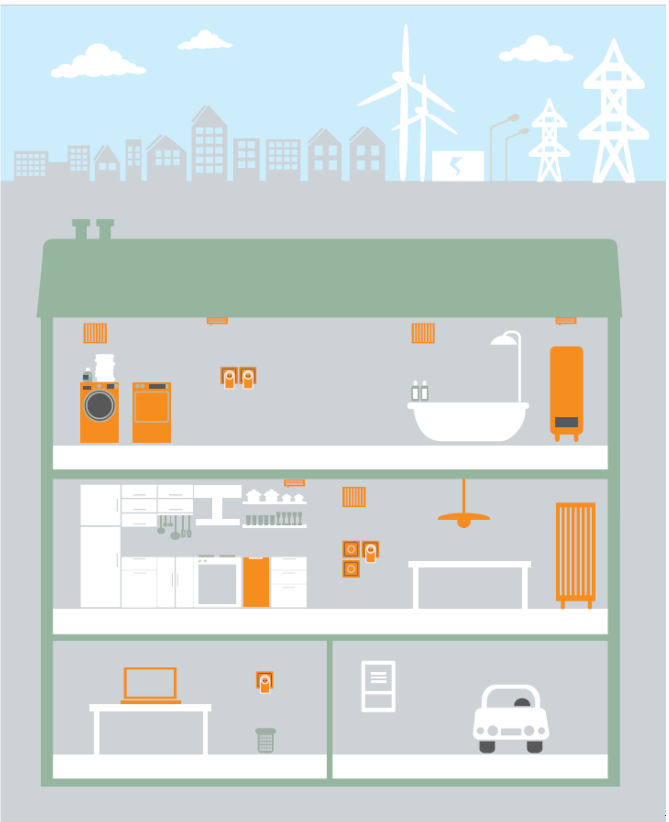
Ecodesign Preparatory study on Smart Appliances (Lot 33)

MEErP Tasks 1-6



FINAL REPORT

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In collaboration with Wuppertal Institute and Joanneum Research

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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/m²] 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.