated as 7.5 million UPS units[356] in EU27, represented by the following size categories:

- Below 1.5 kVA products: 53% of the total installed base
- 1.5 to 5 kVA products: 41% of the total installed base
- Above 5 kVA products: 6% of the total installed base

Important note: The above figures include mainly UPS systems used in data centres and larger organisations (companies, hospitals, etc.), which are however out of the scope of this study. In Western Europe, in 2013 the annual data centre load requirement was an estimated 79 TWh. So only a very small fraction of these systems is located in residential and small business setups. No exact figures were found for these specific products.

Battery Energy Storage Systems:

Figures of the rated power of US battery grid storage projects in 2013 indicated a total of 304 MW (Grid Energy Storage U.S. Department of Energy), but these are all big installations outside the scope of this study. No figures were found on residential systems, but considering the limited amount of vendors and product availability, figures will be very low at the moment.

SHIFTING OR CAPACITY MODULATING POSSIBILITY

The primary purpose of a UPS is to bridge an unexpected power gap and/or to provide the amount of power needed to safely power down the connected load. Apart from that it can also be used to maintain voltage and frequency within rated steady state and transient bands or to compensate distortions or interruptions to the supplied power within specified limits. Although these systems represent a relevant potential capacity, due to their original purpose, the SOC of these systems has usually to be kept at a fixed ‘high’ level, which strongly limits the shifting possibility.

The main purpose of Battery Energy Storage Systems is to store excess energy produced when demand is low and then make it available when demand is high (E.g. store energy from solar panels during the day and use this during evening hours). Another intended usage is peak power compensation. In this case stored energy is delivered from the Battery Energy Storage Systems to avoid power peaks on the distribution grid.

Other intended usages are power smoothing to prevent sudden surges or drops in power supply, to operate remote and isolated installations (temporary or permanent) not connected to the distribution grid, as well as regulation of grid frequency within pre-set limits. Note that respective legislation rules apply on operating in “off-grid mode” as well as converting to grid connection.

[356] ErP Lot 27 – Uninterruptible Power Supplies, Preparatory Study - Final Report

Shifting or capacity modulating potential per appliance

UPS systems for residential and small business range from 100 kVA up to 5,000 kVA and are usually designed to provide short term bridging periods, e.g. for several minutes to few hours.
On residential and small business level the capacity of Battery Energy Storage Systems usually ranges between 1 and 10 kWh. It should be noted that not many commercially available systems exist at the time of this study, but several manufacturers are already in the process of developing and commercialising such products.

The systems exist as standalone setup (e.g. Samsung) or in combination with energy production systems like PV panel invertors (e.g. Tesla, NEDAP). Some vendors provide systems where the control of production, storage and consumption is fully integrated (e.g. SMA), …

Total shifting potential of appliance category

The potential of both systems is very limited at this moment. For the UPS systems, this is due to its original purpose and the small installed base on residential and small business level.
Battery Energy Storage Systems are still in an early phase of commercialisation, so the installed base is currently very small. From its nature it has a large potential once installed in larger numbers.

Comfort and user impact

Both systems can operate automatically and thus require limited user interaction. The comfort is twofold: improving power quality and providing power assurance (for limited periods).

Gaps and/or pre-conditions for the potential to be realised

UPS systems already have a high technical maturity and already were subject of an Ecodesign study[i].
The Battery Energy Storage Systems for residential use are rather new, but share technology with UPS systems. However they will operate frequently in different SOC levels and will have therefore different requirements to the batteries used. Additionally the control logic could be more complex, certainly in combined systems as described above.

Functionalities supporting energy efficiency

Local storage can aid in the reduction of grid losses.

Conclusion

Both described battery storage systems are from a technical point of view similar to each other but differ in their intended usage. The backup systems, by the nature of their usage, do not allow a large amount of flexibility.

The Battery Energy Storage Systems are meant exactly to provide flexibility for different usages, but at the moment their installed base is limited and consequently also the total capacity. However when in future these systems will find broadly their way to the market, they could represent a larger potential.

References

IDC, Gartner and JPMorgan
Gartner (April 2012)
Framework Service contract ENTR/2008/006/Lot 1, Study on the Impact of the MoU on Harmonisation of Chargers for Mobile Telephones and to Assess Possible Future Options
ErP Lot 27 – Uninterruptible Power Supplies, Preparatory Study - Final Report
Grid Energy Storage U.S. Department of Energy

ANNEX 2: SELECTION OF INITIATIVES RELATING TO DEMAND RESPONSE, SMART HOME AND SMART APPLIANCES

1. Framework Document for the physical characterization of grid-connected buildings

The U.S. Department of Energy (DOE) is working on a Framework Document[357] for the physical characterization of grid-connected buildings end-use equipment and appliances.
The US DOE plans to convene industry and other stakeholders for a harmonised development of protocols while avoiding undue burden on industry, and to measure the responses that connected equipment can provide. The main goals of developing this framework are the following:

- Promote innovation among the industry players.
- Help to establish a scalable market for connected equipment through developing data and information to inform consumers/building owners, manufacturers, and electric and gas utilities.
- Protect consumer value through quality of service and other benefits provided by the equipment as well as to minimise life-cycle operation cost.
- Protect manufacturers by avoiding damage to equipment, violation of warranty, and consumer dissatisfaction.
- Inform utilities and service providers of the end-user, societal, grid, and energy market services that the connected equipment can deliver, as well as create an opportunity for new services and value streams for the different stakeholders in the future.

Status
At an initial public meeting held on April 30th, 2014 in Golden, CO, (79 FR 19322) there was general support from attendees for DOE's vision for characterization of connected equipment and their role as convener of industry stakeholders to develop the characterization protocols in an open and transparent process. A second public meeting was held on July 11th, 2014 in Washington, D.C. (79 FR 32542), at which structure and content for this draft framework document was presented and the attendees were given the opportunity to provide input and discuss the details of the characterization framework. The framework covers the scope, terminology, and definitions of connected equipment, the details of the characterization protocol framework, and the process for developing the characterization protocols. On August 14th 2014 DOE announced the Framework Document and performed a request for comment. Comments were accepted till September 29, 2014.

The **primary objective** of this framework is to describe the characterization protocol structure and performance metrics that stakeholders may use to evaluate the services that connected equipment can deliver. This framework applies to connected buildings' end-use appliances and equipment within residential, commercial, and industrial buildings. The document also described a process for collaborating with industry stakeholders to develop characterization protocols and performance metrics for connected equipment in the future. However, communications and interoperability barriers such as cybersecurity, privacy, message syntax, or signal transmission are not within the scope of this framework document. In addition, DOE is generally aware of several activities ongoing within the industry related to connected appliances and equipment, such as the activities in AHAM, AHRI, ASHRAE, EPA and many other professional societies and trade associations. DOE acknowledges

[357] http://www.regulations.gov/#!documentDetail;D=EERE-2014-BT-NOA-0016-0022

the changing landscape of the industry and is performing due diligence to understand ongoing complementary activities underway by stakeholders.

2. Home Gateway Initiative (HGI)

The HGI[358], founded in 2004 by major broadband service providers and joined by leading vendors of digital home equipment, focusses on the way that services are delivered in the digital home. Starting from use cases and service needs, the HGI publishes requirements and test plans for home gateways, infrastructure devices, and the home network. HGI's strategic focus is helping applications, home gateway middleware and home network-based devices to connect seamlessly. The HGI has members from across the globe, representing the entire spectrum of players in the broadband home area.

HGI is currently looking at smart home architecture and device abstraction aspects. Every device automation solution and HAN technology makes use of assumed/defined models (known properties) for the connected devices. Instead of creating a „superset" of those HAN models, HGI is investigating if a modular extensible modelling template (Smart home Device Template, SDT) can be defined to describe almost every device type (Figure).

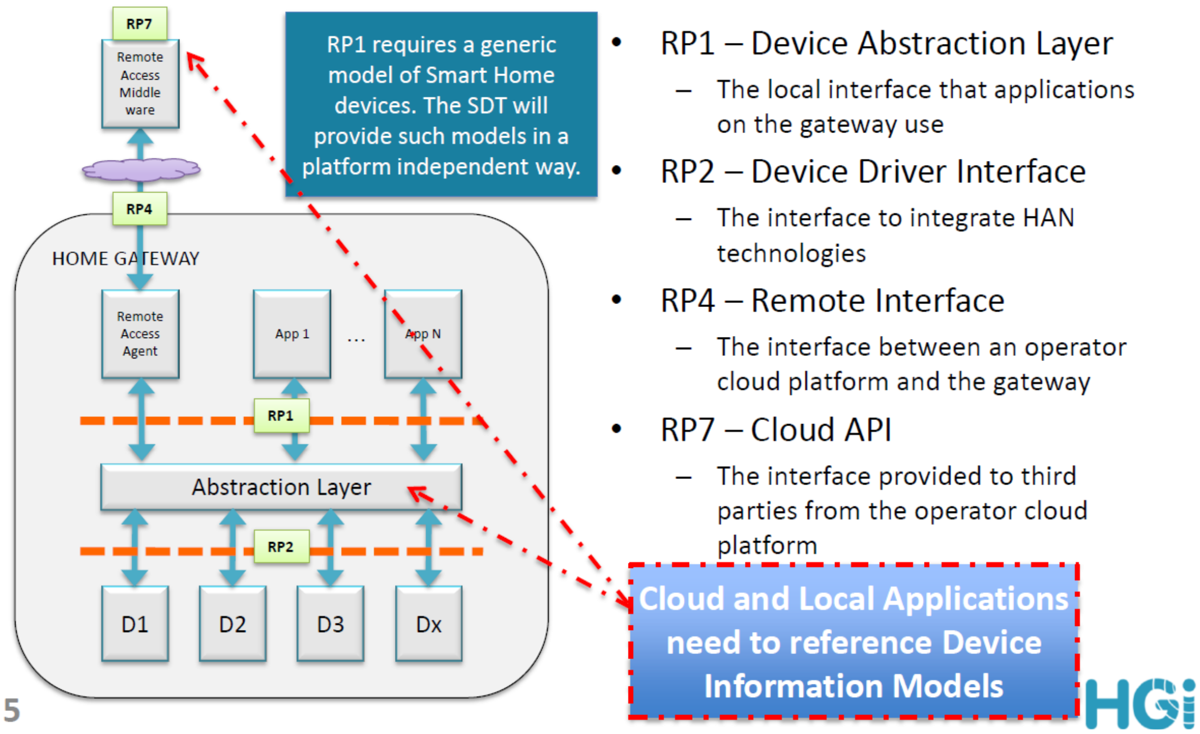

Figure 74: HGIs' Smart Home architecture reference points[359]

[358] http://www.homegatewayinitiative.org/

[359] Open source project at HGI for Smart Home device abstraction templates (SDT), https://www.eclipsecon.org/europe2014/sites/default/files/slides/HGI-SmartDeviceTemplates-Project.pdf

3. OASIS

The Organization for the Advancement of Structured Information Standards (OASIS) is a not-for-profit consortium, that aims at the development, convergence and adoption of open standards for the global information society[360].

Currently, the OASIS Smart Grid Suite of Standards consists of three standards:

- **Energy Interoperation 1.0:** published in December 2011. Energy Interoperation specifies an information model and messages to enable standard communication of DR events, real-time price, market participation bids and offers (tenders) as well as load and generation predictions. Energy Interoperation serves primarily at the interface to deliver DR and DER communications from a grid-side service provider (e.g. a distribution utility, or an aggregator) to a customer facility/home. The specification and schema are all freely available from OASIS[360]
- **EnergyMarket Information Exchange (eMIX)** provides a standardised methodology to describe energy products that might be traded in a competitive marketplace and includes an information model for energy and market information.
- **WS-Calendar** provides a common information model and vocabulary for calendaring and scheduling.

Standards related to IoT/M2M:

- OASIS Advanced Message Queuing Protocol (AMQP) : defines a ubiquitous, secure, reliable and open internet protocol for handling business messaging.
- OASIS Message Queuing Telemetry Transport (MQTT) : provides a reliable lightweight publish/subscribe messaging transport protocol suitable for communication in M2M/IoT contexts where a small code footprint is required and/or network bandwidth is at a premium.
- OASIS Open Building Information Exchange (oBIX) : enables mechanical and electrical control systems in buildings to communicate with enterprise applications

4. Open Interconnect Consortium (OIC)

The Open Interconnect Consortium[361] has being founded by leading technology companies with the goal of defining the connectivity requirements and ensuring interoperability of the billions of devices that will make up the emerging Internet of Things (IoT).
The Open Interconnect Consortium (OIC) will seek to define a common communication framework based on industry standard technologies to wirelessly connect and intelligently manage the flow of information among devices, regardless of form factor, operating system or service provider. OIC also intends to deliver open source implementations for a variety of IoT market opportunities and vertical segments from smart home solutions to automotive and more. At the end of 2014 OIC released the first version of its open source IOTivity[362] resource framework.

The intention of OIC is to create standard specifications for interoperability across connected devices. It will encapsulate various wired and wireless standards and utilise additional standards to create a cross device/cross technology framework for secure device discovery and connectivity. OIC is agnostic to any wireless or wired technology and will work across technologies including Wi-Fi, Bluetooth, Bluetooth LE, Wi-Fi Direct, Zigbee, Zwave, Ant+. It is OIC's intention to create a specification and an open source project that will allow interoperability for all types of devices and operating systems. A OIC certification process is planned but not yet defined.

[360] http://www.oasis-open.org
[361] http://openinterconnect.org/
[362] https://www.iotivity.org/

Leading members (diamond and platinum members) are Intel, Cisco, Mediatek, Samsung, ADT, Atmel, Dell, Eyeball networks, HP.

5. HomeKit - Apple

HomeKit[363] is Apple's attempt to enter the home automation market. It is in fact a home automation framework for developers and uses a common network protocol that devices can employ. The user needs only one app to control all the devices. Thanks to the market dominance of Apple's ecosystem many manufacturers are integrating HomeKit support into their products. Apple's ecosystem is however a closed system. A MFi (Made For iPhone) license is necessary to use particular technology like HAP (HomeKit Accesory Protocol).

6. ThreadGroup

The ThreadGroup[364] is a not-for-profit organization responsible for the market education around the Thread networking protocol and certification of Thread products. Thread is an IP-based wireless networking protocol that addresses the need for a new and better way to connect products in the home. With Thread, product developers and consumers can easily and securely connect more than 250 devices into a low-power, wireless mesh network.
Thread is an IPv6 networking protocol built on open standards, designed for low-power 802.15.4 mesh networks. Existing popular application protocols and IoT platforms can run over Thread networks.
The charter of the Thread Group is to guide the adoption of the Thread protocol. Thread Group founding members consist of industry-leading companies including Yale Security, Silicon Labs, Samsung Electronics, Nest Labs, Freescale® Semiconductor, Big Ass Fans and ARM.

7. Allseen (AllJoyn)

The AllSeen Alliance[365], formed in December 2013, is a nonprofit consortium dedicated to driving the widespread adoption of products, systems and services that support the Internet of Everything with an open, universal development framework. The Alliance hosts and advances an industry-supported open software connectivity and services framework based on the AllJoyn open source project with contributions from Premier and Community Members as well as from the open source community. This open, universal, secure and programmable software connectivity and services framework enables companies and individuals to create interoperable products that can discover, connect and interact directly with other nearby devices, systems and services regardless of transport layer, device type, platform, operating system (OS) or brand.

Initially developed by Qualcomm Innovation Center (QuIC), Inc (Qualcomm's open source subsidiary), AllJoyn is transport-, OS-, platform- and brand-agnostic, enabling the emergence of a broad ecosystem of hardware manufacturers, application developers and enterprises that can create products and services that easily communicate and interact.

The AllSeen Alliance will not develop standards in the traditional sense. The Alliance seeks to advance and promote a de facto standard through reuse of a common codebase developed in an open source project.

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[363] https://developer.apple.com/homekit/
[364] http://www.threadgroup.org/
[365] https://allseenalliance.org/

The AllSeen Alliance has nine working groups. One of the working groups, the Smart Home Working Group, develops an AllJoyn smart home service framework focusing on the centralised management aspects for proximal home appliances based on AllJoyn, including both smart home client API and smart home server API. The device implements AllJoyn smart home server API acting as the central control and management point for home appliances operating in the home network that implement AllJoyn smart home client API. The smart home server in the smart home system provides a number of connected-home services for home appliances like centralised security, group control, data collection and logging and so on.

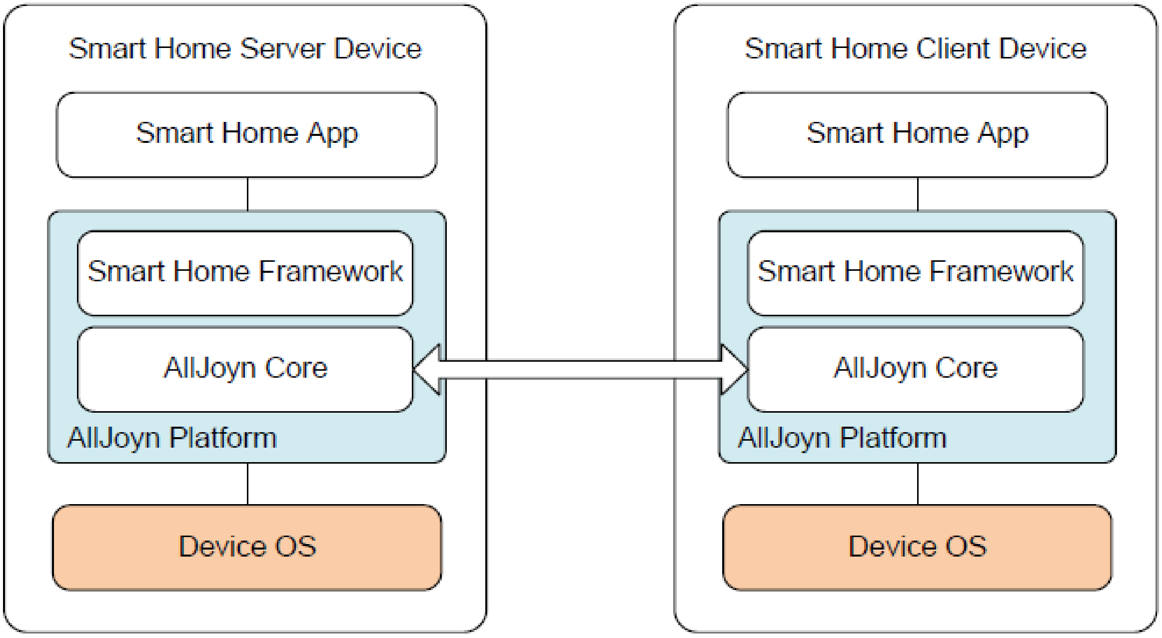

Figure 75: Smart Home service framework architecture within the AllJoyn framework[366]

The Alliance's members are leading consumer electronics makers, industrial solutions providers, service providers, software companies and chipset manufacturers. Premier Members are Electrolux, Hayer, LG Electronics, Microsoft, Panasonic, Qualcomm, Sharp, Silicon Image, Sony, Technicolor and TP-Link.

8. EEBus - EEBus e.V.

EEBus[367] is a data model and framework for a Energy Mamagement System (EMS) gateway at home. Many German and some international companies active in home automation and energy management manufacturers like ABB, Schneider Electric, SMA and others are member of the EEBus Initiative e.V. alliance. EEBus cooperates with the KNX association, ZigBee Alliance, Energy@Home alliance and Agora.

EEBus participates in CLC TC 205 WG 1 regarding the development of standard prEN 50491-12 "Smart Grid interface and framework for Customer Energy Management" and IEC TC 57 WG 21 regarding the development of a Standard IEC 62746 "Systems Interface between Customer Energy Management System and the Power Management System".

[366] Introduction of Smart Home Service framework, Allseen Alliance
[367] http://www.eebus.org/eebus-initiative-ev/

9. AGORA

AGORA[368] was born when several large French companies and SMEs (with an opening to international partners) joined forces to design and distribute components, products and terminals that would communicate with services to provide better «smart home» living. The idea was to jointly review all ways to enable domestic technologies to communicate, interact and cooperate. The Parties' shared goal was to provide residents of «smart homes» with more responsive, more economical and more efficient services by building a bridge linking everything together. This «bridge», in terms of a new household system language, could improve the management of energy, communications, comfort, entertainment, security, home care services and e-health, while protecting personal data. What's more, it would create new opportunities and open up new ideas, for example through interaction with social networks.

10. Energy@Home alliance

Energy@home[369] is a nonprofit association that, for the benefit of the environment, aims at developing and promoting technologies and services for energy efficiency in the home, based upon device-to-device communication. Energy@home envisages a holistic approach where the house is an ecosystem of connected and interacting appliances and sub-systems that coordinate themselves in order to optimise energy consumption, increase energy efficiency and create new services for end customers.

The association's goal is to promote the development and spreading of products and services based on interoperability and collaboration of the different appliances within the household and with the energy infrastructure.

11. OneM2M

oneM2M[370] is a global standards initiative for Machine to Machine Communications and the Internet of Things. Seven of the world's leading ICT standards bodies, five global ICT fora and 200+ companies from all industrial sectors are involved.

The purpose and goal of oneM2M is to develop technical specifications which address the need for a common M2M Service Layer that can be readily embedded within various hardware and software, and relied upon to connect the myriad of devices in the field with M2M application servers worldwide.

12. ClimateTalk Alliance

The ClimateTalk Alliance[371] is an organization of companies who are committed to developing a common communication infrastructure for HVAC and Smart Grid devices, enabling the interoperability of diverse systems. The ClimateTalk Common Information Model defines a set of messages and commands that diverse applications can use to communicate with each other. These messages and commands form the presentation and application layers as defined by the OSI model. Below the application layer, ClimateTalk messages can be carried over any type of physical medium.

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[368] http://www.reseau-domiciliaire.fr/home
[369] http://www.energy-home.it/SitePages/Home.aspx
[370] www.onem2m.org
[371] http://www.climatetalkalliance.org

13. ZigBee Alliance

The ZigBee Alliance[372] developed a set of network and application standards, whereby the network standards provide mesh capability on top of IEEE 802.15.4 wireless networks. Most of the ZigBee application standards are targeted at specific applications (application profiles), but in the context of IoT there is a trend to reunite the different application profiles into one standard, as it is the case with SEP 2.0 and ZigBee 3.0.

ZigBee IP is an open standard for an IPv6-based full wireless mesh networking solution, which provides seamless Internet connections to control low-power, low-cost devices. ZigBee IP was designed to support ZigBee 2030.5 (formerly known as ZigBee Smart Energy 2). It has been updated to include 920IP, which provides specific support for ECHONET Lite and the requirements of Japanese Home Energy Management systems. 920IP was developed in response to Japan's Ministry of Internal Affairs and Communications (MIC) designation of 920 MHz for use in HEMS and Ministry of Economy, Trade, and Industry (METI) endorsement of ECHONET Lite as a smart home standard.

Smart energy Profile 2.0
Smart energy Profile 2.0 (SEP 2.0) has been developed by the ZigBee Alliance in cooperation with WIFI and HomePlug Alliance. It offers a global standard for IP-based control systems, both wired and wireless, for energy management in Home Area Networks (HANs). To ensure interoperability of products, the members of the Consortium for SEP 2 Interoperability (CSEP) are working together to develop common testing documents and processes for certifying SEP 2 interoperability. SEP 2.0 is selected by the United States National Institute of Standards and Technology (NIST) as a standard profile for smart energy management in home devices. IEEE adopted the application standard (formerly known as ZigBee Smart Energy 2) in 2013 as IEEE 2030.5-2013

ZigBee 2030.5 is the ZigBee IP-based implementation of IEEE 2030.5-2013, using ZigBee IP on top of IEEE 802.15.4.

ZigBee 3.0 is the unification of the Alliance's wireless (application) standards into a single standard. It is currently under development and is expected to be ratified by the Alliance members in Q4 2015. ZigBee 3.0 is mainly a wireless protocol stack standard, integrating the former application profiles (ZigBee Building Automation, ZigBee HomeAutomation, ZigBee Light Link, ZigBee Smart energy, etc.) on top of ZigBee Pro.

The ZigBee alliance announced in April 2015 that its' application layer will also run on top of the Thread protocol.

ZigBee Alliance[373]
The ZigBee Alliance consists of a group of companies that maintain and publish the ZigBee standards. The Alliance has three levels of membership: Promoter, Participant and Adopter. The Promotors are: Comcast, Freescale, Itron, Kroger, Landys&Gear, NXP, Philips, Legrand, Schneider Electric, Silicon Laboratories and Texas Instruments.

[372] http://zigbee.org/
[373] http://zigbee.org/zigbeealliance/our-members/

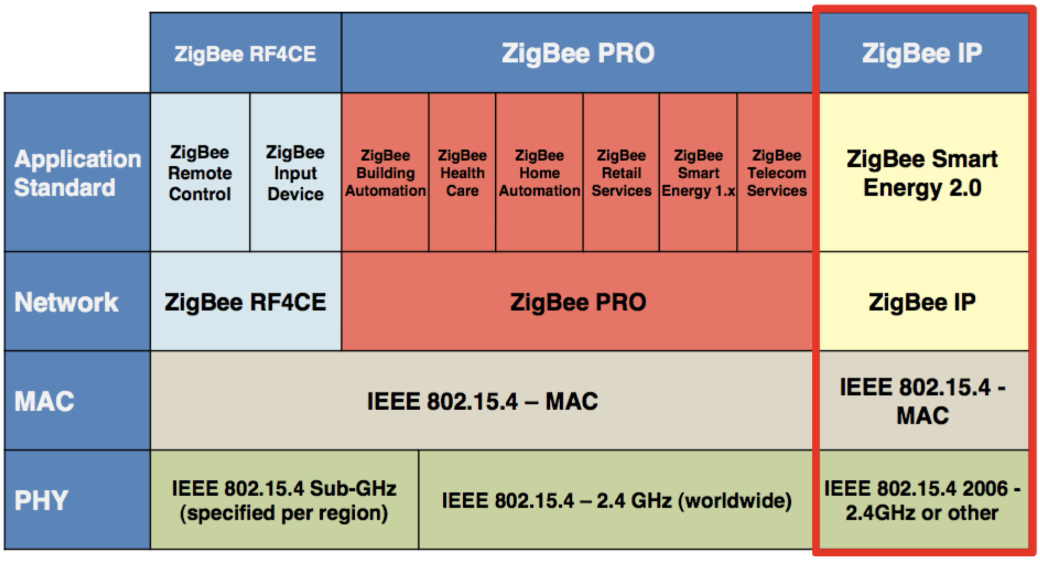

Figure 76: ZigBee protocol stacks[374]

14. OpenADR Alliance

The OpenADR Alliance[375] fosters the development, adoption, and compliance of the Open Automated DR (OpenADR) standard through collaboration, education, training, testing, and certification. The OpenADR Alliance is open to all interested stakeholders interested in accelerating the adoption of the OpenADR standard for price- and reliability-based DR.

OpenADR 2.0 is a profile on Energy Interoperation serving DR and DER communications as well as price distribution for both wholesale and retail markets. The OpenADR 2.0 Profile Specifications are developed and maintained by the OpenADR Alliance and available to the public. There are currently two profiles (a and b; c is in progress) to serve less and more capable devices, and diversity in DR and price-responsive programmes. A testing and certification programme has been set up. OpenADR was developed by Lawrence Berkeley National Laboratory to address a low-cost and reliable automation infrastructure to support DR and price communication, allowing electric service providers to communicate DR event signals to customers with automated response capabilities. OpenADR 2.0 is based upon a subset of Energy Interoperable 1.0 (EI 1.0)[376].

The OpenADR 2.0b Profile Specification is approved by the IEC as the Publicly Available Specification (PAS) “IEC/PAS 62746-10-1:2014: Systems interface between customer energy management system and the power management system - Part 10-1: Open Automated DR (OpenADR 2.0b Profile Specification)”.

[374] http://greentechadvocates.com/2013/04/04/zigbee-ip-smart-grid-meet-the-internet-of-things/
[375] http://www.openadr.org/
[376] OASIS Energy Interoperation version 1, http://docs.oasis-open.org/energyinterop/ei/v1.0/os/energyinterop-v1.0-os.html

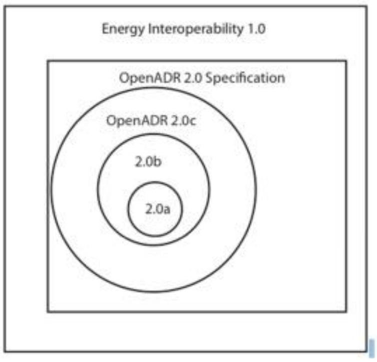

Figure 77: OpenADR profiles

The key difference between the OpenADR and SEP 2.0 is that, while SEP 2.0 is meant to contain all the instructions to command individual devices to take power-saving actions, OpenADR is more of a communications standard to get messages from utilities to their customers.
Originally the scope of OpenADR covered the interface between the utility / energy service provider (ESP) and the customer (energy management gateway), but direct communication with end-devices at the customer premises is included. The scope of SEP 2.0 pertains to the Home Area Network (HAN), but future versions may address communications with other field devices upstream from the home or utility customer premises. (see).

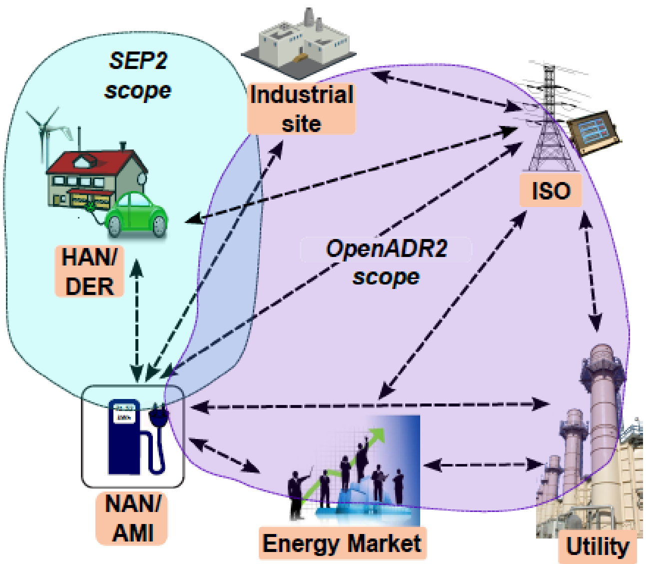

Figure 78: SEP 2.0 versus OpenADR 2.0 scope[377]

[377] [31] R. Kyusakov, J. Eliasson, J. van Deventer and J. Delsing, R. Cragie, "Emerging Energy Management Standards and Technologies - Challenges and Application Prospects.", in Emerging Technologies & Factory Automation (ETFA), 2012 IEEE 17th Conference on, pages 1-8, sept. 2012

15. StarGrid project

The STARGRID[378] project has been initiated by the European Commission in 2012 to provide a clear overview of the current activities, to lay down requirements and evaluation criteria for Smart Grid standards, and to work out recommendations on the future strategy of the Commission regarding Smart Grid standardization. Besides classical Smart Grid topics like interoperability and security, the particular focus of the project is placed on industry requirements. The focus is on three Smart Grid areas: DER integration and Grid Control**,** DR, and Smart Metering.

Two reports (date December 2014) have been prepared by the STARGRID consortium in WP2 ("State of the Art: existing standards and smart grids industry initiatives") to get a comprehensive view of the standardization activities and industry initiatives currently in progress regarding smart grids:

- D2.1 – Smart grid standardization documentation map
- D2.2 – Smart grid industry initiatives documentation map

16. IoT-A

IoT-A[379] was a European FP7 project (September 2010 till November 2013) that addressed the Internet-of-Things Architecture, and created an architectural reference model (ARM)[380] together with the definition of an initial set of key building blocks (terminology[381]). Partners were Alcatel Lucent, CEA, CFR, CSE, FhG IML, Hitachi, IBM, NEC, NXP, SAP, Siemens, Sapienza University of Rome, University of St. Gallen, University of Surrey, University of Würzburg, VDI/VDE-IT and VTT.

17. IPSO alliance

The IPSO Alliance[382] is a global forum that serves as a resource center and thought leader for industries seeking to establish the Internet Protocol as the basis for IoT and M2M applications. The objective of the Alliance is not to define technologies, but to document the use of IP-based technologies defined at the standard organizations such as IETF with focus on support by the Alliance of various use cases. IPSO Alliance promotes the use of smart objects enabling a wide range of applications in areas such as home automation, building automation, factory monitoring, smart cities, structural health management systems, smart grid and energy management, as well as transportation. The Alliance complements the work of entities such as the Internet Engineering Task Force (IETF), the Institute of Electrical and Electronics Engineers (IEEE), the European Telecommunications Standards Institute (ETSI) and the ISA. IPSO Alliance membership is open to any organization supporting an IP-based approach to connecting smart objects.

For instance the IPSO Application Framework document defines a RESTful design for use in IP smart object systems such as Home Automation, Building Automation and other M2M applications. This framework is designed to be complementary to existing Web profiles including SEP2 and oBIX. It provides a 'power' function set to represent power measurement and control related resources, such as power meters, relays and loads. The 'load control' function set is used for demand-response load control and other load control in automation application (not limited to power).

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[378] http://stargrid.eu/
[379] http://www.iot-a.eu
[380] http://download.springer.com/static/pdf/62/bok%253A978-3-642-40403-0.pdf?auth66=1418119352_9e4b9d61f36457488e65265f98fa0c3b&ext=.pdf
[381] http://www.iot-a.eu/public/terminology
[382] www.ipso-alliance.org

18. Open Mobile Alliance (OMA)

OMA was formed in June 2002 by the world's leading mobile operators, device and network suppliers, information technology companies and content and service providers. OMA delivers open specifications for creating interoperable services that work across all geographical boundaries, on any bearer telecommunication services. OMA's specifications support the billions of new and existing fixed and mobile terminals across a variety of mobile networks, including traditional cellular operator networks and emerging networks supporting machine-to-machine device communication.

The motivation of LightweightM2M is to develop a fast deployable client-server specification to provide machine to machine service. LightweightM2M is a device management protocol, but it should be designed to be able to extend to meet the requirements of applications. LightweightM2M is not restricted to device management, it should be able transfer service / application data.

19. Association of Home Appliance Manufacturers (AHAM)

As the trade association that represents the (American) home appliance industry, the Association of Home Appliance Manufacturers (AHAM) is committed to providing innovative and sustainable products that improve the lives of consumers. AHAM represents manufacturers of major, portable and floor care home appliances, and suppliers to the industry. AHAM's membership includes over 150 companies throughout the world.

Because home appliances are an integral part of the Smart Grid, AHAM has drafted a White Paper[383] to communicate the home appliance industry's principles and requirements for the development and implementation of a successful Smart Grid.
A follow-up report of this white paper is a study titled "Assessment of Communication Standards for Smart Appliances"[384] and is a technical evaluation of communication protocols for smart appliances.

This report concluded that:

- For the Application layer, SEP 2.0 and OpenADR scored the highest.
- Across the media and network layers evaluated, Wi-Fi, ZigBee, and HomePlug Green PHY, scored the highest.
- Although there could be other viable architectures, the assessment reflects a clear preference by the home appliance industry that the best communications architecture at this time features a hub or gateway that can communicate using common protocols and serve as the adapter or bridge to other devices on the Home Area Network (HAN).

20. Deutsche Kommission Elektrotechnik and Elektronik Informationstechnik im DIN und VDE (DKE) & Verband Der Elektrotechnik (VDE)

The German Association for Electrical, Electronic & Information Technologies (VDE) with its 36,000 members (including 1,300 companies, 8,000 students, and 6,000 young professionals) is one of the largest technical and scientific associations in Europe. It combines science, standardization work as well as testing and certification under one roof.

The "Die Deutsche Normungs-Roadmap Smart Home + Building"[385] report describes the German standardization roadmap for smart homes and smart buildings focusing on the energy management,

[383] AHAM Smart Grid White Paper, http://www.aham.org/ht/a/GetDocumentAction/i/44191
[384] AHAM study, Assessment of Communication Standards for Smart Appliances, http://www.aham.org/ht/a/GetDocumentAction/i/50696

security, entertainment, eHealth/Ambient Assisted Living/Wellness and smart home infrastructure and automation domains.

The report ”Smart Home, IT-Sicherheit und Interoperabilitat als Schrittmacher fur den Markt”[386] looks at IT security and interoperability in the Smart Home. One of the conclusions of this report is the proposal of a voluntary Smart Home Ready label that guarantees not only the interoperability of the different smart home products, but also the compliance of the overall integrated system to general requirements like information security and data privacy. To support such a label a reliable certification approach is necessary. This is the subject of the German, funded project “Zertifizierungsprogramm Smart Home + Building” or the Smart Home Certification Program. In this context the VDE Institute provides the Smart Home test platform for evaluating, testing, and certification of all smart home technologies of the various industries (multimedia, domestic appliances, building automation, heating etc.) currently on the market.
Test procedures for testing interoperability and IT security of systems, components and devices for all areas of smart home applications are developed based on defined test guidelines.
Key aspects of services for smart home applications:

- Testing interoperability and conformity based on use cases in order to be able to connect devices in different systems;
- Testing information security to protect privacy, availability, and integrity of all information in the entire system;
- Providing test methods for protecting against unauthorised intrusion and undesired control capability in the house;
- Testing the functional overall system security of the networked smart home systems on the system level.

21. White Paper KNX Demand Side Management

The “White Paper KNX Demand Side Management” document[387] describes the application of demand side management by means of the building automation bus protocol KNX (EN50090). Figure shows an overview of the Demand Side Management beyond the SGCP. Beside DR based upon tariffs also direct load control is considered in load management according EN 50090.

[385] DKE-VDE, “Die Deutsche Normungs-Roadmap Smart Home + Building”, November 2013, http://www.dke.de/de/std/Informationssicherheit/Documents/Deutsche%20Normungs-Roadmap%20Smart%20Home%20+%20Building.pdf
[386] DKE-VDE, ”Smart Home, IT-Sicherheit und Interoperabilitat als Schrittmacher fur den Markt”, November 2014, http://partner.vde.com/smarthome/news/statusbericht/documents/broschuere%20statusbericht%20smart%20home_a4_60%20seiten.pdf
[387] KNX Association, “White Paper KNX Demand Side Management”, Version 2, November 2013

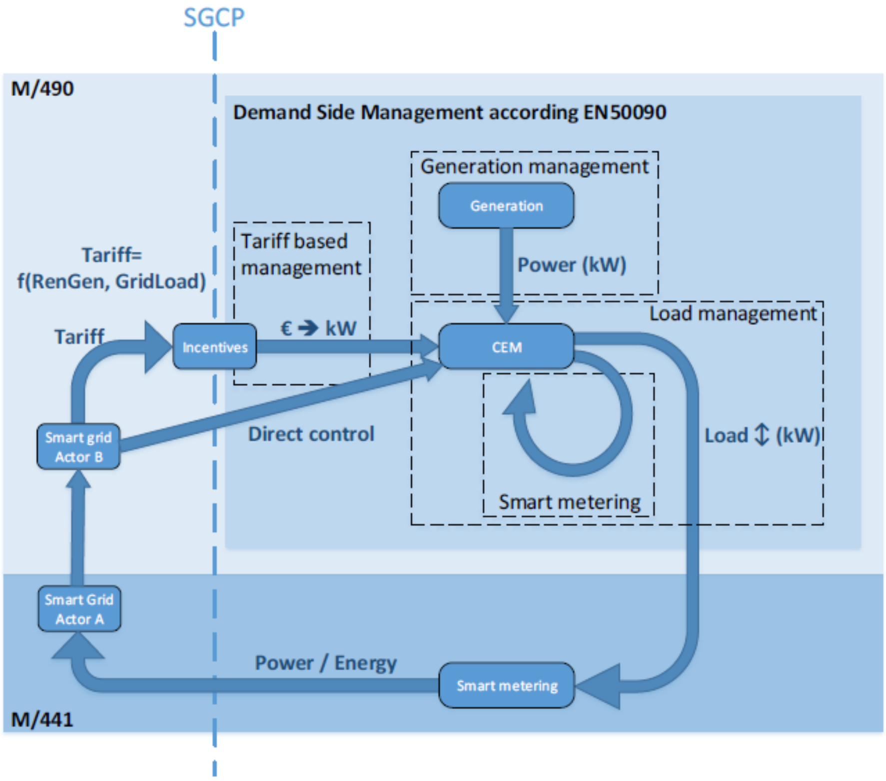

Figure79: Demand Side Management according the EN50090 in the DR use case[388]

For example to provide the tariff information to KNX new datapoint types (DPTS) in accordance to the EN50090 series can be used. In the paper two DSM approaches can be distinguished:

- Decentralised load management: the CEM recommends new load behaviour. Whether the load behaviour is taken over or not is decided by KNX application managers (for instance a HVAC manager, or a lighting manager) depending on local parameters and boundary conditions.
- Centralised load management: the CEM has direct access to the actuator of the load and can increase, decrease the load or simply switch it on or off.

In case of decentralised load management KNX provides a mechanism called 'Mode Based Load Management' for operating different CEM actors in combination with KNX actors. Different CEMs request a KNX application manager to change its mode in order to increase or decrease the load. Only the CEM with the highest priority level p will affect the KNX application manager. This CEM requests a mode level m with a certain priority level from the KNX application manager. The KNX application manager will only follow this request, if the requested priority level is higher than the currently active priority. The KNX application manager determines the MDT internally based on received parameters from the connected KNX application controllers. In this way it is possible to consider local boundary conditions.

22. ABB, Bosch, Cisco cooperate on smart-home platform

ABB, Robert Bosch and Cisco are forming a joint venture to develop and operate a smart-home software platform. The three companies expect the Germany-based joint venture to start operations

[388] http://www.knx.org/media/docs/Flyers/KNX-Demand-Side-Management-White-Paper/KNX-Demand-Side-Management-White-Paper.pdf

in early 2015. The new company will build a platform that will make communication between smart-home appliances and other devices easier. The aim of the joint venture is to develop and operate an open software platform that will enable this simple exchange of data between different manufacturers' devices. The planned platform will also allow the provision of services related to household devices. These could include energy management, security technology and entertainment.

23. Usef – Universal Smart Energy Framework

USEF[389] is a partnership between energy suppliers, network operators, electrical equipment manufacturers, consultancy and ICT companies in the Netherlands. To accelerate the development of commercially viable offerings based on the framework, USEF develops specifications and guidelines that enable you to develop smart energy products, services and solutions in an unambiguous way.

24. IERC - European Research Cluster on the Internet of Things

The IERC[390] - IoT European Research Cluster - European Research Cluster on the Internet of Things is bringing together EU-funded projects with the aim of defining a common vision on the IoT technology and development research challenges at the European level in the view of global development. The rationale for IoT is to address the large potential for IoT-based capabilities in Europe - coordinate/encourage the convergence of ongoing work on the most important issues - to build a broadly based consensus on the ways to realise IoT in Europe.

[389] http://www.usef.info/Home.aspx

[390] http://www.internet-of-things-research.eu/about_ierc.htm

ANNEX 3: KEY STANDARDS RELATING TO DR, SMART HOME AND SMART APPLIANCES

Table 75: Key standards relating to DR, Smart Home and Smart Appliances

TC	TC Reference + title	Availability
IEC, CLC/TC 13	EN 62056-3-1:2014 'Electricity metering data exchange - The DLMS/COSEM suite - Part 3-1: Use of local area networks on twisted pair with carrier signalling'	Available
IEC, CLC/TC 13	EN 62056-5-3:2014 'Electricity metering data exchange - The DLMS/COSEM suite - Part 5-3: DLMS/COSEM application layer'	Available
IEC, CLC/TC 13	EN 62056-6-1:2013 'Electricity metering data exchange - The DLMS/COSEM suite - Part 6-1: Object Identification System (OBIS)'	Available
IEC, CLC/TC 13	EN 62056-6-2:2013 'Electricity metering data exchange - The DLMS/COSEM suite - Part 6-2: COSEM interface classes'	Available
IEC, CLC/TC 13	EN 62056-7-6:2013 'Electricity metering data exchange - The DLMS/COSEM suite - Part 7-6: The 3-layer, connection-oriented HDLC based communication profile	Available
IEC, CLC/TC 13	EN 62056-8-3:2013 'Electricity metering data exchange - The DLMS/COSEM suite - Part 8-3: Communication profile for PLC S-FSK neighbourhood networks'	Available
IEC, CLC/TC 13	EN 62056-9-7:2013 'Electricity metering data exchange - The DLMS/COSEM suite - Part 9-7: Communication profile for TCP-UDP/IP networks	Available
IEC, CLC/TC 13	FprEN 62056-1-0 'Electricity metering data exchange - The DLMS/COSEM suite - Part 1-0: Smart metering standardization framework'	Available
IEC, CLC/TC 13	FprEN 62056-4-7 'Electricity metering data exchange - The DLMS/COSEM suite - Part 4-7: DLMS/COSEM transport layer for IP networks'	Nov. 2015
IEC, CLC/TC 13	EN 62056-5-3:2013/FprA1 ''Electricity metering data exchange – The DLMS/COSEM suite - Part 5-3: DLMS/COSEM application layer'	Nov. 2015
IEC, CLC/TC 13	EN 62056-6-1:2013/FprA1 'Electricity metering data exchange – The DLMS/COSEM suite - Part 6-1: Object Identification System (OBIS)'	Nov. 2015
IEC, CLC/TC 13	EN 62056-6-2:2013/FprA1 'Electricity metering data exchange – The DLMS/COSEM suite - Part 6-2: COSEM interface classes'	Nov. 2015
IEC/TC 13	IEC 62056-7-5 'Electricity metering data exchange – The DLMS/COSEM suite – Part 7-5: Local data transmission profiles for Local Networks (LN)'	Mar. 2016
CEN/TC 294	EN 13757-3 :2013 'Communication systems for and remote	Available

	reading of meters - Part 3: Dedicated application layer’	
CEN/TC 294	EN 13757-4 :2013 ‘Communication systems for meters and remote reading of meters - Part 4: Wireless meter readout (Radio meter reading for operation in SRD bands)	Available
CEN/TC 294	prEN 13757-5 ‘Communication systems for meters and remote reading of meters - Part 5: Wireless relaying	Sept.2015
CEN/TC 294	FprEN 13757-1’ Communication systems for and remote reading of meters - Part 1: Data exchange	Sept. 2014
CEN/TC 294	EN 13757-3:2013/prA1 ‘Communication systems for meters and remote reading of meters - Part 3: Dedicated Application Layer’	New Work
CEN/TC 294	prEN 13757-6 ‘Communication systems for meters and remote reading of meters - Part 6: Local Bus	New Work
CLC/TC 205	prEN 50491-11’ General requirements for Home and Building Electronic Systems (HBES) and Building Automation and Control Systems (BACS) – Part 11: Smart Metering - Application Specifications - Simple External Consumer Display’	Sept. 2015
CLC/TC 205	prEN 50491-12 ‘General requirements for Home and Building Electronic Systems (HBES) and Building Automation and Control Systems (BACS) – Part 12: Smart grid - Application specification - Interface and framework for customer’	2016
IEC/TC 57	IEC 62746 ‘System interfaces and communication protocol profiles relevant for systems connected to the Smart Grid’	2014/2015
IEC/TC 57	IEC 62746-2 TR Ed.1: Systems interface between customer energy management system and the power management system - Part 2: Use cases and requirements	New work
IEC/TC57	IEC 62746-3 ‘Systems interface between customer energy management system and the power management system - Part 3: Architecture’	New Work
IEC/TC 57	IEC/PAS 62746-10-1:2014: Systems interface between customer energy management system and the power management system - Part 10-1: Open Automated DR (OpenADR 2.0b Profile Specification)	2014
SC25/WG1	ISO/IEC 15045-1:2004 Information technology – Home electronic system – Gateway – Part 1: Introduction	2004
SC25/WG1	ISO/IEC 18012-1:2004 Information technology – Home electronic system – Guidelines for product interoperability – Part 1: Introduction	2004
SC25/WG1	ISO/IEC 15045-2:2012 Information technology – Home electronic system – Gateway – Part 2: Modularity and Protocol	2012
SC25/WG1	ISO/IEC 18012-2:2012 Information technology – Home electronic system – Guidelines for product interoperability – Part 2: Taxonomy and Lexicon	2012
SC25/WG1	ISO/IEC 15067-3:2012 Information technology – Home Electronic System (HES) application model – Part 3: Model for an energy management system for HES	2012

ISO/TC 205	Building Automation and Control Systems (EN ISO 16484) (BACS) mainly covers the tertiary sector. EN ISO 16484 Part 5: Data communication – Protocol, prepared by the ASHRAE[391] (this part is identical to the BACnet standard ANSI/ASHRAE 135-2004 standard), defines the communication protocols of Building Automation and Control Systems, including ventilation, air conditioning and heating products.	2010
IEEE	**IEEE 2030.5-2013 - IEEE Adoption of Smart Energy Profile 2.0 Application Protocol Standard**[392] The defined application protocol is an IEEE adoption of the Smart Energy Profile 2.0 protocol and is an IEC 61968 common information model (IEC 61968) profile, mapping directly where possible, and using subsets and extensions where needed, and follows an IETF RESTful[393] architecture.	
ANS/CEA; ISO/IEC	**Modular Communication Interface: ANSI/CEA 2045** The specification details the mechanical, electrical, and logical characteristics of a socket interface that allows communication devices to be separated from end devices. It provide a means by which residential products may be able to work with any load management system through user installable plug-in communication modules. This specification identifies the physical and data link characteristics of the interface, along with certain network and application layer elements as needed to assure interoperability over a broad range of device capabilities. In addition, it defines a mechanism through which application layer messages (defined in other standards) may be passed across the interface. It also specifies a basic DR interface. This standard provides a solution to the heterogeneous communication environment in a building through a modular communications interface (MCI) enabling any product to connect to a variety of demand-response systems. The concept is: encourage manufacturers to build an MCI into their products that can accept a simple communications module. Consumers and programme managers are then free to select whatever communication solution works best for their particular environment. This ANS/CEA standard is being submitted to ISO/IEC and is currently a working draft standard ISO/IEC 10192-3 “Modular communications interface for energy management”.	ISO/IEC working draft standard

[391] ASHRAE : American Society of Heating Refrigeration and Air-Conditioning Engineers
[392] http://standards.ieee.org/findstds/standard/2030.5-2013.html
[393] "RESTful" refers to the Representational State Transfer (REST) architecture

ANNEX 4: FINAL REPORT SECURE SMART APPLIANCES

JOANNEUM RESEARCH DIGITAL

Institute for Information and Communication Technologies

On behalf of

vito

FINAL REPORT

European Commission

Graz, August 2016

Secure Smart Appliances

Survey on the security of Smart Appliances as part of the *Ecodesign Preparatory Study on Smart Appliances* performed for the European Commission

Stefan Marksteiner and Heribert Vallant

THE INNOVATION COMPANY

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Keywords	smart appliances, security, energy
Abstract	This document defines preliminary security requirements for idealized smart appliances that support demand side energy management and points out the possible end-user threats and privacy issues that might be arising. It serves as a basis for future research in order to securely deploy smart appliances on a wide scale.

Version	Date	Editor	Modified
V0.01	2016-04-19	Stefan Marksteiner	Initial Outline
V0.03	2016-05-10	Stefan Marksteiner	First input on exploitation scenarios and privacy
V0.05	2016-05-12	Stefan Marksteiner	Scope definition
V0.1	2016-05-13	Stefan Marksteiner	Finished Introduction
V0.13	2016-05-17	Stefan Marksteiner	Added threat overview
V0.17	2016-05-18	Heribert Vallant	Added privacy introduction and input on technical measures and legislation
V0.18	2015-05-19	Stefan Marksteiner	Added Exploitation Scenarios
V0.19	2016-05-20	Heribert Vallant	Input on right to be forgotten and anonymization
V0.35	2016-05-23	Stefan Marksteiner	Added most of the security recommendations
V0.4	2016-05-23	Heribert Vallant	Added data protection
V0.45	2016-05-24	Stefan Marksteiner	Added anonymization approaches
V0.5	2016-05-24	Heribert Vallant	Added additional anonymization approaches
V0.6	2016-05-24	Stefan Marksteiner	Finished Security section
V0.7	2016-05-25	Stefan Marksteiner	Finished Threads section

V0.8	2016-05-25	Stefan Marksteiner	Sources overhauled, text corrected
V0.82	2016-05-29	Stefan Marksteiner	Text corrected
V0.85	2016-06-06	Stefan Marksteiner	Text added and corrected at various passages
V0.87	2016-06-07	Stefan Marksteiner	Additional sources
V0.88	2016-06-14	Stefan Marksteiner	Additional sources, review of Security recommendations
V0.9	2016-06-15	Stefan Marksteiner	Finished revised Security section
V0.95	2016-06-16	Stefan Marksteiner	Finished anonymization and privacy architecture
V0.99	2016-06-16	Stefan Marksteiner	Added conclusion and executive summary, finished report for stakeholder review
V1.00	2016-08-26	Stefan Marksteiner	Final Version after review

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Contents

1 Executive Summary

Smart Appliances are domestic appliances equipped with information technology to allow enhanced functions, particularly demand-side energy management. As an emerging technology, there is not much known about its security implications. This document describes potential threats to Smart Appliances and describes ideal and basic approaches to mitigate the former, by using the principles of *defense-in-depth*, *security by design* and *security by default.* As the concept of Smart Appliances includes the processing of potentially sensitive user data, also privacy concerns are a major subject of this document, particularly in respect with the European Data Protection Regulation. The according recommendations therefore suggest anonymization and pseudonymization techniques (such as *k-anonymity* and its enhancements) and giving as less information away from end customers as possible (according to the *need-to-now principle*). They further suggest using a neutral party to enforcing this principle or using aggregation to enhance privacy. Further, user data could be marked in order to allow prosecuting data protection violations. The insights gained should serve as a basis for further research in Smart Appliance Security. Particular needs are reference architectures and norms, elaboration of privacy models, certification models and, after adoption of this technology on a broader basis, practical security surveys.

2 Introduction

The presented survey is part of the *Preparatory study on Smart Appliances (Lot 33)* accomplished under the authority of the European Commission DG Energy under framework contract ENER.C3.2012-418-lot 1 and is carried out by JOANNEUM RESEARCH Forschungsgesellschaft mbH under subcontract of VITO NV. The survey examines technical information security implications within this study.

2.1 Purpose

This document provides an overview of the technical information security implications of the usage of Smart Appliances on an abstract level. This is to supplement the *Preparatory study on Smart Appliances* in terms of technical information security aspects. In further consequence, this survey points towards the measurements taken and further research to be carried out in order to assure the technical information security of a broad usage of Smart Appliances.

2.2 Terminology

The most central notion within this document is the *Smart Appliance*. As this survey is part of the “Preparatory study on Smart Appliances”, it follows the definition of a Smart Appliance given within the study, which limits this term to *energy related end devices* (devices that do not control other devices but have an impact on energy networks and that support demand side energy management) and explicitly excludes transportation system devices. It further includes the following (non-exhaustive) examples: Household appliances, heating, ventilation and air conditioning devices, battery operated rechargeable appliances, residential operated rechargeable appliances and lighting systems (Vanthournout, et al., 2015).

Smart Appliances are to be distinguished from *Smart Devices.* The latter are basically all ICT-enabled devices that are aware of their (physical) environment (Schmidt & Van Laerhoven, 2001). As this definition lacks the energy context and end-user focus, it includes a broader set of devices as the one of Smart Appliances. The latter can therefore be seen as a subset of Smart Devices. This document partially uses the term Smart Devices when referring to threat or incident reports, recommendation guidelines or related research that are not specific to Smart Appliances but could or actually does apply to them as well. In that sense the two terms could be seen synonymous within the context of this document.

Further terminology used in this report is the Internet of Things, which refers to an infrastructure that interconnects physical world and virtual world objects into a common network, using present and upcoming information and communication technology (ICT) (ITU Telecommunication Standardization Sector, 2012).

This document also distinguishes between end-users and market parties. While the former are consumers, the latter are services providers. This includes new market entrants and traditional market parties within energy supply, for instance virtual power plants (VPP), power supply companies (PSC), transmission system operators (TSO) or distribution system operators (DSO). It is, however, not limited to the aforementioned as other market parties may provide additional services (for instance analytics or forecast services) not yet relevant or even foreseen within energy systems.

2.3 Scope

This survey concentrates on the technical security of Smart Appliances (in the sense of 2.2), located at customer premises. This includes measures to enhance the security of the device itself, as well as protecting the security and privacy of data stored on or sent to or from the device.

Based on the above, the following issues are particularly NOT WITHIN THE SCOPE of this document:

- IoT Gateway Devices (including Smart Home and Residential Gateways as well as Smart Metering Devices)
- Critical Infrastructure out of the customer's premises (including Operational and Information Technology of Energy Networks and market parties)
- Legal advice

Despite being out of scope of this particular analysis, the above points must be elaborated from a security perspective in the course of further research before Smart Appliances can be deployed on a large scale. As Smart Appliances form an integrated network with their respective gateways, they are ultimately (through the intended purpose, see Section 2.1) within the extended scope of service provider networks. This is similar to cloud computing environments, where traditional security perimeters may not exist in their current form (Takabi, Joshi, & Ahn, 2010)). These aspects must be examined also in a holistic manner, as smart appliances are a part of a smart grid architecture that is densely interconnected and therefore provides many structural points for hackers to attack (Pallotti & Mangiatordi, 2011).

Furthermore, apart from the technical advice given later in this document, it must be stated that implementing security measures may add complexity and, thus, inconvenience for all involved parties, including the end-user. It is therefore utterly important to involve the end-user into any security concept as he or she ultimately operates the devices in question to some extent. This also because some security measures are outside of the sphere of a single Smart Appliance but rather within the design of a home network (e.g. segregation measures as stated in Section 4.1.4) and therefore outside any manufacturer's sphere of influence, although manufacturers are to provide a maximum possible amount of both security and privacy protection per default for any of their products. To achieve this involvement, the party developing a Smart Appliance should give advice to the end-user, resellers and/or installing/implementing parties generating security awareness. This generated awareness should at minimum be sufficient to allow the user making decisions about whether or not to use a Smart Appliance and to which further measures are to be taken, including the possibility of giving the task of securing a home network to an expert of choice (for instance in form of a professional and/or managed service contract). Also, as using smart devices and home networking in general put end-users in charge of securing a potentially large network without the necessary expertise, is yet an unsolved problem. A possible solution is outsourcing to security services, on one hand, is not yet a well-established model and might, on the other hand, have a negative impact on user privacy (Feamster, 2010).

2.4 Impact on implementers and users

The methods described in this document intended to enhance user security and privacy might negatively impact user convenience, cost and interoperability, may require more expertise from both users and implementers, as well as raise development effort. Where possible, this document states measures to mitigate these negative impacts, where not, a sensible balance between, on the one side, security and privacy and, on the other side, cost-efficiency and usability has to be found.

2.5 Categorization of Information Flows

In order to give a better understanding of the different information security implications of the usage of Smart Appliances, it is feasible to Split the communication of these devices into two categories:

- External Communication (between Smart appliances and Market Parties or user remote access);
- Between in-house systems (Smart Home and PV systems, energy storage or other IoT devices);

The difference between the two is because the communication of the former ordinarily uses traditional ICT protocols as it traverses outside of the home area network (HAN) and therefore has higher requirements on confidentiality, integrity and authenticity, while the latter only communicate inside the HAN and often use Machine-to-Machine (M2M) protocols (Carreiro, López, Moura, Moreno, de Almeida, & Malaquias, 2011). This survey concentrates on the first type; however, the second type also has some security implications which are addressed.

Both of these types support uni- or bidirectional information (or data) flows. Especially on the first type the direction of these flows matter: for instance flow from the end-user to the market party might contain information relevant for billing or power quality, while the vice versa direction might have an impact on a Smart Appliance' behavior (Iria, Soares, Madureira, & Heleno, 2014). The two directions therefore have different security implications (in terms of confidentiality, integrity and authenticity).

3 Cyber Security Threats to Smart Appliances

As stated in Section 2.5, the information flow direction of communication between end-user (or the Smart Appliance) and market parties matters. This circumstance can also be used to categorize security threats. Furthermore, Smart Appliances are devices with computational capabilities that interact with the physical world. They therefore can be classified as parts of cyber-physical systems (CPS) (Baheti & Gill, 2011).

Thus, threats to smart appliances may also be categorized by their target aspects which are the device' surroundings, including the device itself, (physical aspect) or the data (cyber aspect), see Figure.

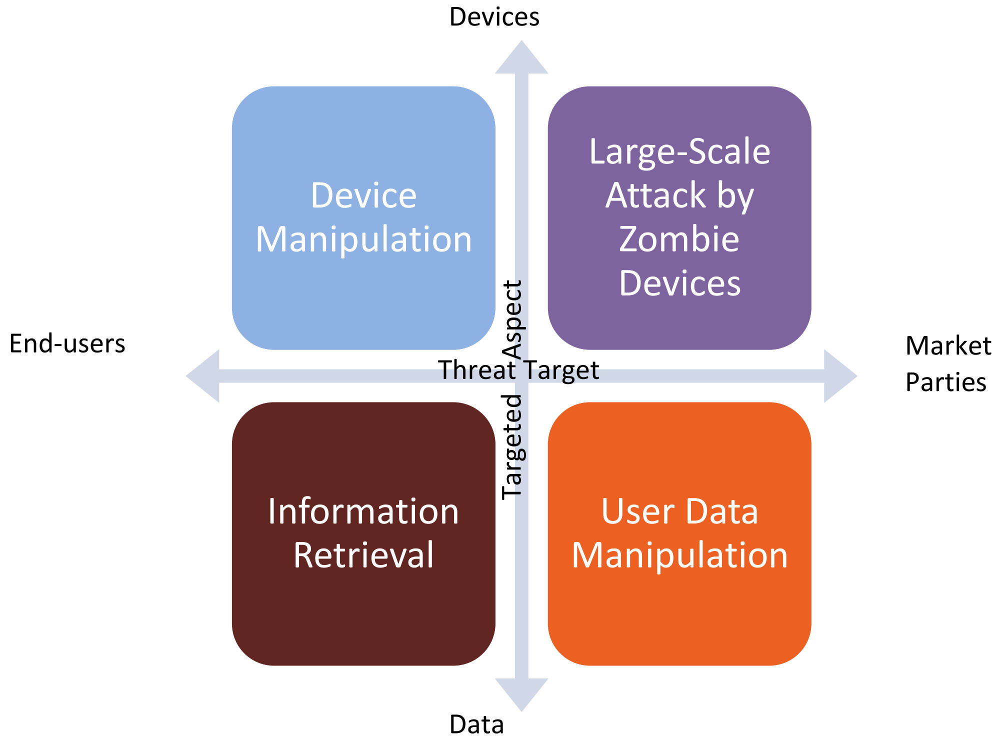

Figure 80: Threat Categorization with Examples

These threats also have been demonstrated to be exploitable. There are reports about IoT Botnets (Attack by Zombie Devices)[394], an intelligent light switch that allows to be manipulated because of a hard coded and published private key (Device Manipulations)[395], a case of Smart TVs spying on users (Information Retrieval)[396] or Smart Meter data manipulation by criminals in Malta (User Data Manipulation)[397]. Apart from that, many more examples can be found[398,399,400,401,402,403,404,405].

394 http://www.cebit.de/de/news/aktuelle-meldungen/internet-der-dinge-das-groesste-botnet-aller-zeiten.xhtml
395 https://twitter.com/mjg59/status/647251446669283328
396 http://www.theregister.co.uk/2013/11/20/lg_smart_tv_data_collection/ (Retrieved 25-05-2016)
397 http://www.independent.com.mt/articles/2014-02-16/news/sparks-fly-over-smart-meter-theft-scandal-3968892934/
398 http://www.bbc.com/news/technology-28582479 (Retrieved 25-05-2016)
399 http://arstechnica.com/security/2014/07/crypto-weakness-in-smart-led-lightbulbs-exposes-wi-fi-passwords/ (Retrieved 25-05-2016)
400 http://www.engadget.com/2014/06/23/nest-thermostat-rooted/

The European Union Agency for Network and Information Security (ENISA) issued a document (Barnard-Wills, Marinos, & Portesi, 2014) that concerns with smart home systems. It divides smart home assets into 16 categories, two of which overlap with the given definition of Smart Appliances: *Home Appliances* and *Integrated Home Services*. For these device categories, the document lists a variety of different threats:

- Erroneous use or administration of devices and systems
- Unintentional change of data in an information system
- Damage caused by a third-party
- Loss or destruction of devices, storage media, and documents
- Lack of resources/electricity
- Strikes
- Replay of messages
- Man in the middle/ Session hijacking
- Manipulation of hardware and software
- Badware
- Remote activity
- Inadequate design and planning or lack of adaptation
- Repudiation of actions
- Unauthorized use or administration of devices and systems
- Unauthorized access to the information system/network
- Unauthorized installation of software
- Abuse of authorizations
- Damage from DRM conflicts
- Generation and use of rogue certificates
- Manipulation of information
- Falsification of records
- Information leakage or sharing
- Intercepting compromising emissions
- Interception of information
- Malicious code/ software activity
- Misuse of audit tools
- Targeted attacks
- Violation of laws or regulations
- Failure to meet contractual requirements

The list above is not only incomplete because of the multifarious threat landscape directly connected to Smart Appliances. In fact, Smart Devices (including Smart Appliances) are small-scale computer systems that are often based on standard operating systems, effectively turning them in, low performing but full-fledged computer systems. This means that they can be, if compromised, misused the same ways as any PC system can[406], lifting boundaries to criminal exploitation.

Furthermore, the priorities in cyber security might differ depending on the respective developer's background. People from industrial environments tend to value availability highest and data confidentiality comparably low, while IT system developers tend to see the priority vice versa (Falk & Fries, 2015). Due to the similar nature of industrial control systems and CPS (both represent digital systems with influence on their physical environment), this conflict is also relevant for the latter.

[401] http://www.theregister.co.uk/2013/11/20/lg_smart_tv_data_collection/
[402] http://arstechnica.com/security/2014/07/crypto-weakness-in-smart-led-lightbulbs-exposes-wi-fi-passwords/
[403] http://www.theregister.co.uk/2014/04/02/smarttv_dumb_vuln_philips_hardcodes_miracast_passwords/
[404] http://www.privacysurgeon.org/blog/incision/google-takes-a-bold-stride-from-your-head-to-your-home/
[405] http://www.bbc.com/news/technology-28582479
[406] For instance be used in a botnet, to calculate passwords or bitcoins, to perform distributed denial-of-service attacks, use it as spam mail server, web proxy to anonymize illegal data traffic and more.

3.1 Development Frameworks

If development frameworks for smart devices (such as Samsung's SmartThings[407], Google's Weave[408], et cetera) are used, they must undergo as strict security examination beforehand as well. Research has demonstrated that, besides smart devices themselves and their used protocols, also development framework contain several vulnerabilities that might be exploited to compromise their respective apps (Fernandes, Jung, & Prakash, 2016). There are already products on the market using such frameworks that provide smartphone apps to control these devices.[409]

3.2 Public Exposure

Every device that supports the Internet Protocol (IP) could possibly connect to the Internet. This implies a severe threat by itself, as it may be found by an adversary. There are search engines (like Shodan[410]) that allow searching for specific device types (as opposed to traditional search engines that allow searching for content). This could be used to directly access Smart Devices (Ko, Ra, & Kim, 2015). In conjunction with vulnerability databases (such as the National Vulnerability Database[411]), this public exposure could also be used to search for devices that contain certain vulnerabilities, which then again might allow to compromise the data or device security (see the next section). Therefore, it is crucial to restrict public access to and from these devices.

[407] https://www.smartthings.com (Retrieved 18-05-2016)
[408] https://developers.google.com/weave/ (Retrieved 18-05-2016)
[409] http://www.cnet.com/news/touchscreen-refrigerators-and-talking-everything-at-ces-2016 (Retrieved 18-05-2016)
[410] https://www.shodan.io/ (Retrieved 18-05-2016)
[411] https://web.nvd.nist.gov/view/vuln/search (Retrieved 18-05-2016)

4 Smart Appliance Security

This Section gives an overview of measurements to protect Smart Appliances from the threats posed earlier in this document. It gives recommendations for a baseline security approach and for a higher but more costly security level. As no hundred percent security can be assured, however, following these recommendations does leverage but not perfect security. It is therefore generally recommended not to rely on single measures but to implement as many layers of security as feasible (also known as defense-in-depth).

4.1 Security Requirements (minimalistic approach)

This section contains recommendations that are believed to be security fundamentals for any entity engaged in developing installing or operating Smart Appliances. Advanced recommendations further enhancing the security level are given in Section 4.2.

4.1.1 Node Security

As with all information technology devices, authentication and access control are crucial elements of any security concept, as they limit the possibility of security breaches (Sandhu & Samarati, 1994).

A minimum level of security regarding these elements can be provided by password authentication. It is, however, up to the implementation whether this actually increases security or merely provides a fig leaf for the lack thereof. There are several factors determining secure access to a device (Schuster, Rüster, & Holz, 2013), (Bishop & Klein, 1995):

- Existence of (hidden) service accounts;
- Password strength (including enforcing strong passwords and regular changes);
- Default passwords
- Secure password storage;
- Possibility of unauthorized access.

The points above are ordered by their level of complexity. While the first three of the points above are regarded as standard security measures, the latter two have proven to be difficult to cope with, especially for developers from small and medium businesses (SMB) (Tawileh, Hilton, & McIntosh, 2007). As service accounts pose potential security holes, the most secure measure is to avoid them. If this is not possible, the same security requirements apply to them as to standard access credentials, which is the enforcement of strong non-default passwords and regular password changes. Furthermore default passwords must be required to change after first use.

This may cause inconvenience for the user, especially when there are many devices inside a smart home. Possible solutions include devices generating one-time passwords (OTPs) or two factor authentication or using a single-sign (see Section 4.2.1).

Ideally, there is only one account active as factory default, which’s password must be changed after first use. Assuming there are no hidden accounts, this does not leave room for a legit account with a widely known default password the user is unaware of. This reduces the risk of unwanted access to device vulnerabilities. Furthermore the password has to be stored in a secure way. We recommend the use of password storing functions available in the respective development framework or programming language that is deemed secure (Di Crescenzo, Lipton, & Walfish, 2006).Today, examples of adequate password storing are provided by password based key derivation functions as *bcrypt* and *scrypt* (Dürmuth & Kranz, 2015).

The last point concerns the discovery of security-related errors, which can constitute vulnerabilities that pose the risk of exploitation. Minimizing these risks requires systematic quality management processes and, due to constantly published security weaknesses (as no system is a hundred percent secure), a mechanism of regular updates. This aspect does not only affect the access control, but also protecting the device itself from threats as stated in Section 3. As a minimum, engineers developing such a system are required to harden the same by restricting the access to the furthest extend they are able and harden the device by turning off all unneeded services within the operating system and applications (Bottino, 2006). This may also add some inconvenience, as updates may fail or introduce functional or other errors. Despite of this, regular updates are an important means against security leaks and therefore rated beneficial for the overall security.

4.1.2 Communication Line Security

It is also crucial to secure communication channels, ensuring confidentiality, integrity and authenticity. Following common practice, we propose a hybrid approach that combines the security of asymmetric encryption for key exchange with more efficient symmetric encryption to encrypt the data. Furthermore, it is also crucial to authenticate and integrity-check the data to prevent data manipulation replay attacks (Krawczyk, 2001).

There are many known protocols that use this approach most prominently IP security (IPsec), Transport Layer Security (TLS) and Secure Shell (SSH) (Albrecht, Paterson, & Watson, 2009).

The latter is mostly used for securing remote shells and uses an Encrypt-and-MAC Scheme (Barnes, Thomson, Pironti, & Langley, The Secure Shell (SSH) Transport Layer Protocol, 2006). This is deemed less secure than an Encrypt-then-MAC Scheme – as supported by TLS (Gutmann, 2014) and IPsec - assuming a strongly unforgeable Message Authentication Code (MAC) (Bellare & Namprempre, 2008). Of the former two, TLS is deemed more efficient for the following reasons (Alshamsi & Saito, 2005):

- TLS is easier to integrate between different vendors
- TLS needs less overhead
- TLS allows quicker handshakes
- TLS is easier to configure

As the computational capabilities of Smart Appliances are likely limited, TLS is recommended for the reasons stated above. If connectionless protocols are in use, relying on the User Datagram Protocol (UDP) rather than the Transmission Control Protocol (TCP), Datagram Transport Layer Security (DTLS) may be used as an alternative to TLS with equivalent security guarantees (Rescorla & Modadugu, 2012).

As it cannot longer be regarded secure, the Secure Sockets Layer (SSL) protocol, predecessor of TLS, must not be used (Barnes, Thomson, Pironti, & Langley, Deprecating Secure Sockets Layer Version 3.0, 2015). The version of TLS should be the newest one (currently 1.2), as former versions generate digital signatures using unsafe components (Bundesamt für Sicherheit in der Informationstechnik, 2016).

Furthermore, secure combinations of algorithms and cipher modes must be used. Section 4.2.2 describes examples of cipher suites currently deemed secure.

4.1.3 Data Storage

Data stored local on the Smart Appliance (data at rest) should be encrypted (encryption at rest) and integrity checked as well to protect the data in case of unauthorized (even physical) access, especially security and privacy relevant data. In principle, the same cryptographic basics as for communications apply but, as it is a sensitive part, special focus on the key management is needed. The according recommendations in Section 4.2.3 give more details on secure data storage.

4.1.4 Intra-site (M2M) Communications

Due to the smart technology, enabling Internet of Things and its underlying machine-to-machine (M2M) protocols can still be regarded as emerging technology, it is difficult to foresee its security implications. A minimum standard for secure M2M protocols used in Smart Appliances (if applicable) is IEC 62351 IEC:2007. As this standard does not guarantee end-to-end protection, the recommendations above remain unaffected (Fries, Hof, & Seewald, 2010). A protocol following this standard is OPC UA with WS Secure Conversation.

Due to security problems in some protocols commonly used in Smart Homes ((Fouladi & Ghanoun, 2013), (Zillner & Strobl, 2015), (Wang, 2005)), relying on a communications protocol alone to secure communications is not recommended.

In general, restrict the internal network from the outside, especially exposing as less devices as possible to the Internet is recommended due to the reasons stated in Section 3.2. In the same manner, restrict a Smart Appliances network from the rest of the home network (i.e. the data network used by laptops, tablets and phones) is recommended.

This could either be achieved by firewalling restricting inbound but allowing outbound or by using proxy or gateway devices, controlling the traffic flow between them. Due to breaking end-to-end communications, the latter allows more control and therefore enhances security but may increase costs and add inconvenience to the end-user. It would also require a considerable amount of standardization efforts from the industry to achieve an inter-manufacturer operable smart device gateway. Restricting outbound traffic should also be considered according to privacy requirements.

However, this does not obsolete the need for node and communications line security, for a single exposed network device that is hacked (e.g. via a vulnerable wireless protocol) forfeits the use of such segregation and perimeters.

4.1.5 Monitoring and Alarming

To facilitate forensics in case of unwanted access or device behavior, a logging mechanism is required, which should have some manner of integrity checking mechanism as stated in Section 4.1.3.

4.2 Security Recommendations (ideal approach)

A recommended approach for a secure Smart Appliance follows the requirements made in Section 4.1, but further extends them with the amendments made in this section. The latter require an amount of effort are deemed to surpass the capabilities of smaller developers but are thought to could be handled by lager manufactures.

4.2.1 Node Security

The access controls postulated in Section 4.1.1, should be supplemented by using a one-time password (Liao, 2009) or two-factor authentication, further minimizing potential unwanted access (Aloul, Zahidi, & El-Hajj, 2009). Although this method is only for passive attacks and does not provide enough additional benefit against Man-in-the-Middle and Trojan attacks, it enhances security in local and certain corporate environments (Schneier, 2005). As it is not deemed secure, using second factors based on the Global System for Mobile Communications (GSM) are not recommended (Güneysu, 2008). An alternative to two-factor authentication, tackling the problem of password management, is establishing a secure single sign-on system (Al-Muhtadi, Anand, Mickunas, & Campbell, 2000).Further, a role-based authorization concept should be introduced, allowing different people (standard users, service technicians) only the amount of access they actually need and simplifies security management (Park, Sandhu, & Ahn, 2001). The device hardening should be extended to compile a customized kernel that uses only needed functions and, therefore, further minimizes the possible attack target (Kurmus, Sorniotti, & Kapitza, 2011). An approach to achieve this is statically linking kernel modules and disabling dynamic loading of the same (Nadji, Giffin, & Traynor, 2011). Furthermore, the update mechanism should be underpinned by a strict process of regular security patches published and automatically installed on devices[412]. If the device' hardware allows doing so, some sort of host-based firewall should be placed.

4.2.2 Communication Line Security

The Internet Engineering Task Force (IETF) has issued a recommendations document that recommended a set of cipher suites that may be used to secure communications lines using TLS/DTLS (Sheffer, Holz, & Saint-Andre, 2015):

- TLS_DHE_RSA_WITH_AES_128_GCM_SHA256
- TLS_ECDHE_RSA_WITH_AES_128_GCM_SHA256
- TLS_DHE_RSA_WITH_AES_256_GCM_SHA384
- TLS_ECDHE_RSA_WITH_AES_256_GCM_SHA384

Using the GCM block cipher mode, these suites support both encryption and authentication and, using Ephemeral Diffie-Hellman (DHE) and Elliptic Curve Ephemeral Diffie-Hellman ("ECDHE") families for key exchange, they provide perfect forward secrecy (PFS), which refers to the inability of an adversary to ex post-compromise the security of recorded communications. Moreover, as of today, the used AES and SHA-2 algorithms are not regarded to be broken and the key lengths are sufficient. Using RSA as digital signature algorithm, it is also important to choose the RSA key length accordingly, as the weaker algorithm of hashing (in this case SHA-2) and digital signature (in this case RSA) determines the total security of both (Barker, 2016). For using ECDHE, DHE and RSA, the German Bundesamt für Sicherheit in der Informationstechnik (BSI) recommends to have key lengths of at least 250 (ECDHE) and 2000 (DHE and RSA) bits, respectively (Bundesamt für Sicherheit in der Informationstechnik, 2016). This is congruent with the IETF recommendations; however, starting 2017, the BSI plans to refrain from supporting key lengths of less than 3000 bits for DHE and RSA in their Technical Guidelines.

As these ciphers are deemed secure, they should serve as recommended ones for the use in Smart Appliances. Following the principle of regular updates, it is recommended to use the (most recent version of TLS (currently 1.2) or its respective successor. Further, the encryption should implement strict TLS, disable compression and should use mutual authentication where feasible (Sheffer, Holz, & Saint-Andre, 2015).

[412] This does not apply for functional updates, which should only be automatically installed if they do not change the device' behavior

Lastly, a key derivation function that is deemed state of the art by current research must be used. A recommendation therefore is Extraction-then-Expansion (Chen, 2011).

4.2.3 Data Storage

As stated in Section 4.1.3, encryption at rest follows the same principles as communications security, with special attention to key storage. Therefore the recommendations given by Section 4.2.2 also apply to data at rest. To provide a high level of security, a tested key derivation function similar to smart cards (Cooper & MacGregor, 2008) or a proven physically unclonable function (PUF) (Katzenbeisser, Kocabacs, Rovzic, Sadeghi, Verbauwhede, & Wachsmann, 2012) is recommended. Furthermore, this could be achieved by using a hardware security module (HSM) (Bouganim & Guo, 2011).

4.2.4 Intra-site (M2M) Communications

In addition to the points made in 4.1.4, it is advisable to categorize device functions, similar to network devices, into control, management, and data plane functions and recognize this in the device' system design (Mizrahi, 2014). The first is, within this context, only used for M2M communications, while the second is for administrative functions only. Therefore, both planes should not be accessible from the outside of their respective networks, unless absolutely necessary, for instance for direct market party communication (control plane) or administrative interfaces (management plane). The data plane, on the other hand, is responsible for gathering and delivering data and is therefore necessary to be accessible at least within the HAN. Due to these different requirements regarding accessibility, it recommended to segregate access to these planes through using different (virtual) networks and only allowing strictly controlled traffic (for instance access to management plane only from distinct hosts within the HAN) through a router/firewall. Together with access controls from and to outside networks and between HAN and non-HAN user devices, this would result in a three-tiered access control to vital smart home functions.

This architecture, however, cannot be expected to be implemented by an end-user but rather a hired expert or managed service. Nevertheless smart appliance manufacturers should consider a multi-tiered architecture in their systems design and provide appropriate interfaces.

As, due to the emerging nature of IoT-related issues, more security research is needed to give thorough advice on this point, no additional recommendations beyond the ones given can be presently made.

4.2.5 Monitoring and Alarming

The roles (and user accounts) mentioned in Section 4.2.1 should be incorporated into the monitoring concept. Additionally, an alerting mechanism, reporting certain device conditions to concerning people, ideally based on different alert levels and categories. As smart appliances are end-user devices, messages should be generated in a form comprehensible to a non-expert, if the user's interaction is necessary. If a security event or other form of malfunction should require maintenance from an expert, a message should clearly state so. Apart from that technical security logging information, which is not accessible to the user might be stored.

5 Smart Appliance Privacy

Smart appliances can be seen as a part of a smart home network, which can be subsumed under the general term IoT. Common for all of these IoT devices is that data that exactly reflects personal behaviour and habits can be collected. This individual information is not necessarily important for services dealing with nonlinear tariffs, load forecasting or state estimation but is very interesting for online trading, insuring and others. Thus, smart appliances are pieces that have to be protected - together with all other smart devices at home, to ensure that no data leaks via other connected smart home devices arise.

5.1 Right to be forgotten

The right to be forgotten is a current topic in Europe's information society and several legal proceedings of local authorities versus serval companies (e.g. Google) are ongoing[413]. Since laws may change and vary in different countries, the crucial point when market parties collect data from smart appliances is the possibility of separating technical information regarding the smart appliance itself and sensitive personal data. Such a strict segregation performed by the market parties will make their system most flexible regarding future legislation. The new European General Data Protection Regulation (GDPR) (Parliament and Council of the European Union, 2016) covers the right to be forgotten and related rights under the articles of section 3 "Rectification and erasure**".** These new rules give customers better control over their personal data as a customer can ask its market parties to erase it. Market parties have to erase personal data concerning this customer without undue delay or they have to inform the customer providing a writing of any refusal of processing restriction, rectification or erasure of personal data, as well as the reasons for the refusal. Within such a refusal, the information of how to lodge a complaint to a supervisory authority or to seek a judicial remedy has to be provided.

While being lucid from human rights and legal perspectives, compliance to the GDPR could be problematic to enforce in practice. Due to the nature of digital data, there is no real proof that a market that has claimed to have restricted, rectified or erased a user's data has actually done so. It furthermore could already have transferred the data to another party or country underlying a different jurisdiction at the time the request arrives.

5.2 Technical Measures

The only assured way to maintain the privacy of sensitive user data is not giving that data away in the first place (thus, applying the *need-to-know principle* (Sandhu & Samarati, 1994)). To still allow business models utilizing user data, the next sections provide an overview of measures that allow for data usage after some level of anonymization or, at least, mark the data to allow for the possibility of prosecuting violations of the directive.

[413] https://epic.org/privacy/right-to-be-forgotten/

5.2.1 Data Protection

The information collected by a Smart Appliance varies; ranging from simple measurement values up to images (e.g. the Samsung Family Hub fridge also takes photos of its content and maybe the person who is opening the fridge). Since the reasons for collecting data have a different background and malicious access or an attack is very likely for such an IoT device directly connected to the internet, it is important that all information is encrypted and only accessible as originally designed (see Section 4).

5.2.2 Data Anonymization and Pseudonymization

There might be situations where data could be used to gain more benefits for the service provider and maybe also for the customer, when the Smart Appliance delivers data to complementary services, such as complex statistical calculations. Under such conditions, unused data has to be removed and personalized data must not be delivered without the commitment of the customer. Depending on the bought-in service and on the necessity of personal data to be traceable later on, personal data has to be either anonymized or pseudonymized[414]. If data is sold to a third party, all personal information has to be removed or explicit consent from the customer has to be obtained in advance for each transaction. If data is shared on an aggregated basis, all personally identifiable data has to be removed in order that the recipient cannot identify a person. Concepts for anonymizing data include l-diversity and k-anonymity (Machanavajjhala, Kifer, Gehrke, & Venkitasubramaniam, 2007).

5.2.3 Architecture

5.2.3.1 Secure Broker

The Secure Broker architecture proposes to establish an independent organisation between the customers and the market parties. Such an independent organisation collects all personalized information from the customer, but only delivers anonymised information further to the market parties. The broker also performs the settlement between the customer and market parties (See *Figure*).

The business models must be well established between customer, market party, DSO and energy provider. In such a model, the DSO could interact as Secure Broker since he collects information about the energy consumptions and has all accounting information. Further, the DSO is already in a regulated market and therefore no market benefits can be obtained when collecting and manage this information. Additional fees for such a service can be agreed in collaboration with the regulator.

Alternatively, a state or European agency (or a third party commissioned one of the former, including company especially founded for this purpose) could assume the role of the Secure Broker. This might ensure a higher degree of neutrality, but in the wake of Edward Snowden's disclosures on global surveillance of state agencies, citizen support for this solution might be low. In all cases, discussions of ethical and legal implications of the Secure Broker have to be discussed, including the right, duty or prohibition to contribute to crime or terrorism prevention by giving law enforcement access to data under the Broker's custody. Furthermore, the legality of market parties circumventing the Broker system and get direct access to the customer's full, unanonymized data by providing incentives (and related questions such as duty to notify) have to be elaborated.

[414] In this context, pseudonymization is similar to anonymization, except that sensitive data is replaced by inexplicable data connected to the original data instead of deleted, therefore providing a degree of linkability. (Pfitzmann & Hansen, 2008)

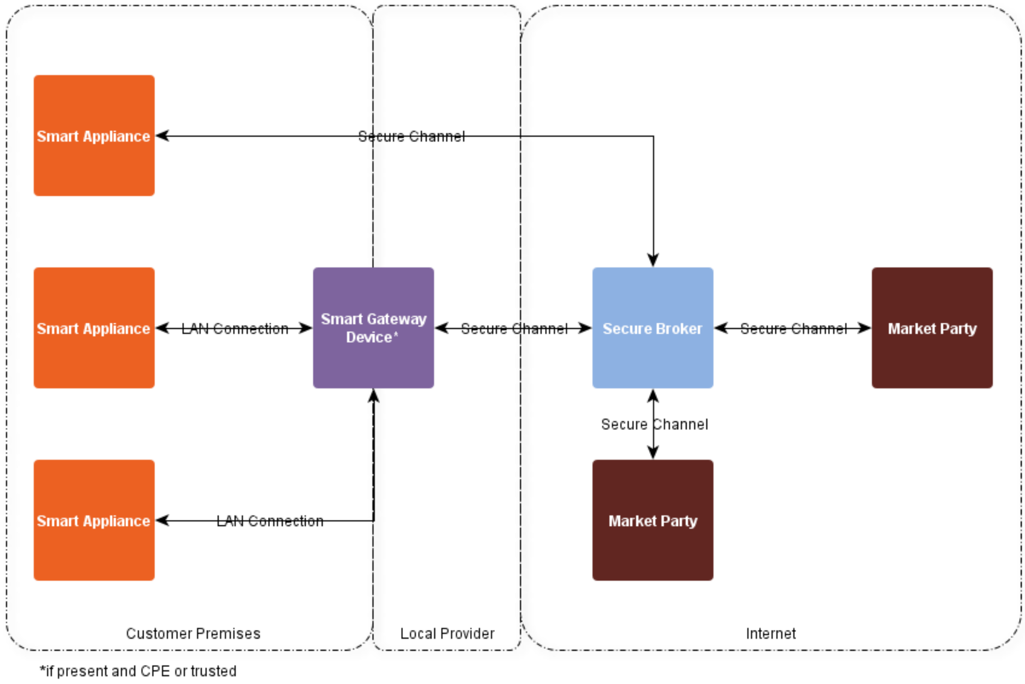

Figure 81 : Secure Broker Architecutre

5.2.3.2 Secure certified customers premise for optimization

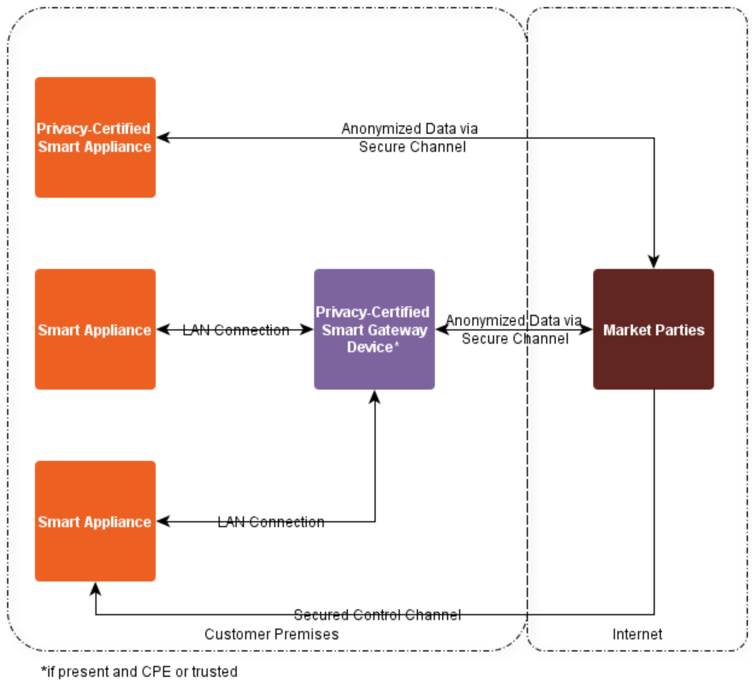

Figure 82: Certified CPE for optimization architecture

This approach differs from the Secure Broker architecture by the lack of participating equipment operated by a neutral third party. All information and optimization is processed and performed locally at the customers premise, subsequently only aggregated (possibly time-based) and anonymized information about the saved energy consumption is delivered to the market provider to enable settlements of accounts according to their contract model (see Figure). The installed hardware and software components have to be certified in a way that they only deliver aggregated and/or anonymized information on the totally avoided energy consumption or beneficially grid usage due to the locally performed optimization. This certification has again to be performed by a trusted, officially commissioned body and has to include thorough functional and security testing, ideally including code reviews that assure the absence of covert data transmission or backdoors.

Alternatively, a smart appliance gateway certified the same way as above might be located between the customer device and the market parties, which performs a filtering and only pass the information needed for settlement (see Figure). This approach is similar to the previous, but has the advantage that not every market party has its product to be certified. Instead, it only has to provide data in certain format most suitable for accounting and which is then passed through the gateway. This gateway (then the only mandatorily certified device) could come from a neutral third party vendor. This approach has the disadvantage that any other communications from CPE to market parties must be successfully prevented to be effective, but, on the other hand, provides the advantage of a market party being able to issue control signals directly to a customer’s device to make optimizations.

5.2.4 Watermarking and Fingerprinting

A method not to prevent data misuse but to enable prosecution of customer privacy violations, such as selling personal data, by market parties is watermarking the data. Introducing some sort of fictitious entries or other special feature of data that distinctly allows identifying the data sent to a certain market party, makes such violations traceable. Depending on the chosen data, it may also render the data unusable and therefore reduces the probability of this sort of data misuse (Agarwal & Hall, 2013).This technique is often confused (or used interchangeably) with fingerprinting. The latter term, however, is not clearly defined, as it may be seen as subtype of watermarking where unique information is added, forming a fingerprint, or as distinguished technique, differing from watermarking by not adding any new information, but rather calculating a unique value from intrinsic properties of the content. Either way, in the present case, the values will have to be calculated separately for every market party *tenured*[415] with user data, for only unique marks enable tracing the data. As discovery of these marking features by a market party may be undesirable, they may be generated using steganographic techniques (Schrittwieser, Kieseberg, Echizen, Wohlgemuth, Sonehara, & Weippl, 2012). A challenge in this setup is to leave the data intact to a certain extent, enough to prevent errors in calculations based on that data (otherwise the data could be rendered useless). Furthermore such markings might be unreliable (Cérou, Furon, & Guyader, 2008). Regardless of the specific technique used, both watermarking and fingerprinting are useful only if illegitimately passed-on data is published in some way, allowing the mark to be recognized.

We propose to establish a database or search engine to search for specific watermarks/fingerprints in order to enable users to detect leaked data.

[415] The user data is entrusted to the market party for a very specific purpose and is, according to the GDPR, also subject to potential reclaim by the respective user.

6 Standards and Legislation Overview

There are many, partly general, partly more specialized data security standards. Some of the standards and guidelines that should be considered in the context of Smart Appliances include:

- NIST Cybersecurity Framework[416]
- NIST SP 800-53 R4 (Joint Task Force Transformation Initiative, 2013)
- NERC CIP standard family[417]
- SANS Criticial Security Controls[418]
- ISO 27001 (International Organization for Standardization, 2013) and its energy-specific version ISO 27019 (International Organization for Standardization, 2013)

These guidelines provide, in general guidance for state-of-the-art level protection. More specialized recommendations are provided in Sections 4 and 5 of this document.

6.1.1 European Legislation

The European Commission plans to unify data protection within the European Union (EU) with a single law, the General Data Protection Regulation (GDPR) (Parliament and Council of the European Union, 2016). This document also aims to harmonize the different national implementations of the aforementioned regulation. On 4 May 2016, the official text of the Regulation has been published in the EU Official Journal in all the official languages. While the Regulation will enter into force on 24 May 2016, it shall apply from 25 May 2018.

6.1.2 National Legislation

As the GDPR is required to be transposed into national law by the EU Member States, the EU Data Protection Officer (DPO) keeps track of the transposal of the Regulation and its predecessor, the Directive 95/46/EC (Parliament and Council of the European Union, 1995). The latter has been replaced by the new regulation as it does not consider important aspects like globalization and technological developments like social networks and cloud computing sufficiently and the Commission determined that new guidelines for data protection and privacy are required. However, due to the much longer period of effect, the directive has been implemented in most Member States. The DPO maintains a website linking to the respective member transforms of the EU data protection laws[419].

[416] http://www.nist.gov/cyberframework/
[417] http://www.nerc.com/pa/Stand/Pages/CIPStandards.aspx
[418] https://www.cisecurity.org/critical-controls/
[419] http://ec.europa.eu/dataprotectionofficer/dpl_transposition_en.htm

6.1.3 Privacy policies introduced by manufacturers

In the television world the Hybrid broadcast broadband TV (Hbb TV) enables the transfer of additional information between customers, program providers and also TV manufacturers. For example Samsung describes in his “Global Privacy Policy - SmartTV Supplement” [http://www.samsung.com/us/common/privacy.html] the set of features that provide enhanced smart TV access and the privacy practices for this SmartTV features when collecting data. Especial the voice recording features is reason for complaint because it records private conversations without informing the customer[420]. Also in Germany a legal proceeding is taken place were the submission of sensitive information due to the default settings is treated. When the TV is connected first time to power supply sensitive information will be transferred without offering the possibility to prevent this to the user[421]. Since smart appliances may or also be equipped with different sensors like cameras or microphones such in principal possible transfer of sensitive information must be considered and legally addressed.

6.2 Certification

Like other information technology, Smart Appliances need a means for certification to assure security. This could be achieved by specifying one or more appropriate standardized protection profiles, for instance according to the Common Criteria for Information Technology Security Evaluation (CC)[422]. We propose the already established protection profile for Smart Meters (Kreutzmann & Vollmer, 2014), established by the German BSI, as a role model for the same process in the context of Smart Appliance certification.

Apart from the Appliances itself, whole environments (as Smart Appliances operate in, specifically Smart Homes or the macro network between end-users and market parties) could be certified similar to corporate environments. While this approach has the advantage of being holistic, compared to Appliance certifications, it is not deemed feasible due to the high degree of individualization in Smart Homes compared with the high effort of established certification processes. Instead we propose elaborating a secure reference architecture for incorporating Smart Appliances into existing environments.

420 https://epic.org/privacy/internet/ftc/Samsung/EPIC-FTC-Samsung.pdf
421 http://www.n-tv.de/ratgeber/Samsung-Smart-TVs-vor-Gericht-article17730981.html
422 http://www.commoncriteriaportal.org/

7 Conclusion

This document has given detailed advice on security aspects related to Smart Appliances. While implementation details and conceptual proposals are to be found in the respective Sections 4 and 5, general advice for enhancing security in designing and implementing Smart Appliances and advanced services can be summed up as follows:

- Each interface and internal process should be separately secured with best feasible effort (*defense-in-depth*)
- Security considerations should be incorporated early in Appliance design (*security by design*)
- Base-level controls should be enforced at all points of access, both internal and external (*security by default*);
- All data must be encrypted using state of the art encryption standards;
- Establish state of the art access control mechanism to all data;
- Specify which personally identifiable and sensitive data types and attributes are collected and used and for what purposes;
- If sensitive data is transferred outside the customers premises, only part of the data which is reasonably useful for the functionality have to be transferred (*need-to-now principle*);
- If data is transferred outside the customers premises, personalized data has to be pseudonymized;
- If data is transferred outside the premises of the contractual bounded market party, personalized data has to be removed or anonymized;
- During the transfer, all data has to be encrypted by using current generally accepted state of the art security standards;
- In general, personal data must only be stored within storage devices located inside the EU otherwise commitment of the customer must be obtained;
- Collected personal data is not shared with third party organisations otherwise explicit consent form the customer must be obtained;
- Specify how long data will be stored;
- Provide information about policies, terms and conditions to the user;
- Provide information and control how the user can decline and personalized data is being removed;
- Changing the service provider will invoke a user request and approval for transferring historical and personal data.

It should be stated that implementing security measures will come at some cost (which might condense in high prices, tight profit margins or, apart from monetary concerns, inconvenience for end-users and implementers). This cost is, however, negligible compared to potential risk of large scale attacks on smart networks potentially ranging to complete blackout scenarios (the threats depicted in Section 3 are considered only the tip of the iceberg).

In any case, some means informing end-users, but also installing technicians (through manuals, web casts, instruction and user-friendly contract terms regarding privacy) is crucial as those parties are also links in the security chain that is to be strengthened as a whole. Furthermore, informing users is a step to support self-reliant customers, capable to decide whether they want to take inconvenience to enhance security, use insecure technology or refrain to use a certain technology at all.

As this is a fairly new field, to support the task of enhancing Smart Appliance Security, research is still needed on reference architectures and norms, elaboration of privacy models, certification models and, after adoption of this technology on a broader basis, practical security surveys.