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DG ENTR Lot 9 - Enterprise servers and data equipment

Task 3: User

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Glossary

AC	Alternating Current
ACPI	Advanced Configuration and Power Interface
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BMC	Baseboard Management Controller
CAGR	Compound Annual Growth Rate
CEE	Converged Enhanced Ethernet
CPU	Central Processing Unit
CRM	Customer Relationship Management
DC	Direct Current
DCB	Data Centre Bridging
DCIM	Datacentre Infrastructure Management
EC	European Commission
EoR	End-of-Row
ErP	Energy-related Products
EU	European Union
FTP	File Transfer Protocol
GUI	Graphical User Interfaces
HDD	Hard Disk Drive
HPC	High Performance Computing
HTTP	Hypertext Transfer Protocol
IOPS	Input Output Per Second
MEErP	Methodology for the Ecodesign of Energy-related Products
MTBF	Mean Time Between Failures
OEM	Original Equipment Manufacturer
OPEX	Operational Expenditure
PCF	Product Carbon Footprint
PDU	Power Distribution Unit
PFA	Predictive Failure Analysis
PUE	Power Usage Effectiveness
PWM	Pulse-Width Modulation
QoS	Quality of Service
REE	Rare Earth Elements
RU	Rack Unit
SLA	Service Level Agreement
SNIA	Storage Networking Industry Association
SPEC	Standard Performance Evaluation Corporation
SSD	Solid State Devices
TDP	Thermal Design Power
TGG	The Green Grid
ToR	Top-of-Rack
TTFD	Time to First Data
UPS	Uninterruptible power supply
VNI	Visual Networking Index
VPN	Virtual Private Network

1. System aspects use phase, for ErP with direct energy consumption

1.1. Product/component scope and extended product approach

Note: Because the scope for ENTR Lot 9 products cannot be simplified and assessed as a strict product scope (e.g. through standards with a nominal load), sections 3.1.1 and 3.1.2 of the MEErP have been merged into a single section in this report.

1.1.1. Introduction

The objective of Task 3 is the identification, retrieval and analysis of data on user behaviour and associated environmental impacts during the use phase for the products in scope.

A screening of environmental aspects on a product level indicates convincingly that electricity consumption in the use phase is expected to be the most dominant environmental hotspot of the products studied in ENTR Lot 9. As an example, existing product carbon footprints (PCF) for servers from IBM[1], Fujitsu[2], Dell[3], and Apple[4] show that the electrical power consumption in the use phase contributes to more than 80 % of the overall product carbon footprint (see Figure 1), with an average four years of active use life.

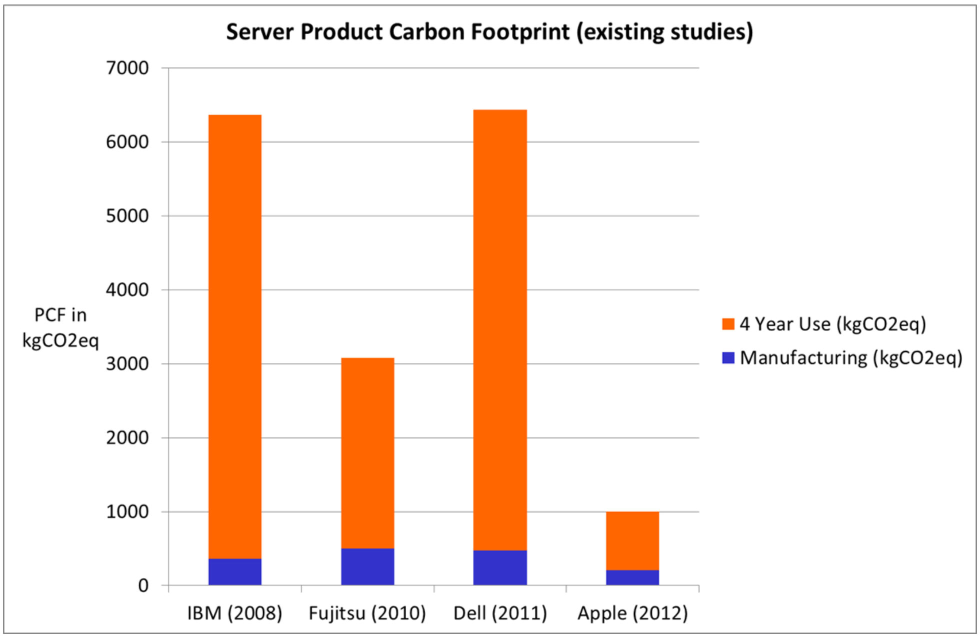

Figure 1: Server product carbon footprints (existing studies)

The use phase remains the most contributing phase to the environmental impacts, even with different CO_2 conversion factors. As an example, Figure 2 shows the carbon footprint of the use phase for the Fujitsu-server, based on the actual power consumption (kWh), but calculated with different CO_2 conversion factors.

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[1] 2008: IBM (Uncertainty and Variability in Carbon Footprinting for Electronics - Case Study of an IBM Rack-mount Server, Christopher Weber, Carnegie Mellon University):
http://www.ce.cmu.edu/~greendesign/research/CMU_IBM_ExecSum_12032010.pdf
[2] 2010: Fujitsu (PRIMERGY RX300 S5)
http://globalsp.ts.fujitsu.com/dmsp/Publications/public/wp-LCAPCF-py-tx-rx-300-S5.pdf
[3] 2011: Dell (PowerEdge R710 2U)
http://i.dell.com/sites/content/corporate/corp-comm/en/Documents/dell-server-carbon-footprint-whitepaper.pdf
[4] 2012: Apple (Mac mini with OS X Server)
http://images.apple.com/environment/reports/docs/macmini_server_oct2012.pdf

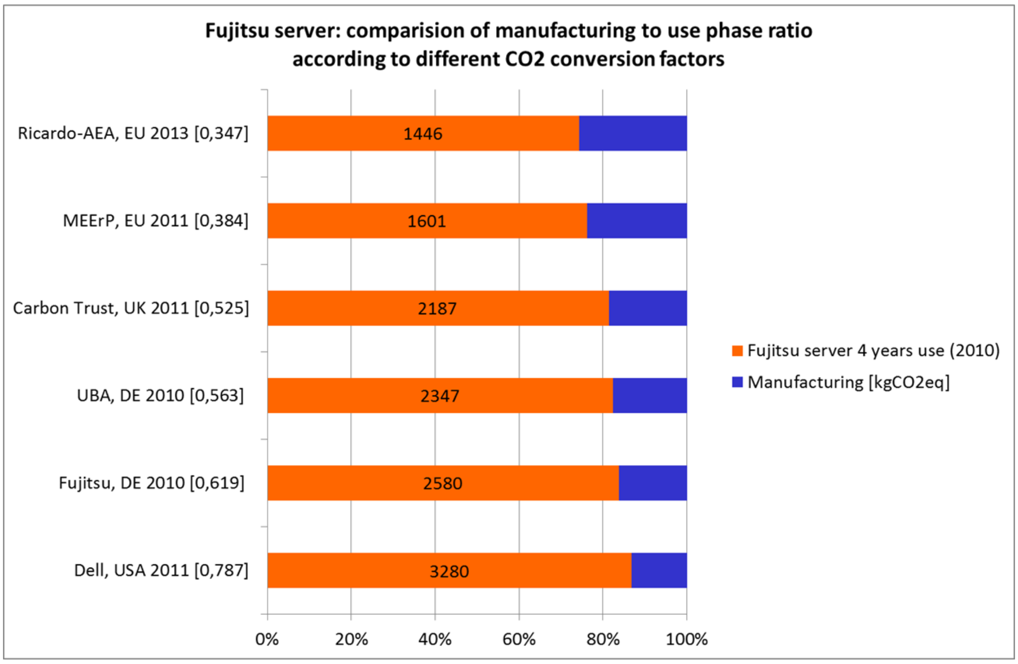

Figure 2: Calculation of the Fujitsu server PCF with different CO_2 conversion factors

This simple exercise indicates how a different type of energy source (e.g. less carbon-intensive electricity from wind or solar power) would alter the result of the environmental impact assessment. However, the electricity demand of the use phase and its carbon emissions is still by far the most important environmental aspect of current servers. Consequently, the improvement of energy efficiency in the use phase is expected to be an important objective for ecodesign on a product level.

With respect to ENTR Lot 9 product scope, this report will investigate not only the power consumption of enterprise servers, but also enterprise storage equipment and related network equipment that connects servers and storage devices in a data centre environment. The following four basic aspects will be investigated in this chapter for each of the three product categories:

- The functionality and operational requirements;
- The energy consumption in the use phase;
- The power management and efficient utilisation; and
- The failures and maintenance activities.

It seems important to underline again the considerably wide product and technical scope of ENTR Lot 9. This poses the challenge of adequately covering all hardware-, software-, and system-related aspects in conjunction with the utilisation and energy consumption of these products in the use phase. Enterprise servers, storage, and related network equipment are embedded into a steady technology evolution.

On a hardware level the energy consumption remains constant and even improves from technology generation to the next while the performance doubles about every two years. Over the past 50 years, the technical and energy performance has been improved by a factor 2 about every 24 months. Industry roadmaps indicate that this trend will continue in the foreseeable future as long as the investments into the expensive technology development are secured by the revenues from an expanding global ICT market (more information on Moore's law and the current semiconductor technologies will be presented in Task 4). The photonic (optical) technology industry that develops broadband and high speed connectivity is a second driver for technical improvement.

On a software level the utilisation rate is improved mainly through virtualization, multi-threading, and other means of active load management. Software improves the interaction of components on the product level but also within clusters of servers and storage devices. Software is increasingly used to analyse system data (provided by sensors) and to control parameters in conjunction with the best operating point. Performance monitoring indicates that a frequent modernization of the hardware and software elements is a viable strategy for improving energy and resource efficiency on the product and data centre level. The figure below shows that the performance and energy consumption significantly improves with the introduction of newer product generations.

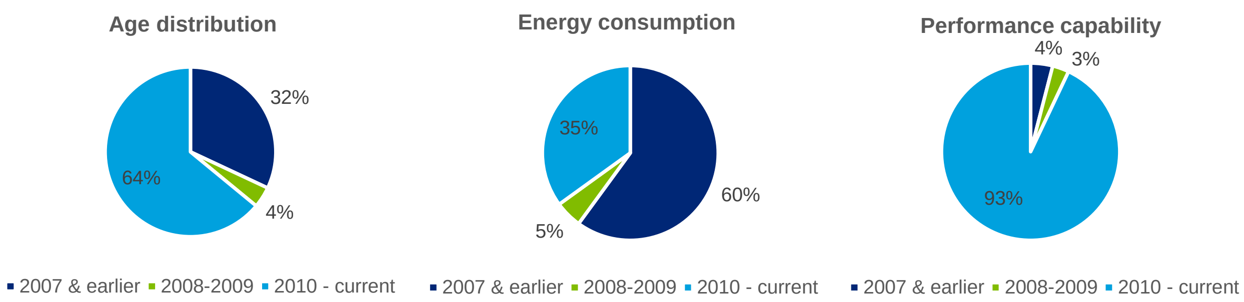

Figure 3: Energy impact according to product generation[5]

Old server population estimated to consume 60% of server energy, but deliver only 4% of performance

On system level, servers and data storage equipment are typically operated in separated server rooms or data centre. They are producing a functional benefit nowadays very often in larges clusters. Such system not only includes various types of IT equipment but a considerable amount of passive and active infrastructure elements such as cooling and air conditioning equipment, undisruptive power supply and power distribution devices, as well as monitoring and fire safety installations. The "users" of the servers and storage equipment are not always the owners of the equipment. As a matter of fact, servers and storage equipment are operated to a large extent in professional environments (co-location hosting) in order to provide its intended functionality as a commercial service. The type and quality of this service (IT production) is usually defined in a so called service level agreement (SLA). Environmental aspects such as energy and resource efficiency are gradually becoming a requirement in service agreements. However, there are no standards for such requirements. A common practice is to meter (measure) the actual power consumption of equipment allocated to a particular service or customer. Another practice is to calculate various key performance indicators (KPI). The most widely used KPIs have been developed by the international industry initiative The Green Grid (TGG).[6] But there are other institutions such as the Uptime Institute that are also developing procedures and indicators for determining the productiveness and overall efficiency of data centres and their equipment. The TGG's best known indicator is the Power Usage Effectiveness (PUE). Around the year 2008, this indicator triggered a very strong movement of the data centre industry to address and improve the overall energy efficiency of their operations. For the first time, comprehensive and continuous power measurement (metering) campaigns were conducted, showing that the cooling and air conditioning overhead in comparison to the actual IT power consumption was enormous. More than often, over 50% of total energy consumption of a data centre was related to active infrastructure elements (PUE >2.0)[7].

[5] http://infrarati.wordpress.com/2011/05/20/aging-servers-are-big-energy-consumers-in-the-data-centre/
[6] www.thegreengrid.org
[7] http://alliancegreenit.org/wp-content/uploads/Alliance-Green-IT-Le-Cloud-est-il-Green.pdf

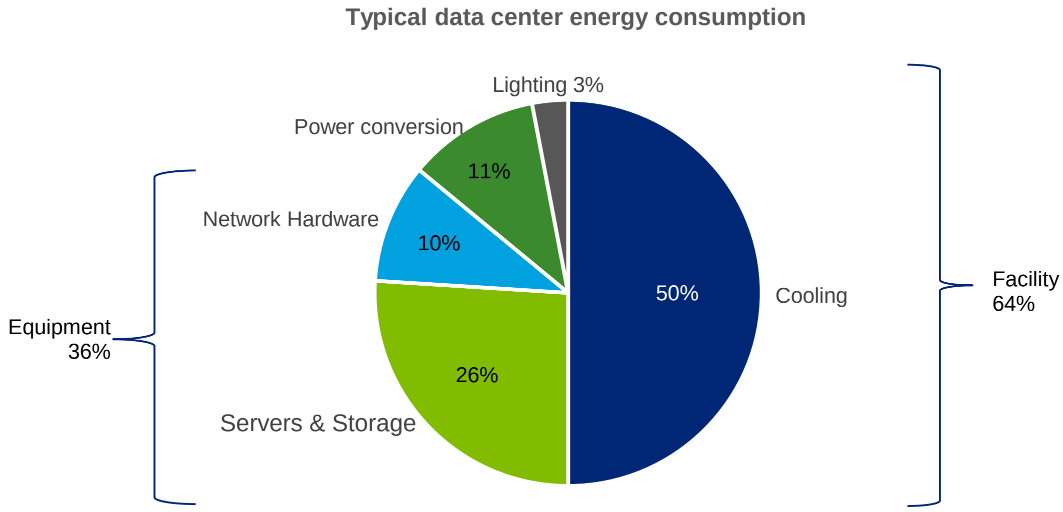

Figure 4: Typical data centre energy consumption in 2010 (Source: Info-tech Research Group, 2010)

Since then energy efficiency measures have been developed and implemented in many data centres. Industry stakeholders have indicated that medium and larger size data centre operations are addressing energy efficiency aggressively in order to consolidate their IT equipment and cut operational costs. Annual data centre surveys[8] also indicate the importance of this issue. Because electricity prices are locally different within the European Union, energy efficiency is an increasingly important economical location factor. Proving best practice with respect to energy and resource efficient data centre operation (IT production) becomes a market requirement but it is also a technical challenge.

With respect to energy efficiency in the use phase it seems justified to investigate the extended system benefit between the energy consumption of the IT equipment and the energy consumption of the data centre cooling infrastructure. The link between both is the ambient operating temperature. Over the past years, data centre operators questioned the necessity for cooling the room temperature of the cold aisle to levels below 27°C (this is the maximum recommended IT inlet temperature defined by ASHRAE). In the past, equipment manufacturer specified this maximum inlet temperature in product warranty statements. While data centre operators increase the inlet temperatures well above 30°C without much hardware failures, the manufacturers provide nowadays product for inlet temperature of up to 35°C. This allows a considerable downsizing of data centre level cooling equipment and reduces the overall energy consumption. The trade-off between increased inlet temperatures, somewhat higher energy consumption or thermal stress on the IT product level, and a considerable reduction of the energy and resource consumption with respect to the cooling infrastructure is a highly considerable ecodesign aspect on the extended system level.

All these developments (hardware, software, extended system) lead at the present to a tremendous variety of system configurations and deployments of overlapping technology generations in the field. As a result, the study investigates a highly heterogeneous product and system situation with no clear cut baseline. The authors of this report would like to stress the understanding that **there is no general baseline and best practice with unambiguous performance values**, but that there is **a lot of individual best practices with conditional performance values**. The following analysis of the use phase attempts to provide data concerning the power consumption, power management and other use-related environmental aspects. At the same time, the report attempts to explain the causal relationship between product configuration (hardware), product utilisation (software) and the extended system interaction (data centre). This task should be read in close conjunction with Task 4, which explains the technical aspects of products in greater detail.

[8] E.g. TechTarget's annual "IT Priorities Survey"

1.1.2. Enterprise servers

1.1.2.1. Functionality and application

The functional performance of enterprise servers can be distinguished by its application, respective hardware and software configuration. Enterprise servers are most often employed as dedicated servers and perform a specific service or task. Typical applications include:

- Mail servers: They move and store email over local networks and across the Internet. Typical software platforms are Microsoft Exchange.
- Web servers: They provide the content of a website to a user's Web browser over the local network and across the Internet utilising Hypertext Transfer Protocol (HTTP). Typical software platforms are Apache or from Microsoft.
- File servers: They move and organise files securely between computers utilising FTP (File Transfer Protocol).
- Database servers: They provide database services to client computers (users). Typical software platforms include SQL, SAP, and Oracle.
- Application servers: They are dedicated to the execution of programs, routines, scripts and work in conjunction with database servers and the user. The application server is programmed via a software platform such as Java, PHP and Microsoft.
- Terminal servers: They support today dedicated remote (virtual) desktop services including graphical user interfaces (GUI). Typical software platforms are from Microsoft and Citrix.
- Proxy / communication / VPN servers: They are dedicated to filter communication requests (gateway/firewall), share connections, and improve and monitor performance.

No statistical data at the EU level on the number of servers according to their applications was found. A 2012 German study by the Borderstep Institute for Innovation and Sustainability, Berlin, provides a breakdown of the data centre structure and allocated servers for the situation in Germany.[9] According to these figures, which have been compiled in close collaboration with IT business associations and their members, about 65% of all servers are operated in small, medium and large data centres. The study points out that the number of servers operated in single server cabinets or very small server rooms are decreasing year by year. At the same time, the overall number of medium to large data centres and respective number of servers is increasing constantly.

Table 1: Data Centre Structure and Number of Servers (Germany, 2012)

	Floor space (m^2)	Connected IT Load	Number of servers	Server total (Germany 2012)	Data Centre (Germany 2012)
Server Cabinet	5	2	3-10 (5)	151 000	31 458
Server Room	20	7	11-100 (19)	344 000	18 105
Small Data Centre	150	50	101-500 (150)	285 000	1 900
Medium Data Centre	600	240	501-5 000 (600)	255 000	425
Large Data Centre	6 000	2 500	>5 000 (6 000)	390 000	65
Total				1 425 000	51 954

The data from the Borderstep study allow the calculation of the IT energy consumption and its distribution according to the size of the data centre. At the assumption of 24/7 utilisation of the server and other IT equipment (connected IT Load) the annual power consumption would amount to 4.8 TWh (Germany 2012). Assuming a conservative PUE (Power Usage Effectiveness) of 2.0 (see section 1.2.1), the overall annual energy consumption of German enterprise servers and data centres is 9.6 TWh (~1.6% of total electricity consumption).

Below figure shows this distribution of this energy consumption according to the type and size of the location. It is interesting to notice that 30% of the energy consumption is due to the few (about 65) large data centres

[9] http://www.borderstep.de/pdf/V-Hintemann-Fichter-Kurzstudie_Rechenzentren_2012.pdf, in German language, Retrieved 3 July 2014

and another large share of 19% to the about 425 medium size data centres, even if the majority of servers are still operated in small and very small installations.

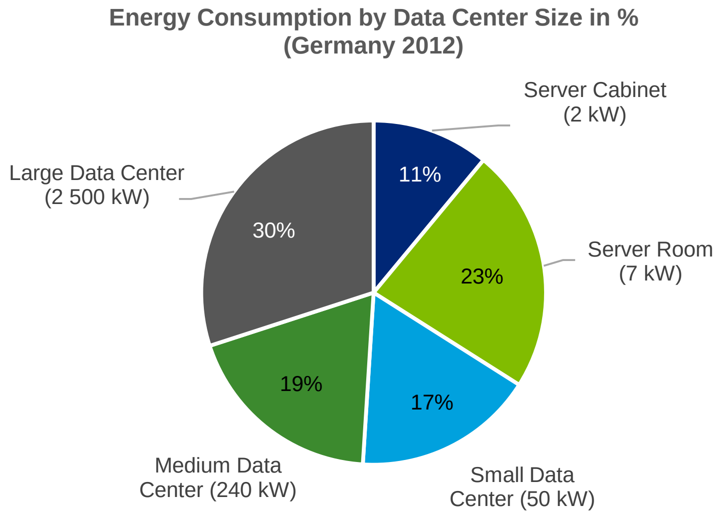

Figure 5: Energy Consumption by Data Centre Size, in Percent (Germany, 2012)

In conclusion, despite the fact that the types of application the existing servers are fulfilling remain unknown, knowing the type of the location where servers are operated is still helpful. It could be assumed that financial services, telecommunications, internet services and media providers, as well as colocation providers and large private businesses are operating their servers in large and medium size data centres. There are strong indications that the larger the data centre, the more energy efficient it is.

Two recent studies (from outside of the EU) help to verify this assumption. The first study is an Australian study by the Equipment Energy Efficiency Program (E3), "*Energy Efficiency Policy Options for Australia and New Zealand Data Centres*".[10] Published in April 2014, it provides some actual figures concerning the distribution of data centres across various business sectors. These data might be indicative also for the situation in the EU.

Figure 6 breaks down the total number of data centres in Australia and New Zealand according to the size of the data centre defined by the overall electrical capacity. This is similar to the calculations shown for Germany above. The overall data centre related energy consumption in Australia/New Zealand represented 8.2 TWh in 2013 (3.4 TWh for IT and 4.8 TWh for infrastructure). In comparison, the German data centres (server room and small, medium and large size data centres, but without single server cabinets) consumed 8.6 TWh in 2012 when assuming a PUE of 2.0. The similar order of magnitude between the overall consumption figures indicates that the data breakdown available for Australia and New Zealand can be considered as indicative of the situation in the EU-28, even if the breakdown of energy consumption by business sector **Error! Reference ource not found.**also depends on the economic structure of the country.

When investigating the breakdown of this overall energy consumption according to the size of the data centre, it is noteworthy that the Australian study assumes roughly comparable "connected load" values to the German study. For instance, the German study assumes for medium size data centres a connected IT load of 240 kW. With an average PUE of 2.0, this means about 480 kW including the data centre infrastructure. The Australian study assumes for medium size data centres a total connected load of 150 kW to 750 kW, i.e. about 450 kW on average. The basic assumptions between the German and Australian studies are therefore quite comparable.

According to the Australian study, small data centres have the largest energy consumption share with 39%, followed by large (enterprise) data centres with 32%. These numbers are in line with the data from Germany. Based on these similarities, it is assumed the data from Australia/New Zealand are to some extent applicable also for the situation in Europe, at least indicating certain order of magnitudes with respect to the distribution of servers (data centres) in different business sectors.

[10] http://www.energyrating.gov.au/wp-content/uploads/Energy_Rating_Documents/Library/Other/Data_Centres/Energy-Efficiency-Policy-Options-for-AUSNZ-Data-Centres_April-2014.pdf. Retrieved: 2 July 2014

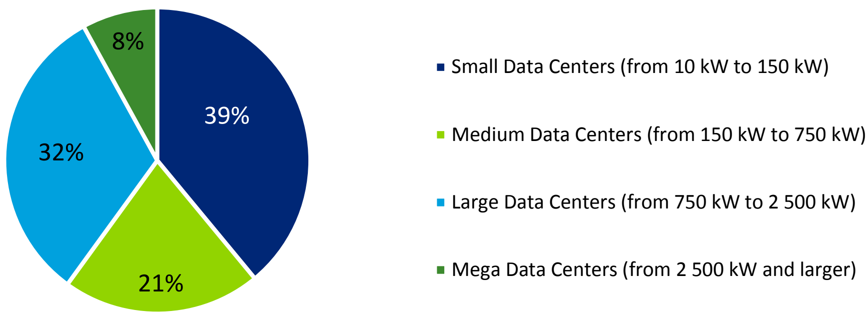

Figure 6: Data centre energy consumption by size of the data centre (Australia and New Zealand, 2013)

The above figure shows the distribution of the data centre space according to business sectors in Australia and New Zealand in 2013. With 23.2% of the overall space the financing and banking sector represents the single largest data centre floor space. The colocation data centres which typically host servers for private business are the second largest space with 21.2%. They are followed by telecommunication and media provider services with 14.3%. In general, internet-based services seem to have the overall largest market share. This would confirm the general trend that data traffic, in terms of workload volume, is shifting towards cloud services.

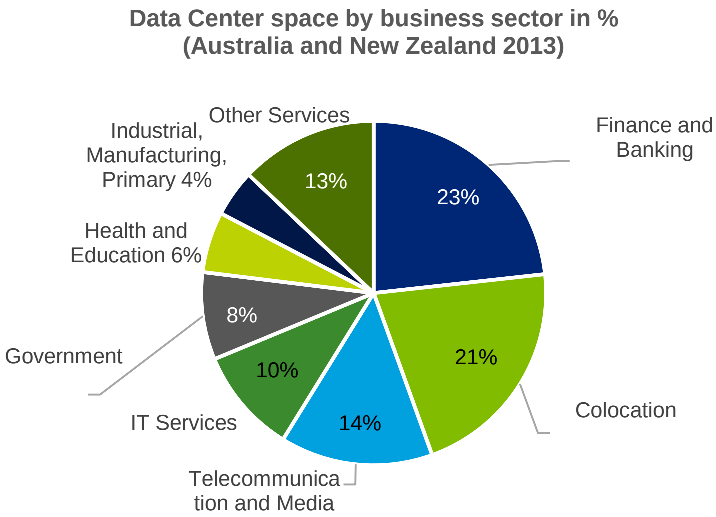

Figure 7: Data centre space by business sector in percent (Australia and New Zealand 2013)

Figure 7 shows the energy consumption of the data centres allocated to business sectors. The data centres of the finance and banking sector in Australia and New Zealand consumed 1.92 TWh in 2013. The same amount of energy has been consumed by the private business sector (mixture of different and diverse sectors, including some public sector services including healthcare) followed by the colocation data centres with 1.70 TWh. These data indicate that the floor space correlates with the energy consumption. Most of the small and medium data centres are likely to found in the private business sector.

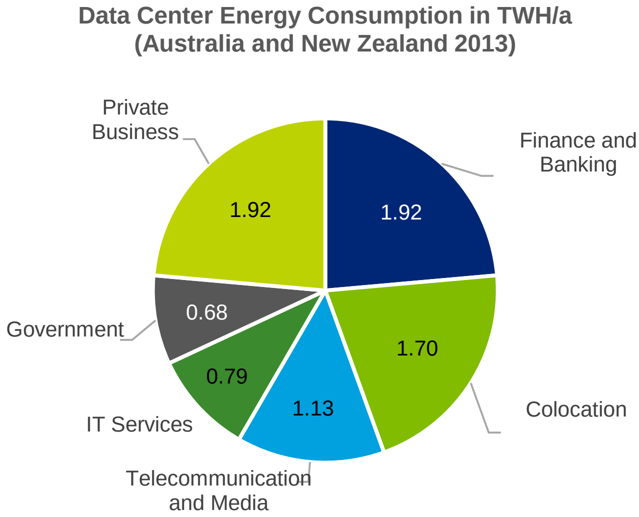

Figure 8: Data centre energy consumption in TWh by business sector (Australia & New Zealand 2013)

In order to indicate the distribution of typical software applications in relationship to the type (size) of data centre where these applications are hosted, a 2013 U.S. case study conducted by Eric Masanet (et. al.) from the Berkeley Labs, California[11], entitled "*The Energy Efficiency Potential of Cloud-based Software*" investigated the distribution and provision of the most common software applications, namely "Email", "Productivity" (typical Office applications), and "CRM" (customer relationship management).

According to this study, the installed base of servers in the U.S. in 2013 was 6.1 million units. Of this total number, about 4.7 million servers (77%) supported local hosting of standard business software including email, productivity and CRM software. Figure 9 shows the distribution of these three main software applications by size of data centre. It is interesting to notice that the majority of volume software applications are still running on volume servers in very small installations. The study is neither indicating the workload these applications create nor the utilisation level of the servers. Nevertheless, the data show that about two thirds of the servers in the U.S. are dedicated to email and productivity software.

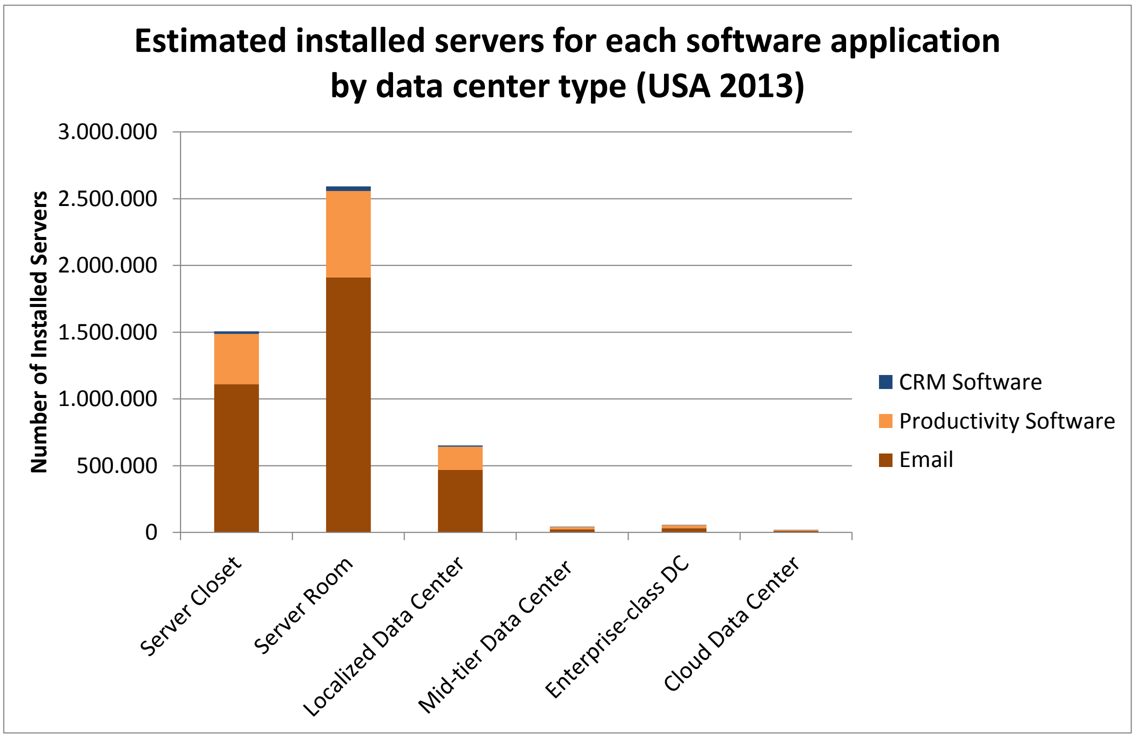

Figure 9: Distribution of software applications by type of data centre (USA, 2013)

Against that observation, the study creates a simple scenario in which these software applications are shifted from (probably low utilised and highly redundant) volume servers into highly efficient cloud data centres on

[11] http://escholarship.org/uc/item/68b51379 Retrieved 2 July 2014

midrange servers. In this “cloud-based business software” scenario, the overall energy consumption and material consumption (based on a carbon footprint assessment) is drastically reduced. In terms of energy use, the “cloud” scenario suggests 87% reduction in comparison to the present day situation. What is also interesting to note is that the “cloud” scenario drastically reduces server redundancy and thus, the overall number of deployed devices.

1.1.2.2. Workload development

The 2013 Cisco Global Cloud Index (GCI)[12] is a public source which analyses the development of the IP-traffic and workloads in data centres. According to a GCI white paper[13], this new index aggregates and evaluates data from several analyst firms and international agencies. The analyst input consists of server shipments with specified workload types and implementations. Cisco then estimates the installed base of servers and the number of workloads per server to obtain an installed base of workloads. The workload is divided in traditional data centre workload and cloud data centre workloads. The GCI also includes directly measured network data (IP-traffic) from 10 enterprise and internet data centres that have been collected over a 12-month period ending in September 2013. With the new (2013) GCI methodology, both workload and IP-traffic categories include associated storage traffic. The baseline for the current index is the year 2012. The forecast is made up to the year 2017. The GCI not only aggregates the worldwide development but provides detailed figures for several regions including Western Europe as well as Central & Eastern Europe.

Figure 10 shows at first the estimated development of the annual data centre IP-traffic worldwide. Unfortunately, this dataset is not available for individual regions. According to the GCI, the cloud-related data centre traffic will increase substantially from 1 177 exabytes (EB) in 2012 to 5 313 EB in 2017. The compound annual growth rate (CAGR) for this development is 35%. In comparison, the traditional data centre traffic will increase at CAGR of 12% from 1 389 EB in 2012 to 2 413 EB in 2017.

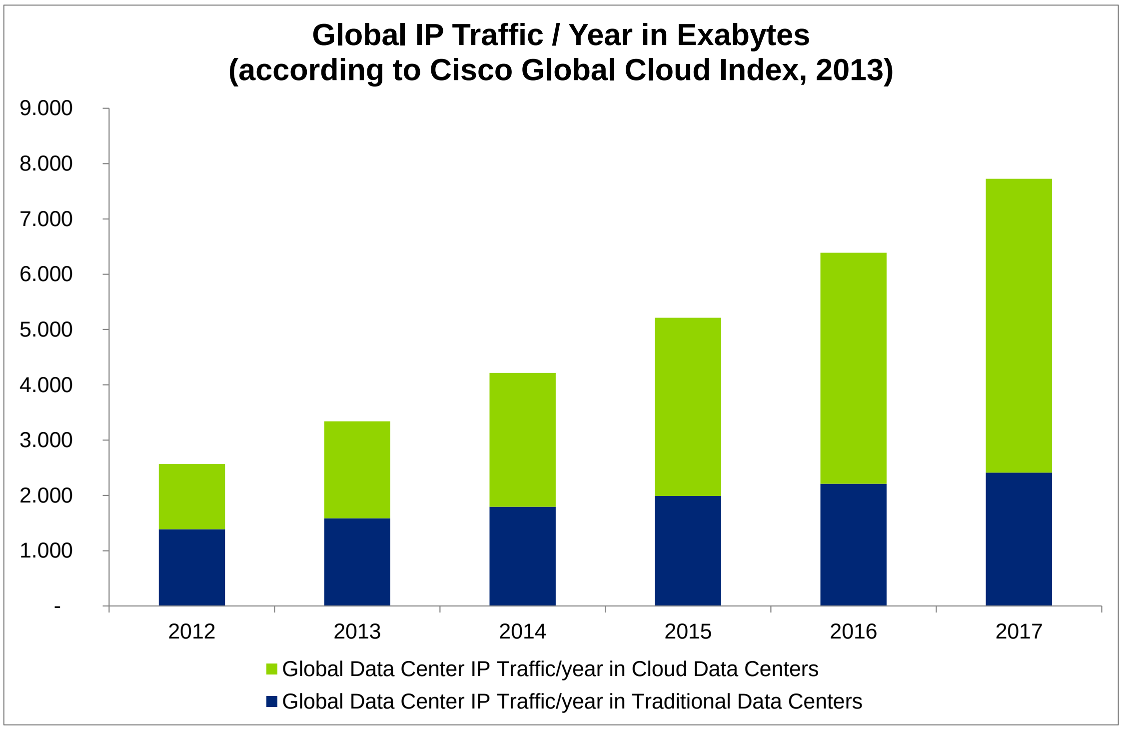

Figure 10: Cisco Data Centre Index 2013 – Data Centre IP-Traffic (worldwide)

By making the assumption that the CAGR for traditional and cloud-related IP-traffic remains constant over the years, a further progression of the scenario until the year 2030 would lead to the considerable increase of data centre IP-traffic by a factor 53 (see Figure 11, introduced in Task 2). The cloud-related IP-traffic would amount

[12] http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns1175/Cloud_Index_White_Paper.html
[13] http://www.cisco.com/c/en/us/solutions/collateral/service-provider/global-cloud-index-gci/Cloud_Index_White_Paper.pdf

to about 93 316 EB and the traditional IP-traffic to 42 381 EB. In 2030, the cloud-related IP-traffic would be 2.2 times higher in comparison to the traditional IP-traffic.

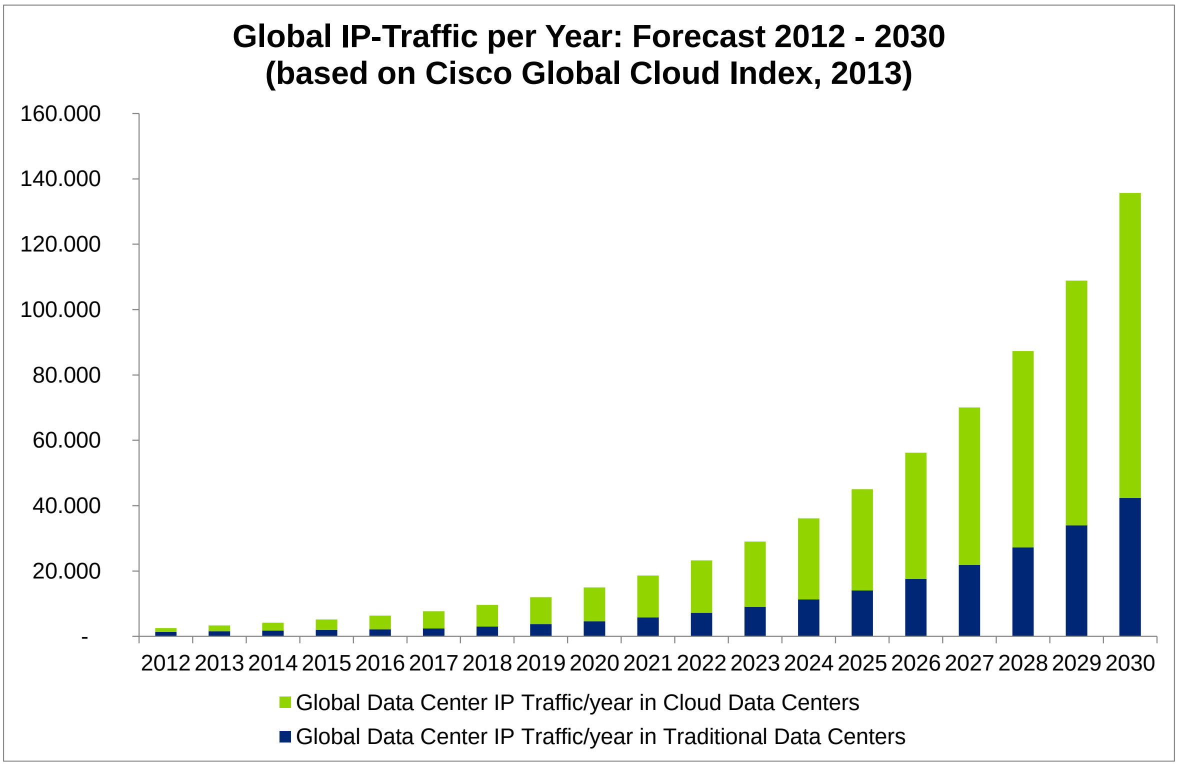

Figure 11: Forecasts for Global IP Traffic in Exabytes / Year until 2030 (calculations by BIO by Deloitte, based on Cisco GCI 2013)

The Cisco Global Cloud Index 2013 also provides assumptions for the status and development of the data centre workload. A workload has been defined by Cisco GCI as the amount of processing that a server undertakes to run an application and support a number of users interacting with the application. Traditionally, one server carried one workload. However, with increasing server computing capacity and virtualisation, multiple workloads per physical server are common in cloud architectures.

The global data centre workload is forecast to increase in total by a CAGR of 18% until the year 2017. Whereas the traditional workloads are only increasing marginally, the cloud-related workloads are scoring with an expected CAGR of 30% worldwide.

The data centre workload development for the regions Western Europe (WE) and Central & Eastern Europe (CEE) are shown in Figure 12. The total data centre workload is expected to grow by 14% annually. While the CAGR of the traditional workload in WE is only 3% and 6% in CEE, the real increase occurs in the cloud-related workloads with CAGR of 24% in WE and 30% in CEE.

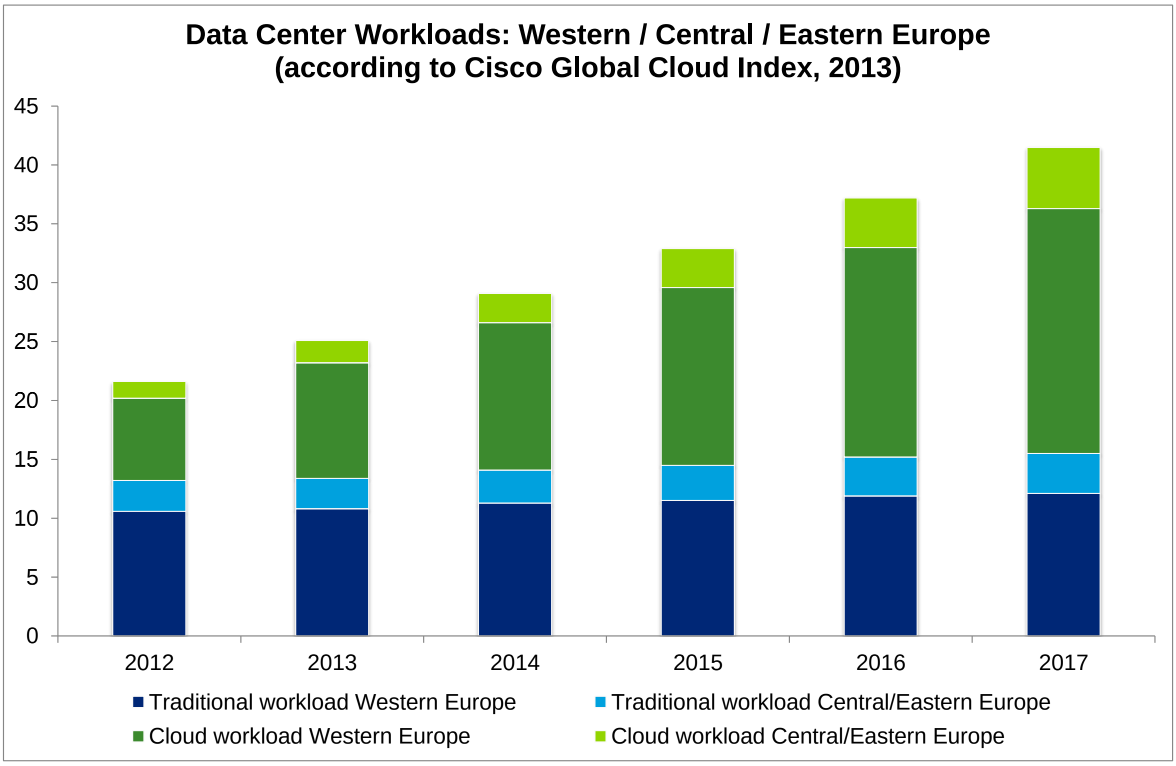

Figure 12: Cisco Global Cloud Index - Data Centre Workload (WE and CEE)

In order to indicate the mid- to long-term development and provide a data foundation for the base case scenarios, the data centre workload development was calculated for Western Europe and Central & Eastern Europe based on the same CAGR until 2030. Figure 13 shows this projection. According to this calculation, the combined workloads of WE and CEE would grow from about 21 million in 2012 to 463 million in 2030. This equals to an overall increase by factor 21.

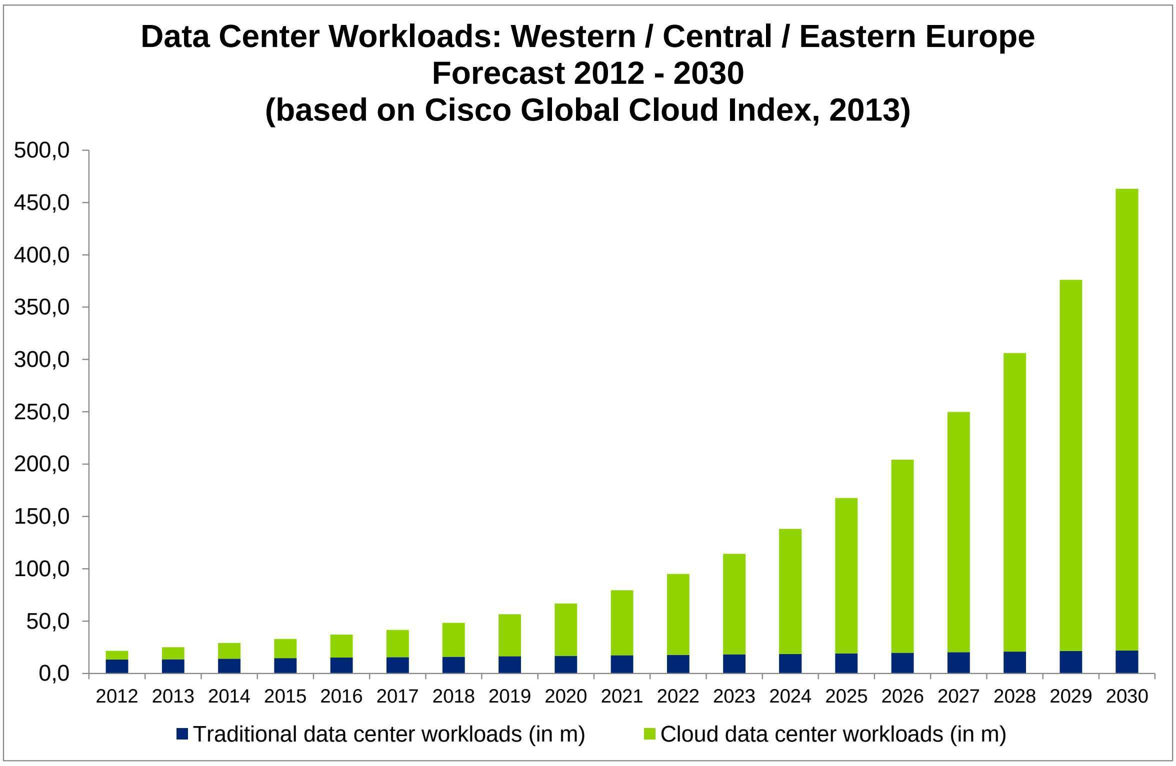

Figure 13: Data Centre Workload: Forecast 2012 to 2030 for WE and CEE (GCI 2013)

In conclusion, based on the data and assumptions of the Cisco GCI the data centre workload is doubling about every 4 to 5 years and the data centre IP-traffic is doubling about every 3 to 4 years.

1.1.2.3. *Average use pattern*

In order to calculate the energy consumption of enterprise servers over their active lifetime, it is necessary to determine or define the following parameters:

- Total years of active utilisation;
- Annual days and hours of active utilisation;
- Average load level and the associated power consumption over a 24 hours period; or
- Mode specific utilisation and the associated power consumption over a 24 hours period.

- **Average years of server active utilisation**

For the purpose of this study, a total of **4 years of active utilisation** is considered (see Task 2). This number is also the lifetime assumption in existing product carbon footprint assessments for servers and has been confirmed by industry stakeholders. Under real life conditions, the actual lifetime of enterprise servers varies considerably depending on its type, price, application, etc. As matter of fact, server vendors indicate that specialised servers might be used for up to 8 years. On the other side of the spectrum, market analysts predict a general decline of the average server lifetime down to only 3 years. Furthermore, some manufacturers successfully started commercial programs that refurbish used enterprise servers after a relatively short first life of about 3 years. The refurbished severs are then typically sold in a lower price segment. However, the whole active life remains higher than 3 years in that case, because of the second life of the product, but it is difficult to get an average estimate of this effect.

- **Annual hours of active utilisation**

For the purpose of this study, a total use time of **8 760 hours per year** is assumed. Enterprise servers are typically "always on" and therefore are running 24 hours a day and 365 days a year, but under different modes, i.e. in idle or under active load. It is common practice to keep servers alive even if no applications are running on the system. However, most data centre operators have to deal with some amount of downtime per year. In particular, 73% of business had some downtime in the past with about 7.5 hours per year on average.[14] Reasons for the downtime are manifold and include interruptions of the grid power (power station failures), hardware failures, network failures, and to a smaller extent software failures. The allowable downtime (or reciprocally the availability) is typically defined in service level agreements (SLA) and also translated into classification of the data centre. An availability of 99.99% means an allowable downtime of about 53 minutes per year.

In the framework of this study, given the high availability required whatever the level of Tier of the datacentre[15], and thus the very limited number of minutes of downtime, downtime is not considered in the average use pattern, as the level of accuracy would not be relevant due to the uncertainty on the average use pattern.

- **Use intensity and average load level**

An older study by The Green Grid (TGG) provides some initial figures for the actual utilisation rate of enterprise servers. The 2009 TGG white paper N°19 "*Using virtualisation to improve data centre efficiency*" investigated a typical sample data centre with 500 servers.[16] The utilisation of the servers in this data centre is categorised under the terms "Innovation" indicating sporadic job-based applications, "Production" indicating continuous services, and "Mission Critical" indicating high availability continuous services. Table 2 shows the results of investigation by TGG. According to these data, the average utilisation rate was only 5%. Mission critical servers, which account for only 15% of the total number of servers in this particular data centre, showed the overall highest utilisation rate (10%). The servers of the category "Innovation", which account for the half of the server stock, showed the lowest utilisation rate (3%).

[14] http://venturebeat.files.wordpress.com/2012/11/infograph_costofdowntime.png?w=580&h=3043, Retrieved 7 July 2014
[15] Tier 1 level of the Uptime Institute (the lowest availability level) requires 99.671% availability.
[16] http://www.thegreengrid.org/~/media/WhitePapers/White%20Paper%2019%20-%20Using%20Virtualization%20to%20Improve%20Data%20Centre%20Efficiency.pdf?lang=en, Retrieved 7 July 2014

Table 2: Server utilisation according to application, in sample data centre environment (TGG, 2009)

Categories	Innovation	Production	Mission critical	Total
Server Count	250	175	75	500
Utilisation	3%	6%	10%	5%
Watts (173 per server)	43 250	30 725	1 297.5	86 500
Consolidation Ratio	15:1	10:1	5:1	~10:1
Remaining Servers	17	18	15	50
Post-consolidation utilisation	50%	50%	50%	50%
Post-consolidation Watts	3 910	4 140	3 450	11 500
Energy Savings	39 340	26 135	9 525	75 000

It seems that the average utilisation of enterprise servers increased to some extent since 2009. Anecdotal information indicates that the average utilisation has been increasing on average to levels of 10 to 30%.

This trend is confirmed by TechTarget's "*IT Priorities Survey*"[17], an annual survey among the IT industry with over 4 000 respondents worldwide in 2014. The survey examines the technical, operational and budget focus of IT departments. According to 2014 survey, the IT priorities continue to address virtualisation, consolidation, and cloud computing. New priorities include mobility and business intelligence. With respect to the European responses, server virtualisation and consolidation projects have the highest priority in existing infrastructure projects and future initiatives. However, energy efficient computing and sustainable or green IT are only a priority for 11% of the respondents, which is rather low. The 2014 survey indirectly indicates nevertheless that the increase of server, storage and network utilisation through virtualisation and other consolidation measures will benefit the energy and resource efficiency of the IT in data centre.

For the purpose of this study, an **average utilisation rate of 20% load is assumed, with the respective power consumption over a 24 hour period**. In reality, this is not the case. In most business applications the server's daily utilisation follows a relative stable day-and-night pattern with low utilisation during the night time and an abrupt rise of activity in the morning hours. Figure 14 further below illustrates a typical daily use pattern in a highly abstract form. In reality the load level and respective power consumption of a server will fluctuate under active load over the complete range from idle to maximum power. DIGITALEUROPE provided specific data regarding different server utilization profiles for average server utilizations of 10%, 20% and 40% (see Table 3). Specifically in the conjunction with new cloud applications the equipment utilisation could increase and range from 20% to 90% depending on the hardware capabilities and configuration, the type and homogeneity of workloads, etc.

Table 3: Different server utilization profiles for average server utilizations of 10%, 20% and 40%

Average server utilisation	10%	20%	40%
76 to 100	0%	0%	10%
51 to 75	5%	5%	25%
26 to 50	10%	35%	35%
1 to 25	60%	50%	25%
0	25%	10%	5%

No statistical data were found to enable the calculation of an average use pattern. Because of the high uncertainty of this typical pattern, resulting from a very wide range of patterns (across business sectors, datacentre sizes, level of best practice, etc.), this parameter will be particular investigated during the sensitivity analysis in Task 7.

[17] http://book.itep.ru/depository/forecasts/prem_IT_priorities_2014_FINAL.pdf

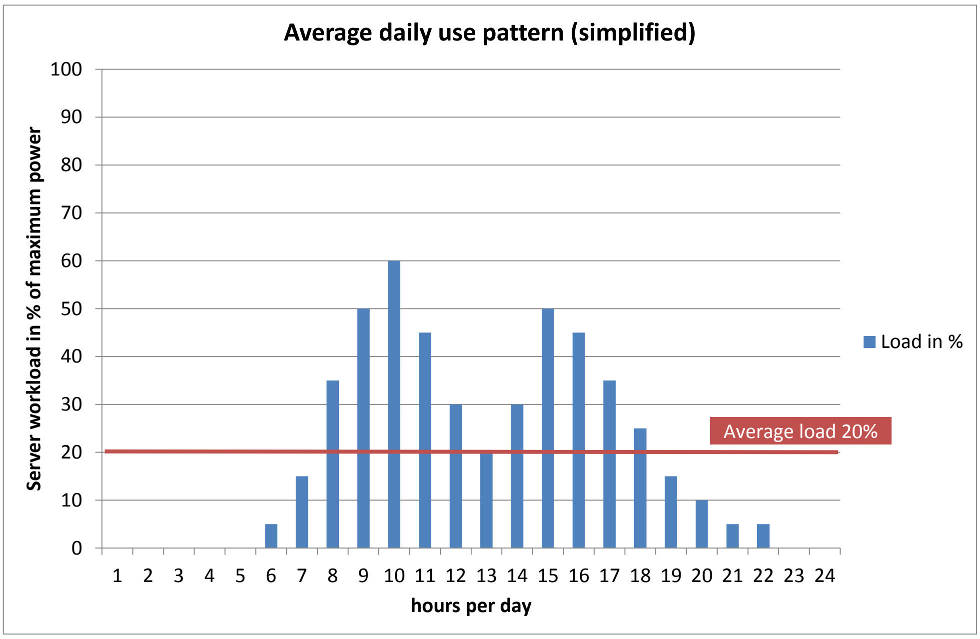

Figure 14: Typical (blue bars) and resulting average (red line) daily use pattern

From the distribution of power consumption, one can conclude that the relatively long night time duration of about 8 hours with hardly any activity contributes substantially to the low average utilisation and respective power consumption. Even during the day, the average utilisation might not be very high due to the application and virtualisation level of the respective server.

In order to support the later base-case assessments with a daily use pattern that can be modified for advanced power management options, **the 24-hours average 20% load is divided and allocated into one 8-hour idle duration with no load and into another 16-hour active duration with 30% average load** (see Figure 15).

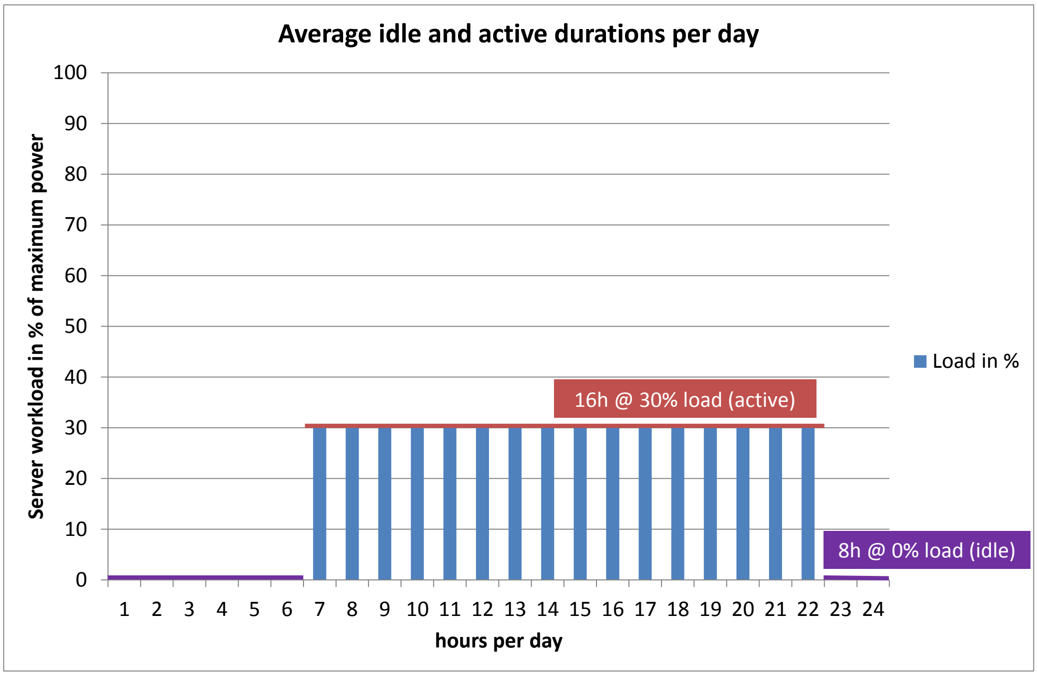

Figure 15: Idle and active durations per day

In conclusion, the actual utilisation of an enterprise server is determined by range of factors including the server type and application, the respective hardware and software configuration, as well as the operational environment and service level agreements under which the server is running. Due to these conditions and resulting variability, **an average utilisation rate of 20% load over a 24-hour period is assumed**. Without doubt, this is a substantial abstraction of reality and a highly pragmatic approach. As an alternative, **this average load is distributed into separate idle phase of 8h at 0% load and an active phase of 16h at 30% load (alternatively we suggest 5h at 0% and 19h at 25% load).** In further tasks, depending on the base-cases considered, the utilisation rate might be modified in order to reflect a considered application or other specifications of the server.

1.1.2.4. Electricity consumption in the use phase

In order to calculate an annual power consumption of enterprise servers, the methodical approach for creating a necessary use pattern is defined in the previous section. One important aspect of the proposed methodology is the adjustment of the power consumption in the use phase corresponding to an averaged utilisation rate (load level). This pragmatic approach considers that there are power consumption data available for different load levels. To date, comprehensive power consumption data are not necessarily provided in product data sheets. Most often, only the rate power of the product and thermal design power of the CPU are published. However, since 2007 many manufacturers have been testing the performance and respective power consumption of their products with the SPECpower benchmark (see Task 1). Over the past year, SPEC made the Server Efficiency Rating Tool (SERT) available which provides a more comprehensive performance to power assessment.

- **Power consumption values according to SPECpower**

A considerable amount of about 500 SPECpower benchmark test results are publically available.[18] The database is providing the following data for individual servers:

- Performance-to-power (ssj_ops/watt) per load level;
- Power consumption (watt) per load level; and
- Product configuration including number and type of CPU, etc.

The main objective of SPECpower benchmark is a performance-to-power assessment (see Task 1 for a detailed discussion on the applicability of this benchmark). The power consumption in active use is varying according to the actual task (application) and the resulting load level. In the past few years, server vendors addressed the optimisation of power consumption in different load levels with the aim to lower the idle-mode power consumption and improve the performance-to-power ratio in the partial loads. Evidence for this improvement derives from the SPECpower test results. The Figure 16 shows exemplarily the results of a SPECpower assessment from 2012. The blue line indicates the power consumption per load level. The line is not linear but slightly curved showing relatively lower power consumption in the 20% and 60% load range. The performance-to-power ratio (red bars) is considerably increasing in the same range.

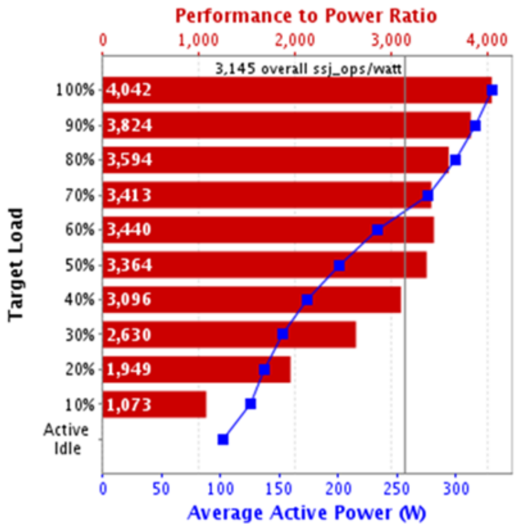

Figure 16: Example of a SPECpower assessment result (2012)

For illustration purposes, the power values per load level separately for servers with 1-socket, 2-sockets and 4-sockets were extracted from the SPECpower database. The objective is to show the relationship between the server power consumption and its defining component – the processor. Figure 17 below shows the development of power consumption for the three different types of servers and with respect to four different load levels (10%, 30%, 70%, and 100%). The coloured lines are the average power values per selected load level.

[18] http://www.spec.org/power_ssj2008/results/

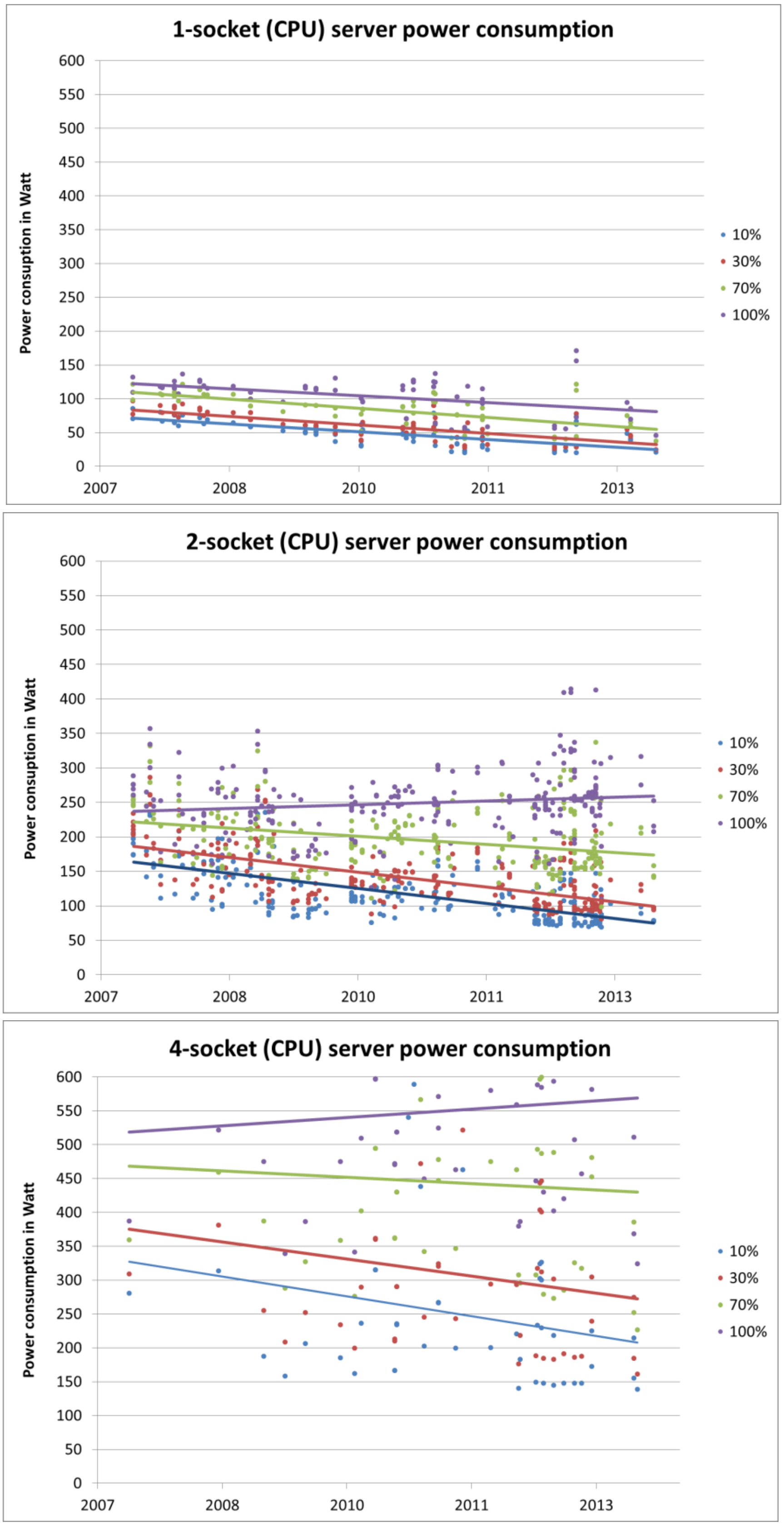

Figure 17: Power consumption development of servers according to number of CPUs

The first aspect we see from the diagrams is the relative overall improvement (decreasing) of the average power consumption in different load levels over time. The 1-CPU servers show a considerable and almost similar improvement in all load levels, decreasing the effective power consumption almost by half between 2008 and 2013. The 2-CPU and 4-CPU servers show also considerable improvements at least for the load levels up to 70%. The maximum power consumption however slightly increases on average. In order to get an idea for the average power consumption of servers, Table 4 lists the average power consumption of the different servers at 30% load.

Table 4: Average power consumption of servers at 30% load

Utilisation at 30% load	Average Power Draw (Watt)					
Servers	2008	2009	2010	2011	2012	2013
1-CPU	80	70	60	50	40	35
2-CPU	170	160	150	135	120	110
4-CPU	360	340	320	310	290	280

A closer look at the SPECpower test results and particularly the power consumption values in the partial loads reveal a certain mismatch: the measured power consumption is considerably low in comparison to calculated power consumption based on individual component data such as the thermal design power of the CPU. This observation is confirmed by stakeholders. According to these sources, server devices under test have been specifically modified with a minimum hardware configuration for the SPECpower benchmark. Therefore, the resulting power consumption is significantly lower than a typically or even maximally configured server.

This is one reason why the U.S. EPA (through the ENERGY STAR® Program) in close collaboration with leading equipment manufacturers took the initiative and asked SPEC to create with SERT a more comprehensive and more realistic set of tests.

- **Power consumption values according to SPEC SERT**

Server Efficiency Rating Tool (SERT) measures the power consumption of a server according to a total of five different product configurations[19]. These include a minimum and maximum power configuration as well as a low-end, typical, and high-end performance configuration. SERT distinguishes seven different (benchmark) workloads for the CPU as well as two different workloads for memory and storage each. SERT also measures a so called hybrid workload similar to SPECpower and the idle power consumption. The particular workloads are called worklets. The individual worklets are measured for full and partial loads. Table 5 shows the individual worklets and respective load levels that are measured for each of the five hardware configurations.

Table 5: SPEC SERT worklets

Workload	Load levels	Worklet
CPU	25% / 50% / 75% / 100%	Compress
CPU	25% / 50% / 75% / 100%	CryptoAES
CPU	25% / 50% / 75% / 100%	LU
CPU	25% / 50% / 75% / 100%	SHA256
CPU	25% / 50% / 75% / 100%	SOR
CPU	25% / 50% / 75% / 100%	SORT
CPU	25% / 50% / 75% / 100%	XMLValidate
Memory	Full/Half	Flood
Memory	4 / 8 / 16 / 128 / 256 / 512 / 1024 GB	Capacity
Storage	50.0% / 100.0%	Random
Storage	50.0% / 100.0%	Sequential
Hybrid	12.5% / 25.0% / 37.5% / 50.0% / 62.5% / 75.0% / 87.5% / 100.0%	SSJ
Idle	No load	Idle

Through this complex distinction of product configuration and worklets, it is now possible to get a more realistic understanding of the actual power consumption in active mode. First results that have been made available to

[19] The Federal Institute of Materials Research and Testing (BAM) noted that according to information on the official SPEC website (http://www.spec.org/order.html), the license fee of SPEC SERT amounts to 2800$.

the project team by industry stakeholders confirm that the power consumption e.g. in a typical configuration is considerably higher in comparison to the SPECpower benchmark results.

For example, a 2013 manufactured 2-socket typical (medium) configured x86 rack server (2xCPU E5-2660 at 2.2GHz, 20 cores) draws about 195W at 25% load and up to 320W under full load. The standard deviation of the power consumption with respect to the seven individual compute worklets is with 2 to 8% rather low and allows utilising a mean value. A comparable product tested with SPECpower draws only about 90W at 20% load and 200W under full load. This comparison indicates that the SPECpower values are underrating the actual power consumption of servers. There is a difference of at least a factor of 1.5 between the SPECpower and SERT results.

For the purpose of this study and to estimate the average energy use associated with the user profile described under section 1.1.2.3, **an averaged power consumption value based on available SERT data will be considered**.

- **Component power consumption**

The single most power-drawing component in a server is usually the CPU. Low energy consumption and better performance-to-power ratio is a high-priority objective in the design of CPUs. The semiconductor industry is achieving and implementing further improvements with each technology generation. This continuous improvement of energy efficiency on chip-level results from the miniaturisation paradigm according to Moore's Law (the number of transistors doubles on the same surface area periodically every 18 to 24 months).

The Thermal Design Power (TDP) value is a practical indicator for the power draw of the chip i.e. the energy that the cooling system needs to dissipate in operation. In order to show the variety of processor options and its varying maximum TDP values, below table lists about half of the configurations available for the Intel® Xeon® Processor E5-2600 Product Family (a typical CPU for servers).[20]

Table 6: Maximum TDP values of Intel Xeon E5-2600 product family

Product Type and Specification	Date of market introduction	Maximum TDP
Intel® Xeon® Processor E5-2687W (20M Cache, 3.10 GHz, 8.00 GT/s Intel® QPI)	Q1'12	150 W
Intel® Xeon® Processor E5-2680 (20M Cache, 2.70 GHz, 8.00 GT/s Intel® QPI)	Q1'12	130 W
Intel® Xeon® Processor E5-2660 (20M Cache, 2.20 GHz, 8.00 GT/s Intel® QPI)	Q1'12	95 W
Intel® Xeon® Processor E5-2650L (20M Cache, 1.80 GHz, 8.00 GT/s Intel® QPI)	Q1'12	70 W
Intel® Xeon® Processor E5-2630L (15M Cache, 2.00 GHz, 7.20 GT/s Intel® QPI)	Q1'12	60 W
Intel® Xeon® Processor E5-2643 (10M Cache, 3.30 GHz, 8.00 GT/s Intel® QPI)	Q1'12	130 W
Intel® Xeon® Processor E5-2609 (10M Cache, 2.40 GHz, 6.40 GT/s Intel® QPI)	Q1'12	80 W
Intel® Xeon® Processor E5-2667 (15M Cache, 2.90 GHz, 8.00 GT/s Intel® QPI)	Q1'12	130 W
Intel® Xeon® Processor E5-2650 (20M Cache, 2.00 GHz, 8.00 GT/s Intel® QPI)	Q1'12	95 W

The maximum TDP values for the different Intel® Xeon® E5-2600 CPUs have a range from 60W to 150W. According to chip manufacturers, the TDP of CPUs for volume servers and storage equipment will not increase much over 150W in the next few years. This limitation will help Original Equipment Manufacturers (OEMs) with respect to midterm planning of product designs.

[20] http://ark.intel.com/de/products/series/61422

In order to get an understanding of the power distribution and energy consumption of the other active and passive components, the following tables provide an exemplary breakdown of component-related power consumption for a single-CPU, 1U rack-optimized server. The power consumption values are educated guesses based on available technical data such as product data sheets and allowances deriving from the ENERGY STAR® program. The first table shows the power consumption in idle state (see Table 7) and the second one, under maximum load (see Table 8).

Table 7: Single-CPU server energy distribution at idle state

Server (1 socket)	Idle (in Watt)	Technical data and assumptions (according to ENERGY STAR®)
CPU	40	TDP of Xeon E5, 19 existing CPU configurations
RAM	19	0.2W per GB for 6 DIMM = 96GB
HDD	16	4W per 3.5" HDD for 4 HDDs
I/O	8	2W per Gbit port for 4 ports
Mainboard	6	Assumption
Fans	8	4 Fans (3 + 1), 2W per fan
PSU	26	Max. 160W at 85% efficiency
Total	**123**	**1 socket rack-mounted**

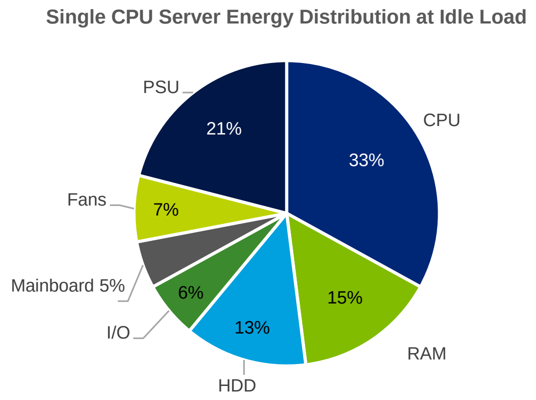

Figure 18: Single CPU server energy distribution at idle level

Table 8: Single-CPU server energy distribution at maximum load

Server (1 socket)	Maximum power draw (in Watt)	Technical data and assumptions (according to ENERGY STAR®)
CPU	100	TDP of Xeon E5, 19 existing CPU configurations
RAM	72	0.75W per GB for 6 DIMM = 96GB
HDD	32	8W per 3.5" HDD for 4 HDDs
I/O	8	2W per Gbit port for 4 ports
Mainboard	10	Assumption
Fans	12	4 Fans (3 + 1), 3W per fan
PSU	42	Max. 450W at 85% efficiency
Total	**276**	**1 socket rack-mounted**

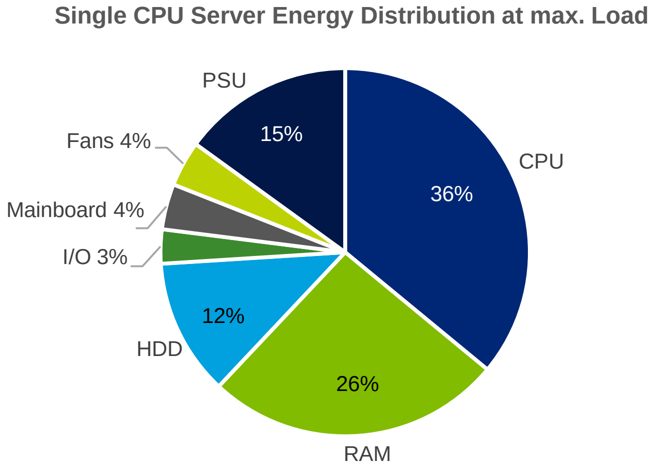

Figure 19: Single CPU server energy distribution at maximum load

This simplified assessment indicates that in a server, the processor and memory together account for almost 50% of total power consumption in the idle state and more than 60% in the full load state. The storage configuration has with 13% and 12% respectively a considerable contribution as well.

Another important factor is the integrated cooling system, i.e. in this case the fans. Depending on the overall configuration, particularly the number of CPUs and their respective TDP, the number and size of the fans may result in considerable energy consumption increase. Without doubt the thermal design is an important indicator for the energy efficiency of the product.

The cooling system consists mostly of passive and active elements. The passive elements are heat spreader, heat pipes and radiators. The size and shape of the air inlets, the design of airflow channels and back flaps are further elements that contribute to the thermal design. The placement of components is also important. The objective is to achieve an optimal airflow that cools all heat-sensitive components and avoids hot spots and turbulences. In the common case of air cooling, the active cooling elements are fans or blowers. The speed of the fans is nowadays adjusted to the thermal load (in thresholds or linearly). Thermal sensors and chip-level algorithms provide the data input for the speed adjustment. The efficiency of the fan varies with the actual load.

With higher energy density, liquid cooling systems have been introduced for special high performing servers. Liquid cooling systems may operate passively or feature pumps. Liquid cooling systems can handle higher thermal loads. However, they are also more complex in installation and maintenance.

Figure 20 below shows the general aspects of the thermal design in a simplified diagram.

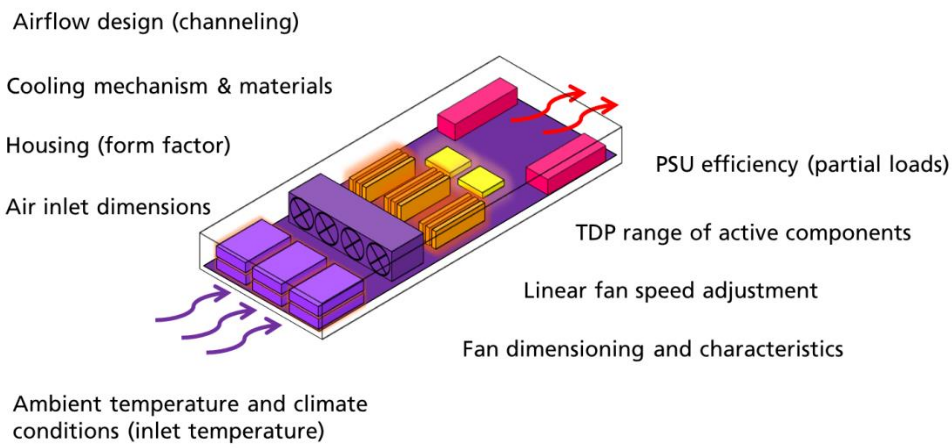

Figure 20: Thermal design elements of servers and data storage equipment

The external conditions including the inlet temperature and air pressure are having an effect on the energy consumption of the server and data storage equipment as well (see section 1.2). Many vendors already offer server products for operation up to 35°C inlet temperature. These products would support free cooling and feature components and thermal designs that are considerably more robust and adjusted to the higher temperatures.

- **Idle power consumption as indicator for energy efficiency**

Low idle power consumption indicates in general high energy efficiency for server products with comparable hardware configuration. The level of idle power consumption is certainly influenced by the type of CPU and the RAM capacity (compute capacity). Another hardware aspect contributing to the idle power consumption is the number of disk drives (storage) and respective connectivity (interface). Moreover, it is important to recognise that the right sizing of the PSU (single or redundant) is influencing the overall idle power consumption. An over-dimensioned power supply results in a very low and energy inefficient load level in idle mode (for more details see Task 4 report). A small ratio of idle power consumption to the PSU's rated power consumption is principally better. In conclusion, low idle power consumption is a possible indicator for an energy efficient product design.

1.1.2.5. Load and power management

Efficient server utilisation, hardware consolidation, and overall energy savings in a server room or data centre are going hand in hand. Efficient utilisation of managed servers and storage equipment as well as associated network technology is effectively realised by a combination of system-level load management and to a smaller extent product-level power management. However, there is not a clear distinction between both aspects.

Enterprise servers are fulfilling nowadays their intended purpose mostly in networked systems that combine multiple physical server and storage units in one virtual entity. Due to this development, it is difficult to allocate the useful work (functional benefit of the energy-related product) solely to a single hardware (server or storage product in a sense of a functionally complete device). Combining multiple (physical) server and storage devices in a large virtual entity is creating a considerable energy and material reduction potential. In a virtual environment consisting of multiple networked devices, it becomes possible to shift (virtual) servers and IT loads between different hardware elements (physical servers).

Virtualisation: Over the past years, virtualisation has become the key technology for improving the utilisation of of managed servers by migrating virtual servers or IT loads on a smaller number of physical machines. Virtualisation software creates one or more virtual environments (e.g. servers) that receive their computing resources from hardware spread amongst several physical systems, resulting in a more balanced load between between physical servers (see

Figure 21). As the total overhead of a server system is reduced, redundant hardware can be tuned down or turned off to reduce energy consumption and cost while maintaining full performance. Keeping in mind that the utilisation of many physical servers (Web, Mail, DNS, FTP, etc.) is with 10 to 30% typically low, the integration of different physical servers as virtual servers into a single physical server saves considerable energy and resources. It is very difficult to quantify the extent to which virtualisation might reduce the number of conventional single application servers. Examples show that about four to eight (old) physical severs can be migrated on a (new) single server. However this all depends on the configuration of the new system and the actual load that need to be handled.

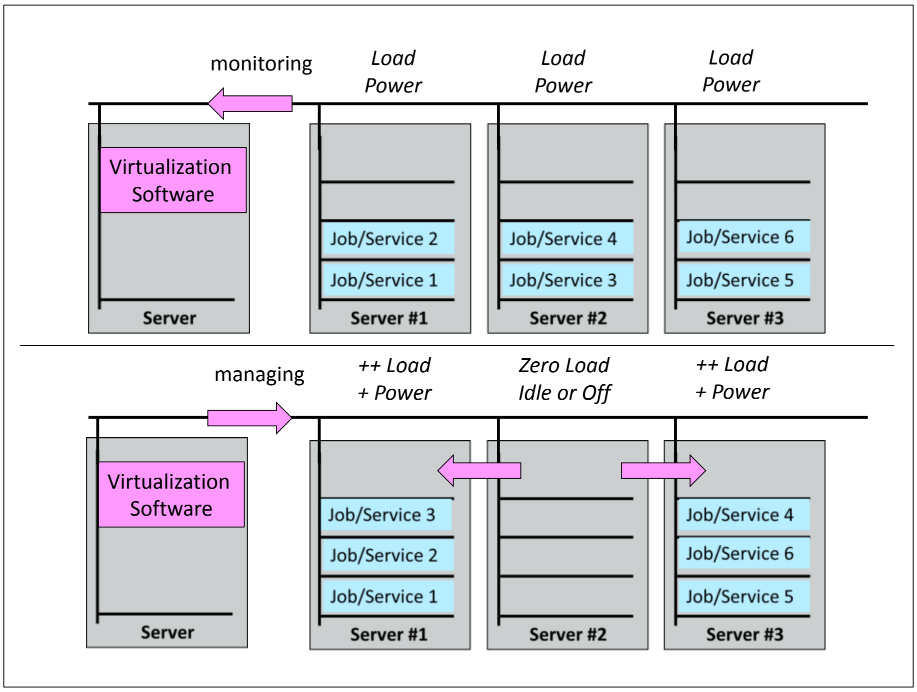

Figure 21: Schematic diagram of server virtualisation (highly simplified)

There are currently two main virtualisation software competing in the market (representing 84% of the market share in 2013[21]) – VMWare's vSphere and Microsoft's Hyper-V. Both programs primarily focus on automatic on-the-fly load and storage shifting in server systems while manual load shifting remains an optional feature. VMWare vSphere 5.5 consists of two software modules: ESXi, a type-1 (bare metal) hypervisor, and vCentre, a management software package controlling a variety of features. vSphere is a standalone operating system utilising Linux and open source code as well as proprietary software modules. Microsoft Hyper-V Server 2012 is provided either as a feature of various Windows versions or as a standalone package. Installation and licensing of Microsoft is far more accessible if the company already uses Microsoft products. As Hyper-V is optimised for Windows systems the performance decreases compared to vSphere when used with other systems like Linux. The more physical memory is installed, the better vSphere handles it compared to Hyper-V. The decision for either one is usually based on accessibility dependent on already-installed software and cost related to lower or higher performance demands. Other hypervisors with a still relatively low market share are KVM, Citricx XenServer and Oracle Virtual Box[21].

In conclusion, virtualisation improves the availability and utilisation of existing IT resources such as enterprise servers and associated storage and network equipment. Server virtualisation is a software solution that allows operating multiple virtual servers on one physical server hardware. If the migrated or unloaded servers are turned off, then virtualisation achieves the goal of energy saving and consolidation of hardware. Virtualisation is a system-level solution that provides operational flexibility, but does not guarantee a fixed, quantitatively measureable improvement. It is also noteworthy that virtualisation is influencing the thermal management and related energy consumption on the hardware and infrastructure level. Due to the fact that the IT load translates into thermal load (see thermal design power of CPU), migrating IT loads must be done consciously and with a consideration regarding the impact on the rack and room level air conditioning and cooling infrastructure.

Product and device level power management – the way we know it from personal computers, notebooks, and other mobiles – is not very common in the field of enterprise servers. In a personal computer, the open standard Advanced Configuration and Power Interface (ACPI) enables the operating system to identify and initialise individual hardware devices of the computer, generating through that various sleep states (modes). ACPI is also possible on x86 server systems but like mentioned before, much less common according to industry stakeholders. The hardware control in servers is realised by a platform management controller in conjunction with standardised interfaces (IPMI).

Intelligent Platform Management Interface (IPMI) is a specification for standardised interfaces on hardware level. The IPMI architecture consists of a baseboard management controller (BMC), platform and chassis

[21] http://blog.unitedlayer.com/infographic-hypervisor-marketvmware

management busses, and other system/network interfaces. IPMI provides control functionality including (1) inventory of hardware, (2) monitoring and control of hardware devices (e.g. system temperature, fans, power supply unit) and its system state (on/off), (3) logging of out-of-range system states, and (4) recovery control of the server. IPMI is commonly utilised with some kind of system management software and works independently of the CPU, BIOS and operation system of the server, even in “off-mode” as long as one PSU provides power. IPMI has been developed by HP, Dell and NEC and the current version is IPMI v2.0. The new version defines further platform management aspects in order to enable better interoperability and scalability with new intelligent hardware elements in support of high availability of the sever, but also to enhance security for remote management.

Individual manufacturers, for example Fujitsu (Primergy), have developed **server management software** that includes power control functionality. Such software enables the control of power supply units according to load on the operating system of the server. In this case it cuts off the power supply during night “off-hours” and holidays in order to reduce energy consumption. **Monitoring** the own power consumption and limiting power consumption on product level is also possible. Some power management is automatically done by the processor (CPU) in conjunction with its thermal management. Modern servers are for instance featuring thermal sensors e.g. on the air inlet and on critical position of the mainboard as well as on component level. The obtained thermal data are processed and used for adjusting the processors or other devices performance as well as for adjusting the fan speed for better cooling. **Active thermal management** contributes to higher performance and can save energy on a system level such as rack and room (see later sections on system interaction).

1.1.2.6. *Product failures and maintenance*

Service level agreements (SLA) specify the availability and allowable downtime of server and storage equipment in enterprise environments and data centres. Downtime and product failure are important aspects with respect to quality of service (QoS). They translate into life cycle costs and consequently into energy and resource consumption.

There are three basic questions that need to be answered when dealing with product failure:

- Where is the location of the failure?
- What is the failure mechanism?
- What is the cause of the failure?

To give an example, it has been reported that electrolyte capacitors failed in server products. The electrolyte capacitor therefore represents the place or location of the failure. The failure mechanism has been analysed and it was concluded that the electrolyte dried out. The cause of failure was determined as overheating. In other words, the electrolyte capacitor was placed at a location where cooling was insufficient. The reason for this could be a suboptimal layout, component selection or an operation not according to the prescribed specification.

- What are the general reasons for product failures?

Downtime and product failure is influenced often by a combination of technical and operational factors. This could be a thermal, mechanical, electrical or electromagnetic stress induced in the product system due to the way and conditions of operation. If a product is operated according to its specifications, failures are unlikely to occur. The following aspects are possible sources for failures:

- **Operating conditions:** Failures occur mostly as a result of frequent or massive events during which the product is not meeting the specified operating conditions. Frequent events are for example considerable temperature changes in consequence of load alternations. A massive event could be an overheating as a result of problems in the cooling infrastructure.
- **Product lifetime:** The overall expected lifetime of the product also has an influence on failures due to the technology and component selection (design decisions) that have been made. If a product or device exceeds its intended use life, the probability of a failure will increase.
- **Product design:** Due to different production tolerances (e.g. 5%, 2%, 1%) the technical properties of electronic components vary with an influence on the lifetime. If not properly selected for its particular purpose, an electronic component might fail prematurely under certain operating conditions. Electronic components of high quality (e.g. 1% tolerance) are considerably more expensive and might be more prone to mishandling. Cost-oriented products on the other hand have typically a very small margin for mishandling. An operation outside of the prescribed specification might lead to quick failure.
- **Production quality:** This includes the imprecise placement and soldering of electronic components, assembly mistakes and damage during product handling and shipment. Quality control of OEMs is usually detecting these potential products and sorting them out.

Equipment manufacturers and data centre operators implement various measures in order to ensure sufficient service availability. This includes:

- **Information disclosure:** Extended product tests, performance benchmarks, meantime between failure (MTBF) calculations and detailed product data sheets are useful information for selecting the right product for the right purpose. Proper product selection and configuration based on known technical data avoids over/under dimensioning and helps to save resources.
- **System architecture**: A redundant product configuration including failover technologies and automatic backup solutions ensures availability. Service availability has a very high priority in the operation of a data centre and justifies overprovisioning to some extent. Nevertheless, overprovisioning increases CAPEX and OPEX and needs to be properly managed.
- **Condition monitoring:** Condition monitoring and predictive failure analysis e.g. based on combined sensor data is a precondition for failure prevention. Most equipment manufacturers employ sensors that continuously monitor the technical data and operating conditions of main subassemblies including the processors, memory, storage drives, voltage regulators, fans and

power supply units. Some equipment manufacturers provide logic components for predictive failure analysis (PFA) based on the obtained data.[22]

- **Maintenance:** Frequent product checks, tests and exchange of devices can ensure proper operation of the servers in a data centre. Manufacturers support ease of maintenance through more modular product designs, color-coding of hot-swappable devices (e.g. HDD, PSU), display information and a multitude of diagnose options.

1.1.3. Enterprise storage

1.1.3.1. Functionality and application

Enterprise storage systems including data centre deployments are providing non-volatile data storage services to direct connected server devices (hosts) and/or to remote computing devices (clients) via network connections. The data storage system supplements the server's internal memory. It controls access and handles storage requests. The data storage services are mainly specified according to capacity and access performance criteria including latency and reliability. According to the Storage Networking Industry Association (SNIA) taxonomy, enterprise and data centre level data storage is largely characterised by the following features and functionalities:

- Access pattern (random or sequential);
- The maximum time to first data (max. TTFD in ms), required to start receiving data from a storage system;
- The requirement for user access;
- Connectivity over network or direct connection to a single or multiple hosts;
- Integrated storage controller (optional or integrated);
- The status (optional or required) of storage protection, non-disruptive serviceability, no single point of failure, and storage organisation;
- Maximum supported disk configuration.

Against these features and functionalities, SNIA makes the distinction of six product group categories with differing operational profiles:

- **Online**: Storage system for very fast random or sequential I/O request. The main distinction criteria is maximum TTFD of <80ms.
- **Near Online**: Storage system for moderate response time with maximum TTFD of >80 ms.
- **Removable Media Library**: System for sequential I/O request with long response time. This is an automated or manual media loader such as tape or optical library.
- **Virtual Media Library**: System for very fast sequential I/O request with maximum TTFD of <80ms. The media are not removable and intended for long-term data storage.
- **Adjunction Product**: Special purpose storage service, dedicated data path from host to storage device, no end-user access, maximum TTFD of <80ms
- **Interconnect element**: Managed interconnect elements within a storage area network such as switch or extenders

Figure 22 provides a visual overview on the distribution of storage product categories and levels. No quantitative data were found regarding the shares of the different categories used in data centres.

Low-end to mid-range Online 2, Online 3, and Online 4 (and Near Online 2 and 3 to a lesser extent) are the product segments with the highest volume in the enterprise sector. These systems feature a storage capacity of a few ten up to a few hundred terabytes. They are designed for random and partially sequential I/O requests. Storage media are typically more economical HDDs or for certain purposes SSDs. The low to mid-range online

[22] The accuracy of the PFA is unknown.

systems are utilised in storage pools with defined redundancy (RAID) and respective control. **These categories are considered as the priority** storage scope of ENTR Lot 9.

Others categories are estimated less relevant for the following reasons:

- Online 5 and 6 are considerably higher performing (specialised) storage systems. They are designed, configured and utilised e.g. for optimum sequential access, speed or very high storage capacity. The high performance requirements (including availability) are demanding capacity, compute, and control overheads so that the capacity per watt or I/O per watt performance might not be comparable to the volume storage systems of Online 2 to 4.
- Online 1 is typically a small, low capacity end-user product.
- Near Online segments have insignificant market shares, according to stakeholders.
- Removable media libraries and virtual media libraries including tape libraries are data back-up systems. One of the industry stakeholders states that tape systems would have a relatively small power draw, 400 Watts maximum for smaller systems and 1500 Watts for large systems to support mainframes, as they only consist of a controller and a system for extracting and running tapes to save or recover data (no permanent reading/writing as for HDD or SDD systems). Given the size of the market, the low power use, and the fact that tape systems provide highly power efficient storage, there does not appear to be justification for further assessment of the tape system market within the next chapters.

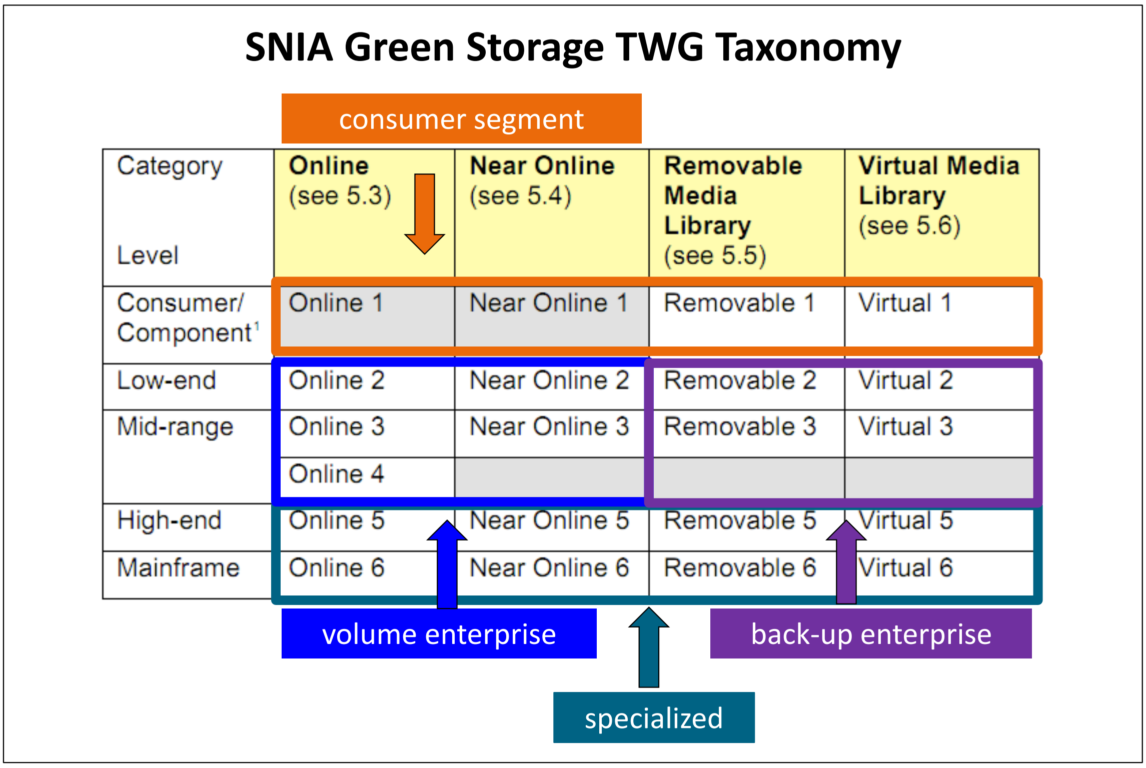

Figure 22: SNIA Storage Taxonomy

1.1.3.2. *Workload development*

Workload capacity: The storage capacity is increasing continuously, as indicated by the growing sales figures in terms of storage capacity and respective number of devices (see Task 2). The demand in storage capacity is primarily driven by (data intensive) video and other media. The Cisco Visual Networking Index (VNI) provides an indication for storage demand based on data traffic assessment and forecasts.[23] Figure 23 shows a breakdown of the expected monthly IP-Traffic in the region Western Europe and Central Eastern Europe (without Russia) according to applications. Even if the IP traffic cannot be representative of the data stored in private datacentres for instance and which are kept on internal systems, these volumes are estimated very

[23] http://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/index.html Retrieved 14 July 2014

small, given the file types and the predominance of video and picture files. The first observation is that consumer-related traffic (end-users) accounts for about three quarters (78%) of the overall traffic, while business-related traffic accounts for the rest. Secondly, video applications are in total absolutely dominant in comparison to web and file applications. In 2013, consumer and business video accounted for 55% of total IP traffic. By 2018, it is expected that video applications will represent 75% of total IP traffic.

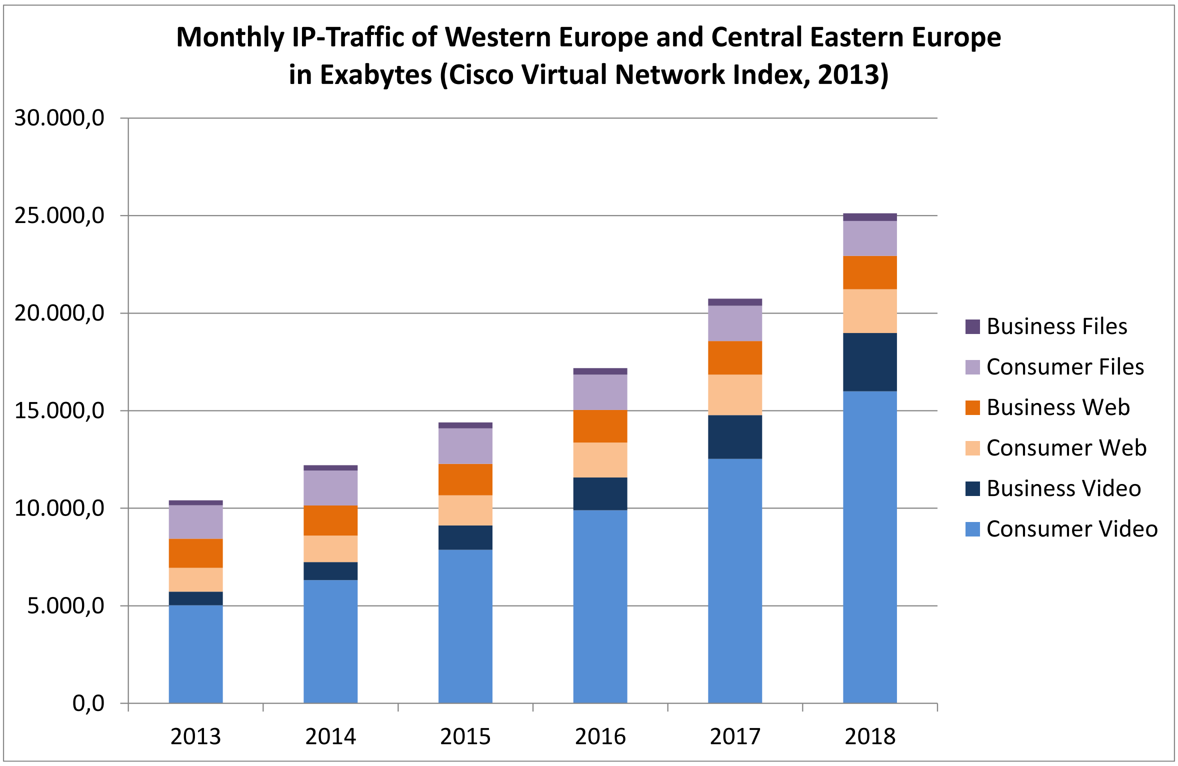

Figure 23: Monthly IP-Traffic of WE and CEE (w/o Russia) Cisco VNI, 2013

In conclusion, although there are no direct statistics available concerning the storage volume and type/application of stored data, it is reasonable to deduce from related data sets (e.g. data traffic assessments and storage media capacity sales assessments) that the demand on storage systems and the availability of stored data is further increasing. Video, TV, file sharing, web, email, instant messaging, social network services, remote surveillance and maintenance are all applications that include storage of data for later use. In fact, the internet of things and continuous data collection is the key for Big Data analysis, a huge driver for business. A lot of data will move into business owned data centres in the cloud. Cloud services including software as a service and storage as a service are currently growing despite the public debate about digital privacy and data protection. According to a recent study by the German BITKOM business association, about 15 million Germans or 27% of the German population is using already cloud storage services. Cloud storage is used for pictures (65% of all users), documents (53%) and music (42%).[24]

Workload properties: Against the background of growing data storage demand, it is necessary to analyse not only the origin, type or application of the workload, but the actual properties and technical characteristics of the storage workload. Enterprise storage devices are supporting various activities or workload including:

- Seeking data;
- Reading data;
- Writing data; and
- Idling (ready to receive workload request).

Sleep mode and off mode are states that are not common in the case of enterprise storage devices. Due to the relatively long active utilisation of enterprise storage devices of up to seven or eight years, administrators periodically check and scrap storage devices. These tests are done by calculating checksums.

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[24] http://www.bitkom.org/de/presse/8477_79748.aspx. Retrieved 14 July 2014

The storage workload is typically distinguished by several properties including:

- I/O access random or sequential;
- Size of I/O request;
- Ratio of seek, read and write; and
- Degree of parallelism.

I/O access and storage system performance characteristics can be monitored and measured. The performance depends on the type of the storage media (e.g. HDD) as well as on the interface (bandwidth). On a device level, such as a hard disk drive (HDD) or solid state device (SSD), the primary performance indicator for random and sequential access is the Input Output Per Second (IOPS) value. It is common practice to distinguish and measure random and sequential I/O operations as average number of read or write I/O operations per second:

- Random I/O operations are typically related to small data transfer sizes of 4 KB. The storage device is accessed in a non-continuous (random) manner.
- Sequential I/O operations are typically related to larger data transfer sizes of 128 KB. The storage device is accessed in a continuous (sequential) manner.

The sequential IOPS value indicates the sustained bandwidth that the storage device can maintain. There is no particular difference between HDDs and SSDs in terms of capacity. With respect to random I/O operations however, the technological differences between HDDs and SSDs need consideration. In the case of HDDs, the random IOPS value aggregates the average rotational latency and read/write seek latency (time).[25] The equation to calculate random IOPS is:

- IOPS = 1000/(Seek Latency + Rotational Latency)

Average ranges for random IOPS values for HDD with common rounds per minute performances (7.200, 10.000, and 15.000 rpm) have been measured for particular interfaces.[26] As matter of fact the random IOPS values for HDD are about 10 to 100 times lower in comparison with SSDs. In the case of SSDs, random IOPS numbers are primarily dependent upon the storage device's internal controller and memory interface speeds.

The performance characteristics for specific workloads need to be placed in relation to the characteristics of the deployed storage technology (e.g. HDD, SSD) when deciding on the configuration of a storage system for a particular job/workload. Anecdotic reports indicate that administrators tend to slightly overprovision their storage systems in order to avoid shortages. There are always “spare disks” ready for use when needed. These storage devices are naturally not fully utilised. Other activities include periodical “scrapping”.

1.1.3.3. Average use pattern

In order to calculate the energy consumption of enterprise storage over its active lifetime, it is necessary to determine or define the following parameters:

- Total years of active utilisation
- Annual days and hours of active utilisation
- Average load level and the associated power consumption over a 24 hours period, or
- Mode specific utilisation and the associated power consumption over a 24 hours period.

According to data presented in Task 2, the average lifetime of data storage systems are between 5 and 7 years. Individual stakeholders indicated that HDD in storage systems are even used up to 8 years. For the purpose of this study, a **6 year average use life is considered**, reflecting current market developments (e.g. introduction of SSDs) and somewhat faster exchanges of hardware.

Enterprise storage systems are categorised according to latency including online, near-online, and off-line. Online systems are building the majority of devices in enterprise environments and are therefore assumed to be running 24/7 or **8760 hours per year**. This means that the storage devices are idling (but even idling, a HDD is spinning) or actively seeking, reading or writing data on the storage media. Storage systems are

[25] http://vmtoday.com/2009/12/storage-basics-part-ii-iops Retrieved 15 July 2014
[26] http://www.symantec.com/connect/articles/getting-hang-iops-v13 Retrieved 15 July 2014

pooling storage media and data centre administrators are typically distributing the storage workload evenly to the overall capacity. They are also checking the system periodically through application of checksums.

There is unfortunately no statistical utilisation data available, neither for the average daily time duration of the individual activities nor the daily time distribution of active (load) and idle. It is reasonable however to assume that there are considerable idle durations when no data are sought, read or written. Moreover, it is also relevant to assume that enterprise storage mirrors the utilisation pattern of enterprise servers.

In conclusion, the following pragmatic assumption is made for the study: enterprise storage devices are **8 hours in idle (no load) and 16 hours in active (at 30% load) per day (alternatively we suggest 5h at 0% and 19h at 25% load).**. This assumption mirrors the utilisation pattern of the enterprise servers, presented under section 1.1.2.3.

1.1.3.4. Electricity consumption in the use phase

The power consumption of storage systems is influenced by a number of factors. It is important to understand that the storage capacity alone is not indicative for the power consumption. All of the following aspects need to be considered:

- Type of storage media including HDD, SSD, tape, etc.
- Number of storage devices and overall storage capacity
- Different system states including under load or idle
- Type of interface including SATA, SAS, etc.
- Controller / Software set-up

SSDs in comparison to HDD are not necessarily consuming less power in active mode. However, SSD are faster seeking, reading and writing data and, through that capability, reducing the higher power consuming periods. Thus, for a given workload, the SSD is more energy efficient than the HDD due to its speed and respectively shorter active periods. HDD idle power is not very much lower (ca. 90%) than maximum power, as the majority of the power use comes from the drive rpm.

Table 9: Average power consumption of storage devices

	3.5 HDD	2.5 HDD	SSD
Average Capacity	0.50 – 6.00 TB	0,25 – 1.00 TB	0.20 – 1.00 TB
Average load power consumption (in watts)	9.8 Watts	5.2 Watts	7.0 Watts
Average idle power consumption (in watts)	No data	No data	3.5 Watts

The power consumption of the individual storage media are presented in Task 4.

The power consumption on the product is exemplarily shown on the FUJITSU Eternus DX80. This is a mid-level example system[27] which has a separated controller enclosure.

Table 10: Selected specifications of a 2.5 inch FUJITSU Eternus DX80

Model	Maximum number of attached drives	Maximum capacity [TB]	Maximum power consumption per device [W] (AC 200-240 V)	Maximum total power consumption [W]	Maximum weight [kg] (35 kg per enclosure)	Dimensions (BxTxH) [inch]
2.5 inch	120	480	CE: 630 DE: 570	2,910 (CE + 4xDE)	175	CE: 19x25.4x3.5 DE: 19x21.3x3.5

[27] http://www.fujitsu.com/downloads/STRSYS/system/dx80s2_datasheet.pdf Retrieved, 22. July 2014

Table 11: Selected specifications of a 3.5 inch FUJITSU Eternus DX80

Model	Maximum number of attached drives	Maximum capacity [TB]	Maximum power consumption per device [W] (AC 200-240 V)	Maximum total power consumption [W]	Maximum weight [kg] (35 kg per enclosure)	Dimensions (BxTxH) [inch]
3.5 inch	120	480	CE: 610 DE: 550	5,570 (CE + 9xDE)	350	CE: 19x26.4x3,5 DE: 19x21.9x3.5

1.1.3.5. Load and power management

The reduction of actual data stored on storage devices is typically achieved through a combination of hardware and / or software measures. They are based on various capacity optimising methods.

The ENERGY STAR® Program Requirements for Data Centre Storage – Eligibility Criteria (Rev. Mar-2014) is listing the following capacity optimising methods which are consistent with the terminology developed by the Storage Networking Industry Association Green Storage Initiative as defined in “SNIA Emerald Power Efficiency Measurement Specification” Version 2.0.2.:

- 1) Thin Provisioning: A technology that allocates the physical capacity of a volume or file system as applications write data, rather than allocating all the physical capacity at the time of provisioning.
- 2) Data Deduplication: The replacement of multiple copies of data – at variable levels of granularity – with references to a shared copy in order to save storage space and/or bandwidth.
- 3) Compression: The process of encoding data to reduce its size. For the purpose of this specification, only lossless compression (i.e. compression using a technique that preserves the entire content of the original data, and from which the original data can be reconstructed exactly) is recognised.
- 4) Delta Snapshots: A type of point-in-time copy that preserves the state of data at an instant in time by storing only those blocks that are different from an already existing full copy of the data.

As for software measures, industry stakeholders state that the use of Capacity Optimisation Methods Software (COMS) on a storage system can result in an increase in power consumption for the individual storage system, but reduce the overall power required to store the data by reducing the number of storage devices/systems required to manage a given quantity of data. An additional software system, software defined storage, enables storage systems to be further virtualized. It manages data on the storage device appropriately to the data type and its frequency of use, and further reduces the number of storage devices to manage a given quantity of data. The effective ability of storage products to manage more data per unit of energy consumed is dependent on the software capabilities that are enabled on the specific storage product and on the overall storage data network within a data centre or group of data centres. Increasingly, optimisation of the right mix of COMS and software defined storage will eclipse the importance of the efficiency of individual storage products.

1.1.3.6. Product failures and maintenance

With respect to enterprise storage systems, data centre operators apply similar strategies to avoid downtime and product failures like the ones for servers. Product quality assurance, redundancy, condition monitoring, failure prediction and failover technologies are all measures that are regularly applied (see section **Error! Reference source not found.**).

A specific issue of HDDs is related to off-times. During the active use phase, storage media devices such as HDDs are constantly spinning with hardly any off-time. As a matter of fact, in the case of HDDs, off-time has been known to create failures basically related to the induced temperature changes. When the HDD is in operation, the servo motor and spindle are moving, thus creating some heat which influences the fine-mechanical components depending on their thermal characteristics. When the HDD is turned off, the system cools down and material starts working. The motor’s and spindle’s swivel (fine-mechanical parts) are mostly affected. They are prone to galling (jamming the swivel) and tend to be the main source of failure.

According to a statement from industry, it is possible to slow down or turned off drives without increasing the risk of hardware failure. However, integration of this capability into products at a system level in a way which insures execution against Service Level Agreements (SLA) will require two to three technology generations for these capabilities to appear in products. It should be also noted that previous products which offered this capability are no longer offered on the market. Storage media are nowadays typically hot-swappable and an exchange of devices is easily possible.

1.1.4. Server and storage connectivity and networks

1.1.4.1. Functionality and application

There are two basic types of switch distribution on the floor or application level: End-of-Row and Top-of-Rack.

End-of-Row (EoR) switching is a conventional networking approach, featuring a single large chassis-based switch support of one or more racks. This type of switch topology requires considerable long cabling. However, it also provides good scalability and flexibility to support a broad range of servers. EoR switching performs best, when two servers exchanging considerable traffic are placed on the same line card. This configuration improves latency due to port-to-port switching. The latency will be increased by a card-to-card or switch-to-switch topology.

From an energy efficiency point of view, there are two considerations in respect to EoR:

- Advantage: Centralised switching with good scalability
- Disadvantage: Considerable cabling effort with inefficiency in dense systems

Figure 24 below illustrates the EoR switching concept and its proper utilisation.

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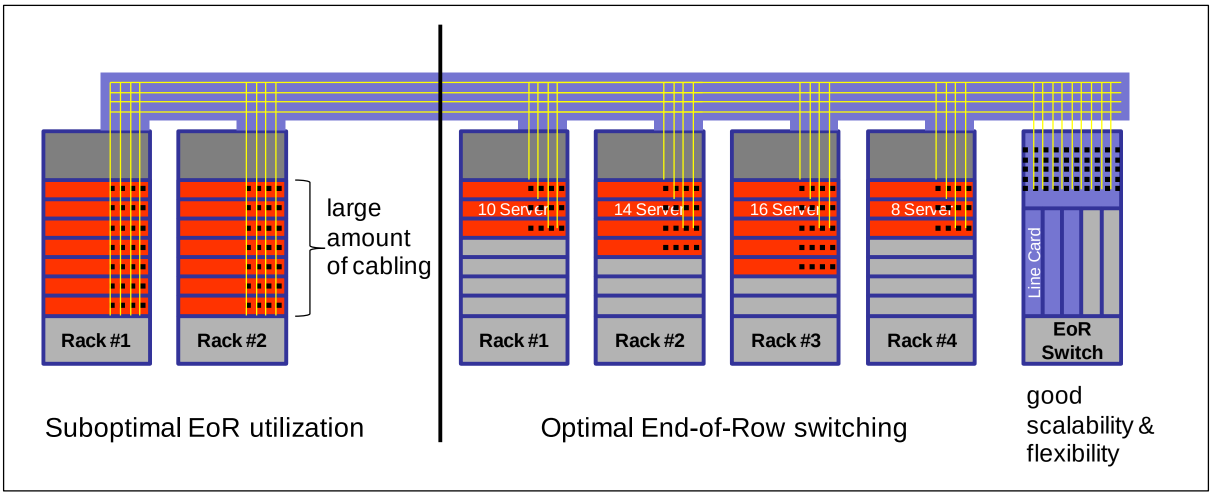


Figure 24: End-of-Row Switching

Top-of-Rack (ToR) switching is a networking approach that has been developed in conjunction with densely packed blade servers, high performance computing (HPC), virtualisation and cloud computing. The ToR concept reduces, with decentralised and resulting one uplink, the cabling efforts on the aggregation layer. This has the advantage of fast port-to-port switching between servers within the rack. With the switch integrated in the rack, this concept ensures short latency and high data transmission. A precondition for high efficiency is a dense server environment with good utilisation of available ports.

With this excellent networking performance, ToR switching not only supports high performance computing but also Data Centre Bridging (DCB) and therefore the migration towards (lossless) Converged Enhanced Ethernet (CEE) or a fully integrated Data Centre. For adequate efficiency in support of 10/40GbE networking, ToR-switches feature slots for transceiver modules with a port density (unit) of 48 ports with SFP+ modules.

From an energy efficiency point of view, there are two considerations with respect to ToR:

- Advantage: Decentralised switching for dense server environments (I/O consolidation) that reduces cabling effort. The shorter cabling distance between server and switch improves transmission speed and reduces energy consumption for this transmission.
- Disadvantage: If ToR is utilised in less dense computing (few servers in a rack), the system is over-dimensioned. Energy efficiency is low due to suboptimal utilisation of available ports.

In conclusion, ToR has advantages in terms of used resources when applied in properly dimensioned systems.

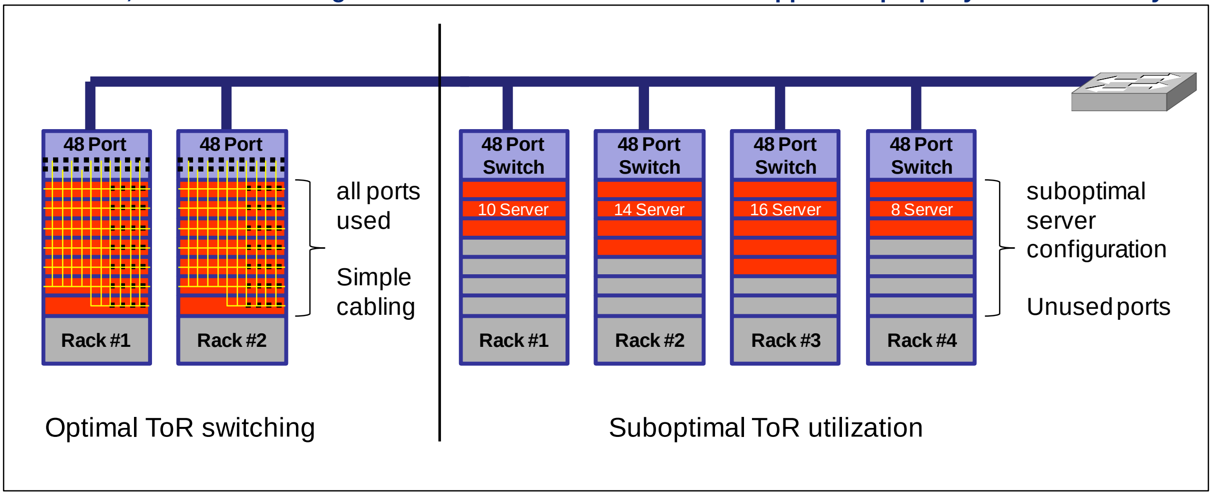


Figure 25 below illustrates the ToR switching concept and its proper utilisation.

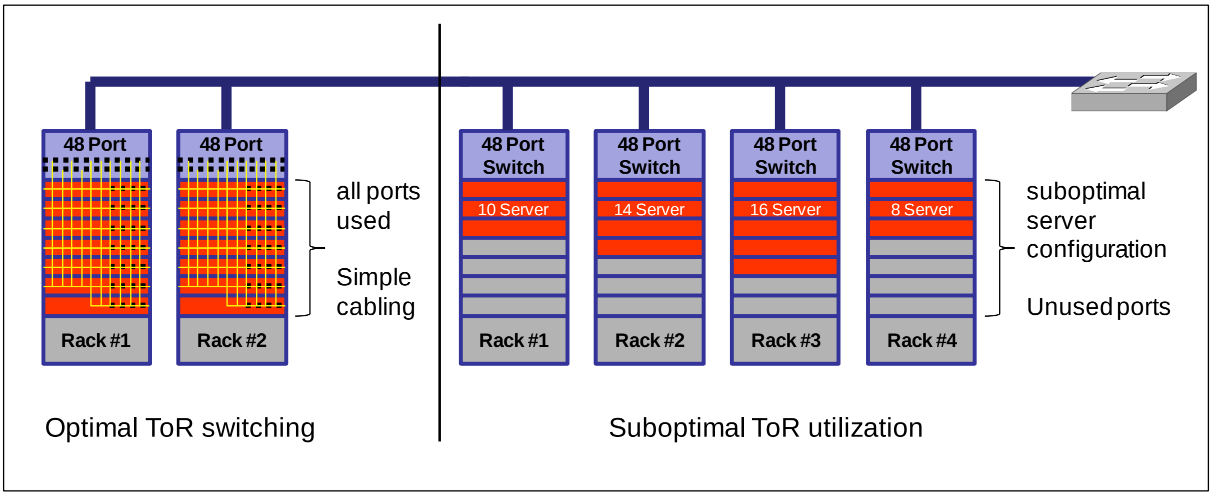


Figure 25: Top-of-Rack switching

1.1.4.2. Workload development

The current and anticipated development of the workloads related to data centre network equipment is indicated in the CISCO Global Cloud Index that has been presented already in chapter 1.1.2.2. As a general assumption, the network workload will double about every four years if not in shorter intervals.

1.1.4.3. Average use pattern

The complexity of the actual network product spectrum makes it very difficult to determine an average use pattern. Because network equipment such as LAN or FC switches are operated in conjunction with the server and storage equipment, it is justified to deduct a similar daily use pattern of about 8h in idle mode and 16h in active mode.

A more complex aspect is the actual load level and port utilisation. Both aspects are influencing the resulting power consumption. As indicated in section 1.1.4.1, the implemented network architecture and topology determines the utilisation to some extent. Furthermore, the traffic load depends on server and storage applications and other factors for instance the location of the equipment within the network. Network equipment (performance) is usually selected according to an assumed “peak-to-average” data traffic ratio (and the specific throughput value). All these aspects will influence the actual utilisation rate.

1.1.4.4. Electricity consumption in the use phase

The power consumption of network equipment varies according to its functionality, network standard, supported bandwidth, signal modulation, port configuration, controller architecture and other factors. A more detailed description of server and storage connectivity and respective network equipment is provided in Task 4. As a very general orientation, the power per port is in a typical range of 0.5 to 6 watts. The power consumption typically increases with increasing bandwidth but this is only a general statement. The network technology actually determines considerably the power consumption.

Note: Due to the functional and technological complexity of connectivity aspects and related network equipment, it is highly recommended to investigate this product spectrum in a separate preparatory study.

1.1.4.5. Power management and efficient utilisation

The magnitude of the network equipment energy consumption is related to active use and periods of idling. The difference in power consumption between active (100% load) and idle (with established link) equipment is typically about a factor 1.1 (less than 10% difference). If the link is deactivated, the power consumption drops by a factor 2 (50% of active).

With the introduction of the standards IEEE 802.3az "Energy Efficient Ethernet" and Standard ECMA-393 "proxZzzyTM for sleeping hosts" specific approaches for low power management are underway.

Virtualisation is a well-established technology to consolidate physical server with multiple virtual machines. Network virtualisation follows the same principle and describes various hardware and software approaches to manage network resources as logical units independent of their physical topology. This results in reduced network traffic, simplified security and improved network control. Key elements for high efficient networks are network level awareness and visibility of the virtual machine lifecycle. The ability to configure network and port level capabilities at the individual VM level as well as dynamically tracking VMs as they move across the data centre are important for an efficient management of virtualised environments. Energy efficiency is mainly archived by consolidation of routers, physical adapters for I/O ports, and additional hardware for specific network services.

Extending system virtualisation to the network includes:

- Virtual router (software with routing functionality, multiple systems on 1 real machine)
- Virtual links (logical interconnection of virtual router)
- Virtual networks (Virtual routers connected by virtual links)

The increase in server virtualisation will result in additional complexity and overhead for the network. Obsolete networking switches are not aware of Virtual Machines (VM) and this exposes the risk of service outage and security breaches due to incorrect network configuration. Networking is a key area that also needs to be virtualised to achieve the same level of agility, bandwidth and performance.

Network service virtualisation is a strategy to simplify the network operations and consolidate multiple appliances. Reduced power consumption is achieved by consolidating multiple services into a single physical device without requiring deployment of dedicated hardware for each instance. Eliminating the need for additional physical devices effectively removes the need for additional power supplies, cooling, and rack space which would otherwise have been required.

In summary, benefits for network service virtualisation are:

- Management interfaces are more flexible;
- Reduced acquisition cost by use of software;
- Increased application performance by simplified service extension and allocation;
- Potential decreased power consumption by equipment consolidation.

A successful implementation of network virtualisation depends on aspects like capital expenditure, the definition of precise objectives or the compatibility with existing hardware. Therefore, virtualisation projects require a well-balanced cost-benefit analysis, a comprehensive project management and a consequent consideration of possible security risks

1.1.4.6. Product failures and maintenance

The principles described under section **Error! Reference source not found.** also apply.

1.2. Technical systems approach

This section discusses the influence of the extended technical environment on the utilisation and resulting performance of the product. The so-called technical system approach covers the rack and room level cabling, power distribution, ambient climate conditions including in particular the setting of the air inlet temperature by cooling/air-conditioning equipment.

A "system" in the general sense can be defined as a set of independent elements (components) which are deliberately structured and interact to form an integrated whole or functionality. A system is usually defined by its structure, interrelationship of elements, and its boundaries and respective surroundings.

With respect to enterprise server and storage equipment, the term "system" in practice is applied to various technical levels including:

- Component configuration on product level: including e.g. the type of processor and chipset or the storage media and capacity;
- Modularity: a solution for optimising server and storage scalability on the base of prefabricated network, power and cooling capacity;
- Connectivity: defining not only bandwidth and latency but the location and efficiency of the interface control;
- Software on product level: including type of operation system, respective performance of application software;
- Virtualisation: including the option of creating virtual entities, shifting loads and improve utilisation of existing resources;
- Climate on rack and room level: including thermal conditioning in order to ensure reliable operation;
- Power supply: including power distribution and power conversion AC/DC as well as DC/DC.

Keeping in mind that the ENTR Lot 9 preparatory study has the objective to investigate and assess the environmental impacts and improvement potential on both the product level and the extended system level, the first task is to clearly differentiate between product and system.

Enterprise servers, data storage equipment and networking equipment are often operated in larger clusters in order to fulfil a specific service. The equipment is therefore installed in separated server rooms or data centres. This operational environment is considered as the technical system. It consists of the following auxiliary equipment and support systems (infrastructure):

- Interface and controller equipment (remote access / KVM[28] switches, asset and task management systems, etc.);
- Mounting systems (rack-cabinets, hot-aisle cold-aisle screens or containments, raised floors, cable ducts, etc.);
- Power system (building switchgear and medium voltage transformer, power-line bus-bars, uninterruptable power supply (UPS) including generators and battery packs, floor-level power distribution, power monitoring and control equipment, etc.);
- Cooling and air conditioning system (this equipment depends on the local cooling concept and could include chillers, compressors, pumps, pipes, water tanks, evaporators, filter banks, blower units, etc.);
- Fire control system (fire detectors, fire-extinguishing medium and distribution system);
- Security system (video monitoring system, intruder alarms system, automatic door locks, etc.);
- Lighting system.

This list indicates the complexity of the technical environment – the data centre – that the operator or in other words the customer utilising the ErP needs to design, setup, and manage. The data centre operator constantly improves this technical environment according to the functionality, quantity and (most importantly) the quality of services that the data centre provides. The main objective of the data centre operator is a continuous, reliable, safe, secure, and efficient operation of servers and data storage equipment.

But continuous, reliable, safe, secure, and efficient operation translates into costs. The costs for electricity are already important in that respect. They are driving the market, leading to improved equipment, power and cooling infrastructure concepts that consider local advantages (e.g. access to cool air, water, ice), and holistically designed data centres. Optimising the cooling system seems to be the prime objective.

[28] KVM stands for Keyboard, Video, Mouse

The notion that energy efficiency of data centres is already a top priority of the industry is supported by the abundant projects, whitepapers, product solutions, and software support tools advertised on the websites of major players, local enterprises, national forums and expert blogs. Searching the websites of following companies and initiatives with the keywords “data centre”, “energy efficiency”, “green IT”, etc. provides a tremendous amount of information and good impression of the status:

- IT-equipment vendors (IBM, Dell, HP, Fujitsu, Cisco, Hitachi, NEC, Sun, Huawei, EMC Corporation, NetApp, etc.);
- Chip and software manufacturers (Intel, AMD, ARM, Microsoft, VMWare, etc.);
- Data centre auxiliary equipment vendors (Rittal, APC Schneider, Emerson Knürr, Raritan, PDI, etc.);
- Cloud data centre and servers providers (Google, Facebook, Amazon, Twitter, ebay, etc.);
- Initiatives (Data Centre Dynamics, Open Compute Project, The Green Grid, etc.);

The Green Gird (TGG) is currently the most prominent and largest industry initiative in that respect promoting overall energy and resource efficiency of data centres.[29] In particular, TGG is leading the development of certain metrics such as the PUE (Power Usage Effectiveness) that tries to assess the energy efficiency of a facility. Recently, TGG has been placing the focus on a more holistic ascertainment of energy and resource efficiency of data centres in conjunction with performance requirements and other operational factors.

1.2.1. Power Usage Effectiveness (PUE) concept

The PUE is a well-known key performance indicator for data centre energy efficiency, introduced by The Green Grid:

- PUE = Total Facility Power / IT Equipment Power

Total facility power and IT equipment power described in the Figure 26 below.

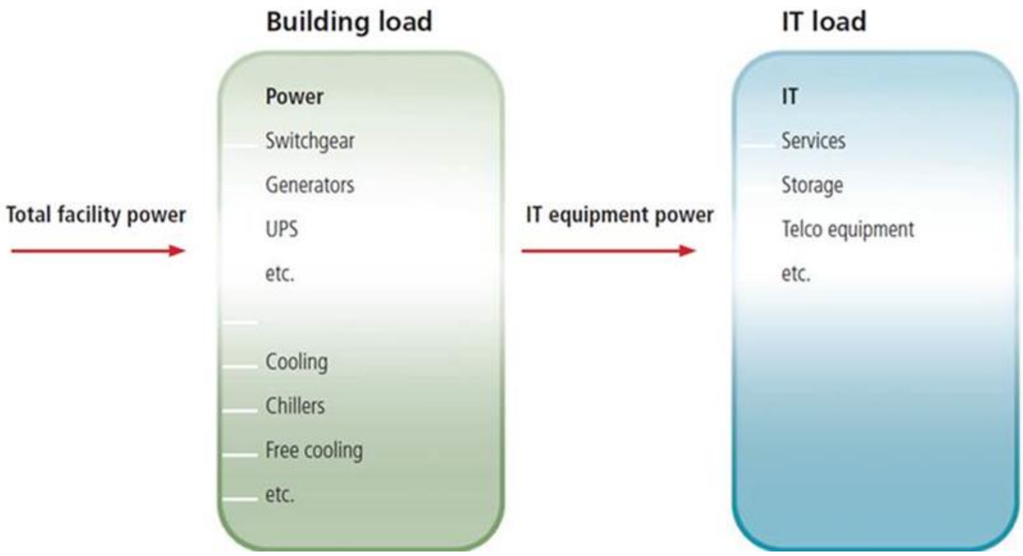


Figure 26: Typical equipment used in a datacentre, for the calculation of the PUE

In the context of this study, a PUE needs to be introduced to represent the “indirect energy” consumption in the environmental assessment, i.e. the energy consumption not due to the servers and storage products themselves but due to supporting equipment (cooling, power supply, lighting, etc.) required for the proper functioning of the IT equipment. Therefore, the PUE is not introduced as an energy efficiency indicator and its relevance or feasibility is not expected to be discussed in this study, but **it is introduced only as an energy overhead parameter**, i.e. the power, cooling and air conditioning overhead of the IT equipment.

An average PUE of a data centre today is 1.6 to 2.0, but this is also highly dependent upon the size and type of the datacentre considered. As a general statement, the bigger the datacentre, the lower the PUE, since

[29] http://www.thegreengrid.org/

energy costs represent more important operational costs. There are a lot of best practice examples that feature much better PUE of 1.1 or 1.2.

In conjunction with determining the PUE, data centre operators identified the energy magnitude of individual types of equipment. Whereas it became clear that the cooling equipment contributed significantly to the overall energy consumption, it also became clear that servers (mainly the processer) contribute the most to the energy consumption of the IT equipment. Storage and network equipment contribute typically only in a range of 4 to 10% each. Stakeholders expect that the continuous demand on storage capacity will increase the energy share of the storage equipment, while at the same time the share of the network equipment might shrink due to the implementation and growth of modular server system with integrated network fabrics such as blade server systems and multi-node servers.

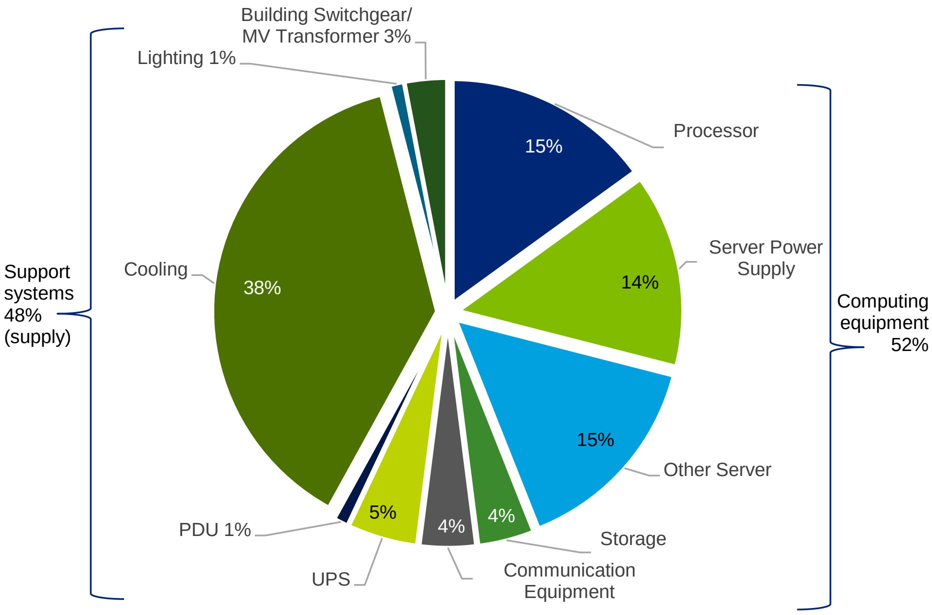


Figure 27: Average distribution of power consumption in a data centre in 2010 (Source: Emerson Power)[30]

The following subsections present sub-systems contributing to the non-IT load of the PUE, in order to discuss the relationships between these and the IT equipment (possible synergies, trade-offs, etc.).

1.2.2. Rack cabinet and enclosures

The 19-inch computer rack cabinet is the most common way to mount an enterprise server and data storage equipment. The rack cabinet provides mounting options for multiple modules of different height. The basic rack unit (RU or U) is 1.75 inches in height. The rack cabinet is not only a mounting device but also an essential part of the overall cooling concept (e.g. separation of hot and cold aisle). The rack cabinet might be open or closed (featuring doors). It might also contain active cooling and passive airflow technology. The cabinet doors, top or bottom frame or side panel (in-row) are places for positioning fans, blowers or liquid cooling technology.

The placement and operational load of individual servers or data storage equipment within the rack cabinet has an influence on the airflow, local temperatures, and respective cooling effectiveness. Unbundled cabling, cover plates and the like, might obstruct the airflow leading to hot spots, air leakages and eventual short-circuiting the airflow.

A Dell study from 2002 (Dell™ PowerEdge™1650: Rack Impacts on Cooling for High Density Servers) investigated the impacts of higher temperatures (temperature variations) in a fully equipped 42U rack cabinet (29 x 1U servers). The study concludes that at such a density, considerable temperature differences (up to 6°C) occur at the server inlet depending on the actual position in the cabinet. The study also discusses the impact of airflow obstruction (blockages) and poor cooling flow rates (e.g. outside of the cabinet).

Such involuntarily raised in-rack temperature triggers response from the integrated cooling system of the server or data storage equipment. Products with variable speed fans (e.g. pulse-width modulation - PWM fans) will react instantly and increase speed. This will increase the specific power consumption of an individual

[30] http://www.emersonnetworkpower.com/documentation/en-us/latest-thinking/edc/documents/white paper/energylogicreducingdatacentreenergyconsumption.pdf, retrieved September 10th 2014

server or data storage equipment. Higher fan speeds (>50 load) reduce the energy-performance efficiency and also increase the noise level by a few decibels. Industry stakeholders pointed out in that respect that noise level is also a benchmark criteria for data centre operators.

1.2.3. Ambient climate and temperature setting

As already indicated in the previous section, the ambient climate conditions including inlet and output temperature, humidity, and dust particles have an influence on the energy performance of servers and data storage equipment. Conventional server and storage equipment are typically operated in air-conditioned rooms at an average range of 20°C to 27°C. Higher or lower temperatures and respective humidity levels have had negative effects on the reliability of electronic and electromechanical components. However, air-conditioning is energy and resource intensive as well. Many examples in the past years have demonstrated considerable energy savings on a system level (data centre) when the temperatures envelop was pushed somewhat further to higher temperatures (e.g. free cooling).

Higher inlet temperatures will likely increase the energy consumption of the IT equipment on the one hand and reduce the energy consumption of the data centre cooling system (infrastructure) on the other hand. Depending on the scale, cooling concept, server density and actual load, the data centre operator can balance the energy consumption between the “internal” cooling on the server-level and the “external” cooling on the floor-level of the data centre. The energy trade-off on the system level (data centre) can only be determined by continuous measurements. Such monitoring needs to consider the IT performance, the power consumption on all equipment levels, temperature and airflow conditions as well as noise level. Data centre operators are also interested in a large “delta temperature” between the inlet (cold aisle) and the outlet (warm aisle). A considerably higher outlet temperature has the advantage of more efficient use of the heat exchanger or even direct exhaust heat utilisation.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) is a globally acknowledged institution for developing standards and guidelines for the design and maintenance of indoor climate environments.[31] In 2004, ASHRAE issued the first edition of “Thermal Guidelines for Data Processing Environments” with recommendations for a temperature and humidity range in which IT equipment can be safely operated. In 2008, a revision of this guideline was extending the temperature envelope (18 degrees to 27 degrees Celsius) in order to provide greater flexibility in facility operations, particularly with the goal of reduced energy consumption in data centres.[32] ASHRAE also published results showing that the fan speed drastically increases with inlet temperatures rising above 27°C. ASHRAE also defines even broader allowable temperature and moisture limits for different equipment classes although these are not recommendations.

There is a wide range of ventilation and cooling technologies available for datacentres and servers rooms. Some of these products are already considered under the Ecodesign Directive, e.g. the following Lots:

- Ventilation fans, circulators in buildings: DG ENER Lot 11
- Local room heating products, DG ENER Lot 20
- Central heating products (other than CHP), DG ENER Lot 21
- Uninterruptible power supplies, DG ENER Lot 27
- Tertiary Air Conditioning, DG ENTR Lot 6.

Despite the energy performance, it is in that respect necessary to consider reliability and possible product failure as well. It seems very important to understand that product failure has not only a very negative economic impact but also a considerable environmental impact. Low reliability not only increases the consumption of hardware to replace the failed product, but also leads to over-provisioning and unnecessary redundancy concepts, thus increasing the overall carbon footprint of the operation.

Product damage and failure could result from following factors:

- Unsuitable temperatures for the hardware (e.g. inlet temperatures >35°C and resulting of temperatures fluctuation [ΔT] on a higher level);

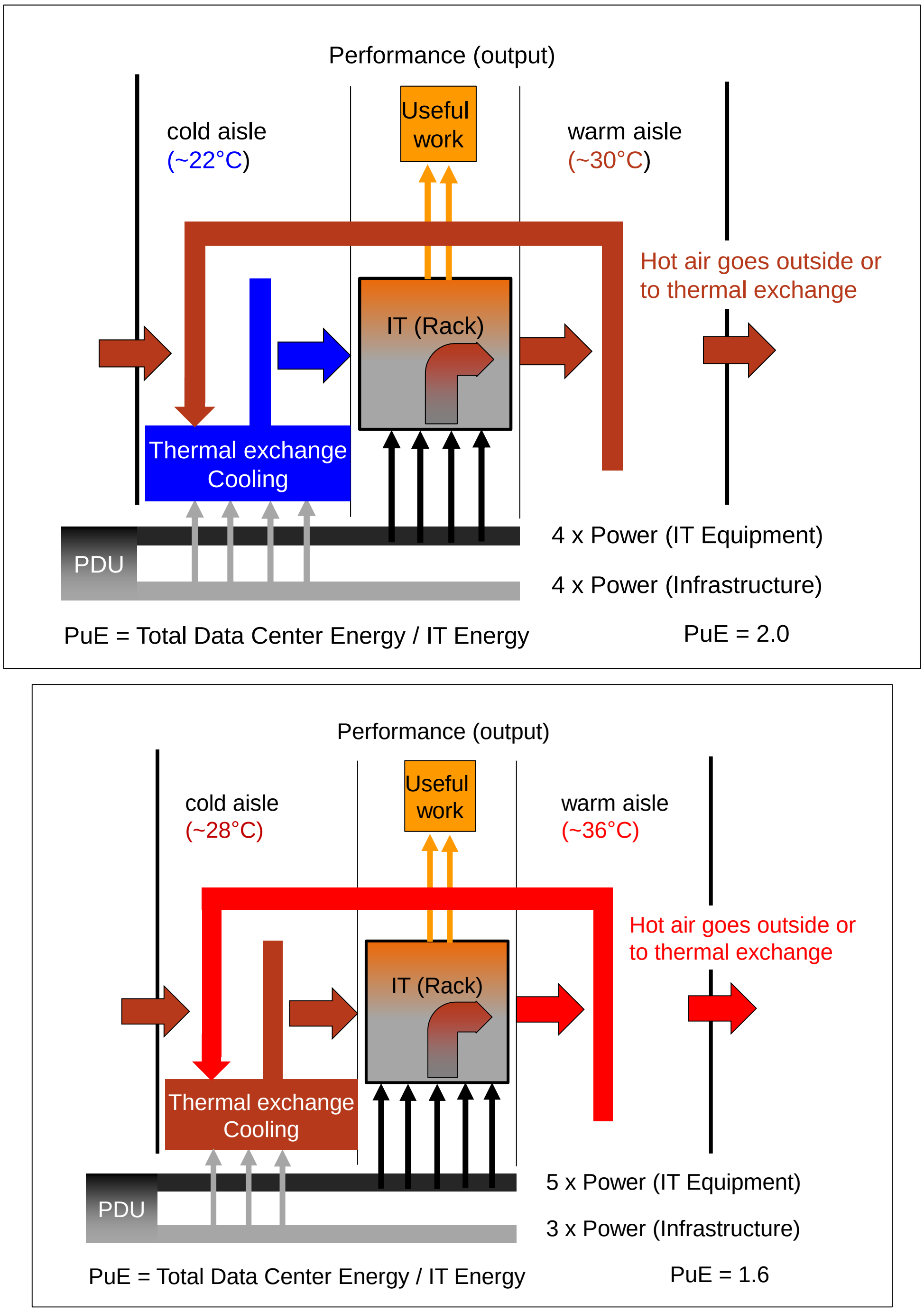
[31] https://ashrae.org/standards-research--technology/standards--guidelines
[32] http://www.eni.com/green-data-centre/it_IT/static/pdf/ASHRAE_1.pdf

- Humidity in conjunction with unsuitable temperature (e.g. leading to condensation on the one end and electrostatic charging on the other);
- Dust (e.g. can build obstructions and resulting in hot spots).

In conclusion, **the environmental benefit of extended system (e.g. overall reduction of energy consumption on the data centre level) could result from an increased material and energy consumption of the server and storage equipment (product level)**. The individual products certified for higher temperature operation might have to use more or more resource-intensive materials for the thermal management. Vice versa, improvements on the product level could lower the efficiency of the extended system, as these trade-offs may be highly non-linear.

The interdependencies are illustrated in the Figure 28 below. The bottom figure illustrates a case with no energy savings compared to the top case, but with an improved PUE. The operator will have an improvement in total energy consumption and PUE only if infrastructure energy consumption is substantially decreased or IT energy consumption only marginally increased.

Figure 28: Principle schemes showing the interaction between IT equipment and cooling infrastructure



1.2.4. Power system and power distribution unit

The electricity consumption of a server or data storage equipment comes with an overhead. The electric power system of the facility that is feeding the IT equipment is typically using alternating current (AC). As matter of fact, there are multiple power conversions within the data centre. These multiple conversion steps are creating power losses and thus wasting energy. In order to reduce these conversion losses there have been numerous projects investigating direct current (DC) utilisation on rack and data centre level. The results of these projects are controversial and a detailed discussion of the pros and cons of DC power is not considered at this point. However, it seems important to recognise that neither AC power nor DC power has an absolute advantage and given preference. Regardless of what type of power feeding system is used, it should be in total as efficient as possible.

The power distribution unit (PDU) feeds electric power through multiple outputs to the individual server or storage devices. The power conversion efficiency of this device is important on the system level. PDUs come in different configurations and with a variety of extra functionality. Large PDUs are stand-alone and may contain technologies to improve power quality. Smaller products (power strips) are typically fitted directly into the rack-cabinet. Modern PDUs provide load balancing capability, thermal sensors, remote monitoring functionality via SNMP, and power consumption measurement features. Such intelligent PDUs are very useful for monitoring and optimising operations.

2. System aspects use phase, for ErP with indirect energy consumption effect

This part of the MEErP is not relevant for ENTR Lot 9. All indirect effects are investigated through the technical systems approach (see section 1.2).

3. End-of-life behaviour

3.1. Product use & stock life

The stock life, being defined as the time between purchase and disposal is estimated as being the same as the economic lifetime. These figures are presented in Task 2 and reminded in Table 12 below. Whereas it is common that consumer goods (e.g. old mobile phones, TVs) are stored for a certain amount of time (sometime years) by their owners because they are considered not fully out of order for instance, this is not likely to happen for enterprise IT products like servers, as these are bulky and still represent a financial value with take-back systems implemented or products on lease.

Therefore, no additional time lag between the operational end-of-life, and the time of disposal by the customer (and entering in the EOL management chain) is considered.

Table 12: Average lifetime, by type of equipment, according to DIGITALEUROPE

Equipment type	Average economic lifetime (in years)	Average technical lifetime (in years)
Tower, rack, multi-node or blade servers	3 for lease 3 to 5 for primary users up 5 to 7 for secondary user	7 - 10
Mainframe servers	7 - 15	20
Data storage devices (hard disk drives, solid-state drives, hybrid drives) and systems	5 - 7	7 - 10
Server and storage related network equipment (switches and routers)	5 - 7	15 - 20

3.2. Repair- and maintenance practice

Given the modularity of enterprise servers, storage and associated network equipment, maintenance and repair practices represent an important aspect of the use phase of these products.

Maintenance can be included in the contract between the vendor and the consumer, e.g. with a technician visiting the site at a certain frequency. Most manufacturers include a three year repair warranty in their purchase prices for servers, even though it can sometimes be only a one year warranty, in particular for low-end models. Common maintenance practices for servers, storage and associated network equipment include for instance disk cleanup and scan (for early detection of potential hard drive crash), cleaning tape drives, monitoring fans and system temperature (especially for CPUs and drives), or upgrading drivers and firmware.

The frequency of repair and maintenance activities is very dependent upon the components/sub-systems considered, the utilisation, and the operating conditions, i.e. temperature and humidity (especially their variations). Hard disk drives, power supplies and memory are the components with the higher failure and replacement rates. HDD are easily replaced and hot-swappable, with tiering practices enabling to avoid any impact on the QoS after a failure. In other words, failures are part of the business-as-usual functioning of the system.

SSD have a lower failure rate than HDD: the mean time between failure rates of SSDs is around 2 million hours, vs.1.5 million hours for HDDs[33]. These figures are in line with the drive failure rates presented in the NetApp Guide on Storage Subsystem Resiliency[34]. According to this document SSD, SATA, SAS, and FC drives have the following mean times between failures (MTBF):

- SSD (SLC) drives are 2.0 million hours
- SAS & FC drives are 1.6 million hours

[33] Storage Review: SSD vs HDD. http://www.storagereview.com/ssd_vs_hdd (last accessed: 13/06/2014)

[34] http://www.netapp.com/us/system/pdf-reader.aspx?m=tr-3437.pdf&cc=us

- SATA drives are 1.2 million hours

The common warranty for drives is five years (43.800 hours), however the MTBF cannot compared to the usable life of the drive but rather refers to the error rate within the useful drive life. Expressed in failures per year, simple calculations suggest the following probabilities:

SSD	0.44% failures per year
SAS & FC	0.55% failures per year
SATA	0.73% failures per year

The following example shows how many failures would be expected to occur over the operating life of these configurations:

- 30 SAS drives*0.55% = 0.165 failures/year * 6 years = 0.99 failures within 6 years
- 30 SATA drives*0.73% = 0.219 failures/year * 6 years = 1.3 failures within 6 years
- 30 SSD * 0.44% = 0.132 failures/year * 6 years = 0.792 failures within 6 years

As illustrated below, the failure rates are highly dependent upon the chosen configurations and the age of the devices. The displayed values are only to be considered, as illustrative as the full context of the study sources is not described here.

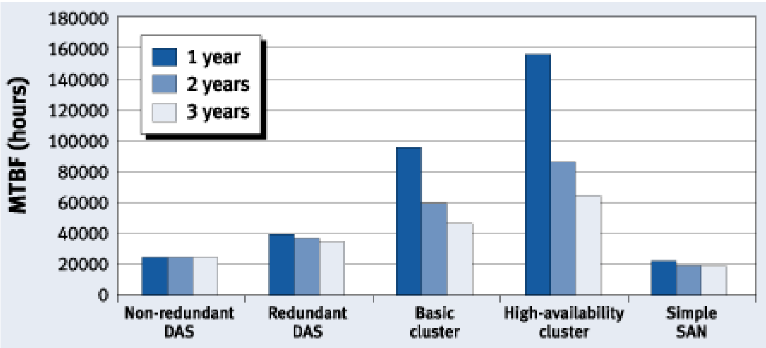


Figure 29: Comparison of MTBF over three years, for different configurations[35]

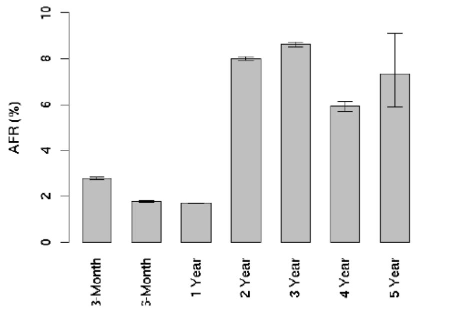


Figure 30: Annualised failure rates broken down by age groups[36]

According to stakeholders, a common practice is that spare parts and services are available around 5 years after end of production[37].

In a 2007 study Schroeder and Gibson[38] have analyzed disk replacement data from a number of large production systems, including more than 100,000 drives (SCSI, FC and SATA interfaces) from at least four different vendors. Their main conclusions are quoted in the following box:

[35] http://www.dell.com/content/topics/global.aspx/power/en/ps3q02_shetty?c=us

[36] Source: Eduardo Pinheiro, Wolf-Dietrich Weber and Luiz Andr´eAndre Barroso (2007), Google Inc.. “Failure Trends in a Large Disk Drive Population”

[37] See e.g. the eco-declaration of HP’s ProLiant DL380e Gen8: http://www.hp.com/hpinfo/globalcitizenship/environment/productdata/Countries/_MultiCountry/iteco_server_2012628232257.pdf

[38] https://www.usenix.org/legacy/event/fast07/tech/schroeder/schroeder_html/index.html

- *Large-scale installation field usage appears to differ widely from nominal datasheet MTTF conditions. The field replacement rates of systems were significantly larger than we expected based on datasheet MTTFs.*
- *For drives less than five years old, field replacement rates were larger than what the datasheet MTTF suggested by a factor of 2-10. For five to eight year old drives, field replacement rates were a factor of 30 higher than what the datasheet MTTF suggested.*
- *Changes in disk replacement rates during the first five years of the lifecycle were more dramatic than often assumed. While replacement rates are often expected to be in steady state in year 2-5 of operation (bottom of the ``bathtub curve''), we observed a continuous increase in replacement rates, starting as early as in the second year of operation.*
- *In our data sets, the replacement rates of SATA disks are not worse than the replacement rates of SCSI or FC disks. This may indicate that disk-independent factors, such as operating conditions, usage and environmental factors, affect replacement rates more than component specific factors. However, the only evidence we have of a bad batch of disks was found in a collection of SATA disks experiencing high media error rates. We have too little data on bad batches to estimate the relative frequency of bad batches by type of disk, although there is plenty of anecdotal evidence that bad batches are not unique to SATA disks.*
- *The common concern that MTTFs underrepresent infant mortality has led to the proposal of new standards that incorporate infant mortality. Our findings suggest that the underrepresentation of the early onset of wear-out is a much more serious factor than underrepresentation of infant mortality and recommend to include this in new standards.*
- *While many have suspected that the commonly made assumption of exponentially distributed time between failures/replacements is not realistic, previous studies have not found enough evidence to prove this assumption wrong with significant statistical confidence. Based on our data analysis, we are able to reject the hypothesis of exponentially distributed time between disk replacements with high confidence. We suggest that researchers and designers use field replacement data, when possible, or two parameter distributions, such as the Weibull distribution.*
- *We identify as the key features that distinguish the empirical distribution of time between disk replacements from the exponential distribution, higher levels of variability and decreasing hazard rates. We find that the empirical distributions are fit well by a Weibull distribution with a shape parameter between 0.7 and 0.8.*
- *We also present strong evidence for the existence of correlations between disk replacement interarrivals. In particular, the empirical data exhibits significant levels of autocorrelation and long-range dependence.*

3.3.Collection rates, by fraction

Given that Lot 9 products are in the scope of the WEEE Directive, they are subjected to required collection and recycling targets, as well as the implemented "extended producer responsibility". Under this principle, producers are expected to take responsibility for the environmental impact of their products, especially when they become waste (see Task 1). This ensures in particular that appropriate dismantling and depollution (i.e. removal and treatment of hazardous substances) is carried out before recycling or disposal, while individual manufacturers/vendors are still free to go beyond these requirements (see section 3.5 for best practices).

Many of the major hardware manufacturers have end-of-life policies implemented, aiming at product reuse, refurbishment and recycling. Refurbishment refers to repairing, replacing parts or re-assembling a product while maintaining its original identity, functionality and specifications. The product can then be sold again, usually with a reduced price.

Given the modularity of the products, a substantial number of components and parts are still functional when the product is removed from the customer’s location, for economic or operational reasons. Some vendors programs thus target to harvest these components and material commodities that can be re-used for refurbishment activities, and integrated into new products. This also explains why product leasing is a common contract option.

A review of practices implemented in 2012 by some manufacturers for which data was publicly available is presented in Table 9 with an overview of treatment methods with their respective shares. Please note that these statistics are not communicated by type of products (servers, storage, etc.), but only for all equipment sold by each manufacturer worldwide. Therefore, absolute amounts cannot be compared, given the different products portfolios (for instance, HP includes cartridges).

Furthermore, the sources do not specify the definitions used, when referring to “recycling”, “reuse”, etc. and this can be a reason for important differences in the communicated figures (e.g. recycling can refer to materials sent to a recycling plant but where many material losses still occur, or to materials actually 100% fit for recycling at the outputs of the recycling plant). An important share of the materials going to the recycling process are still expected to be lost (i.e. not recovered) during the process and ultimately sent to landfill or incineration, because products cannot be fully dismantled and materials separated.

Also, the relationship between IT equipment sold and EOL quantity processed should be made with caution since this is influenced by the recent sales trends and product light weighting trend over the past few years.

Table 13: Overview of treatment methods implemented by manufacturers, for returned/collected equipment

<table>
<tr><th>Treatment method</th><th>IBM – 2012[39]</th><th>Cisco – 2012[40]</th><th>HP – 2012[41]</th></tr>
<tr><td>IT equipment sold in 2012 (in tonnes)</td><td>54 300</td><td>-</td><td>1 003 250*</td></tr>
<tr><td>Total mass/Total annual quantity processed (in tonnes)</td><td>36 100</td><td>13 324</td><td>140 455</td></tr>
<tr><td>Resale (share of total processed)</td><td>35.9%</td><td rowspan="2">25% (also includes refurbishment)</td><td rowspan="2">19%</td></tr>
<tr><td>Reuse by vendor (share of total processed)</td><td>8.2%</td></tr>
<tr><td>Recycling (share of total processed)</td><td>53.1%</td><td>n/a</td><td>81%**</td></tr>
<tr><td>Incineration for energy recovery (share of total processed)</td><td>2.5%</td><td>n/a</td><td>n/a</td></tr>
<tr><td>Landfill/final disposal (share of total processed)</td><td>0.3%</td><td>0.43%</td><td>n/a</td></tr>
<tr><td colspan="4">*Value estimated from the following statement: “We achieved a total reuse and recycling rate in 2012 of approximately 14% of relevant HP hardware sales worldwide”. **This amount seems to refer to the quantities sent to recycling, which are expected to result in recycled materials, but also some incineration for energy recovery and disposal.</td></tr>
</table>

In 2012, each manufacturer recycled more than 50% of the returned products, the range lying between 53% for IBM and 81% for HP. As stated above, these figures should be considered with caution regarding the definitions, as they may not refer to the same treatments. The second most deployed treatment methods concern parts and components, which have not yet reached their technical end-of-life and can thus be resold or reused. Finally, landfill and incineration with energy recovery are the least used treatment methods. Landfilled material consists of non-electronic and non-recyclable materials such as wet cardboard, broken pallets or shrink wrap.[42]

Figure 31 below shows that the quantities of products returned and processed over time (2009-2012) are relatively stable, or increasing.

[39] IBM: IBM and the Environment - 2012 Annual Report (2012)
[40] Cisco: 2013 Corporate Social Responsibility Report (2013)
[41] HP: HP 2012 Global Citizenship Report (2013)
[42] Cisco: 2009 Corporate Social Responsibility Report (2009)

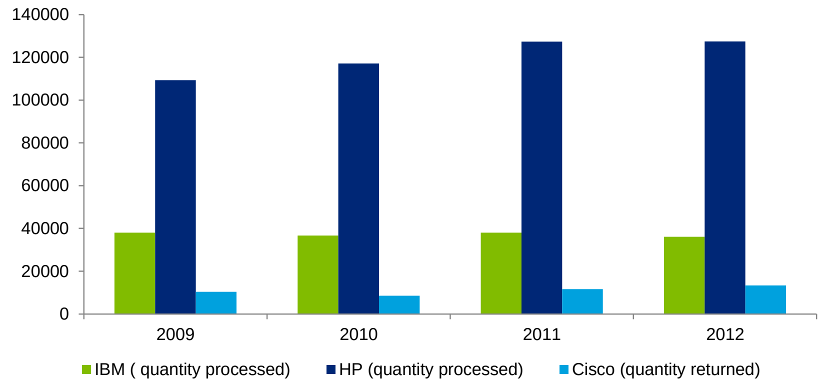


Figure 31: Products returned and processed at major manufacturers, 2009 – 2012 (in tonnes)

These activities and associated figures are global. Regarding IBM, the repartition of EOL processing between the different regions is presented in Table 14. This breakdown is in line with the unit shipments breakdown. It is estimated that the **worldwide picture can be considered as representative of the EU-28 situation**.

Table 14: Share of world regions in processed IBM IT equipment in 2012[43]

Region	Share of total in 2012
North America	44%
EMEA	30%
Asia Pacific	19%
Latin America	7%

Table 15 below illustrates the progressive improvement over time with the particular example of Cisco EOL activities: the share of refurbishment, resell and reuse increased between 2011 and 2013 while the landfill rate decreased to 0.33% in 2013.

Table 15: Treatment of Cisco EOL products worldwide, 2011-2013[45]

Treatment	Share of total in 2011	Share of total in 2012	Share of total in 2013
Refurbishment, resell and reuse	17%	25%	25%
Landfill for final disposal	0.89%	0.43%	0.33%

It should be noted that other considerations than the potential economic and environmental benefits of refurbishment have an influence the share of products and components that are recovered for refurbishment. In particular:

- Data property and security can be a reason why certain equipment or components (especially hard disk drives) cannot be harvested and re-used after their first operational lifetime. In that case, customers can implement or ask for data wiping before disposing of the equipment (overwriting, degaussing, puncturing, stripping, etc.).
- Technical relevance and feasibility: technologies that are too old are not recovered for refurbishment, in particular refurbishment is usually possible for generation n-1 equipment, but not before.
- Practical considerations, like storage and logistics limitations and/or the lack of need for refurbished devices.
- Legislative requirements, e.g. the entry into force of the RoHS Directive has reduced the share of recovered parts, according to stakeholders.

[43] Source: IBM: IBM and the Environment - 2012 Annual Report (2012)

It is also possible that parts are recovered in the EU-28 but re-used outside the EU-28. Stakeholders reported that difficulties to move waste from one Member State to another can make take-back programmes less efficient, because manufacturers have a limited number of sites capable to implement refurbishment.

To this point, HP's Financial Service business operates an asset recovery service (ARS) and a lease program (shown as "EOL" or "end-of-leases" in the table). The re-use rates from these programs are approximately as follows:

Table 16: HP server re-usage rate[44]

Program		% Resold	% Recycled
ARS	Servers	77%	23%
EOL	Servers	88%	12%
ARS	Storage	31%	69%
EOL	Storage	33%	67%

However, it should be noticed that these programmes do not cover the entire products and that overall average values can be assumed to be lower.

No breakdown of the EOL treatment process by type of materials is available, but major differences across the different materials (metals, plastics, electronics, etc.) can be expected. For instance, Cisco claims that over 99% of the electronics sent for processing are recycled[45]. Metals are the materials that have the higher recycling rate.

In November 2014, the French Environment and Energy Management Agency (ADEME) published its latest report on professional WEEE in France[46]. This report contains survey results on professional equipment tonnages treated in 2013 by type of treatment. The following table shows results for category 3 of WEEE, which is related to professional IT and telecommunications equipment.

Table 17: Treatment of professional IT and telecommunication equipment in France (2013) in t

Landfill	Reuse	Reuse of parts	Recycling	Energy recovery	Total (2013)
676 (4%)	4 193 (26%)	124 (1%)	10 558 (64%)	888 (5%)	16 438 (100%)

Although this category contains not only servers and storage equipment, but a large amount of different professional IT and telecommunication products, the results are considered to be adequate for an approximation for the end-of-life treatment of the products in scope of Lot 9.

3.4.Estimated second hand use

The real end-of-life of a server or storage device happens when the "box" with the serial number, containing all the different components and parts reaches its end-of-life. As a general observation, servers are rarely used to the end of their technical lifetime.

However, because re-use and refurbishment practices vary across vendors, it is very difficult to get a reliable estimation of the share of products that undergo a second hand use, and also to know what the operational lifetime of this second hand use is.

As far as storage products are concerned, The Green Grid SNIA Emerald Analysis Working Group collaborated with the SNIA Emerald Working Group to assess current practices in storage device "sanitation" and the impact of storage device sanitation on the reusability of drives. In general there are two methods available to remove data from drives with different levels of security regarding data accessibility: software overwrite or physical destruction of the data or drive.

[44] Source: DIGITALEUROPE
[45] http://www.cisco.com/web/about/ac227/ac228/ac231/about_cisco_takeback_recycling.html
[46] http://www.ademe.fr/sites/default/files/assets/documents/equipements-electriques-electroniques-donnees-2013-8229.pdf

Software overwrite methods are generally regarded as acceptable for internal reuse of drives or for noncritical data. Available methods include a single overwrite (internal reuse) or multiple overwrites, such as the U.S. Department of Defense standard, for a more secure sanitation. Using a software overwrite enables drives to be repurposed.

However, for companies that want to insure that data is not accessible, it is necessary to degauss or shred the drives. In both cases, the drives are rendered unusable and they must be scrapped. The experience of the Green Grid and SNIA members who manage end-of-life for storage products is that many customers insist on physical destruction methods for end-of-life storage devices to insure that data cannot be recovered.

3.5. Best Practice in sustainable product use

This section provides a few examples of best practices in EOL management, but is not expected to be exhaustive.

IBM pursues various product EOL management activities, such as recycling and reuse. The company began offering product take-back programs to its European customers in 1989 and has since then extended and improved them. They can purchase back the products from customers or take them for free, and products are shipped as used equipment in that case. A very low rate of landfill and incineration are recorded for the end-of-lease products returned to IBM (less than 0.2%). Of the returned equipment, a large share is sent to a remanufacturing/refurbishing centre, where functional components/parts are extracted from the products either for refurbishment, or as spare parts for maintenance. Equipment can then be re-used and resold at a lower price under a label “pre-owned certified equipment”: this usually concerns equipment from the previous generation. This practice is nonetheless driven by market demand: if there is no specific need or demand for refurbished products or spare parts, the EOL equipment is sent to the usual waste management chain, undergoing the required dismantling and depollution processes, which includes material recycling. Demanufacturing leads to components (e.g. electronic cards) being sold on the broker market, provided they fulfil required conditions (e.g. insurance requirement, environmental specifications).

Cisco[47] offers nine trade-in and take-back programs in three categories, namely customer programs, programs for companies producing or repairing Cisco products and internal programs for Cisco. Cisco’s trade-in program for customers purchasing new equipment makes them eligible for a discount when returning used equipment. It is the companies’ most successful program in that the largest quantity of IT equipment returned takes this way. The traded-in items are then analysed in order to determine the possibilities for reuse and refurbishment or in case they are not functional anymore for recycling. As a consequence, Cisco reused over USD 360 million of equipment in 2013 when calculated at standard cost.

HP[48] offers product take-back programs in 69 countries, having added 16 more since 2008, as well as hardware reuse (trade in, donation etc.) initiatives in 53 countries. Dismantling and recycling of REE in HHD magnets

In the course of manual dismantling HDDs to recover rare earth elements (REE), the casing has to be opened with special fine mechanic tools in order to reach and loosen the magnet assembly. A problem during this process is associated to the strong magnetic force that is exerted on the tools, which complicates the operation. Another challenge is related to the separation of the magnets from the securing metal plates. Most of the magnets are glued to the metal and in combination with the magnetic force it is not straightforward to loosen the magnets. When cranking too hard, the magnets can easily crumble, showing the expected porosity of rare earth elements (REE) based permanent magnets.

For these reasons a manual separation is most of the time not economical and automatisation would be desirable to disassemble the magnets from the HDDs[49]. Since it has been difficult to safely and cheaply extract rare earth magnets in the past, Hitachi developed a technology applicable to HDDs and air conditioners, partially automating the disassembly. They also put in place a take-back program, which allowed the company to extract 2 620 kg of rare earth magnets from approximately 200 000 HDDs in 2012[50].

[47] Cisco: 2013 Corporate Social Responsibility Report (2013)
[48] HP: HP 2012 Global Citizenship Report (2013)
[49] see e.g. Zepf, V., 2013. Rare earth elements: A new approach to the nexus of supply, demand and use : exemplified along the use of neodymium in permanent magnets, Berlin and London: Springer.
[50] Hitachi: Hitachi Group Sustainability Report 2013 (2013)

The main problem that occurs during the mechanical processing of electronic waste is that the Nd magnets crack and adhere to iron parts, especially to the parts of the shredder itself. For a mechanical recovery it would be necessary to demagnetize the Nd magnets first. The simplest technique to demagnetize large amounts of neodymium magnets is to heat them up above the Curie point. The required temperature is around 300°C. The mass fraction of Nd in the HDDs amounts to around 3%. Without prior demagnetization, about 2/3 of neodymium remains in the shredder[51]. Despite a vast, mostly lab-scale research effort on REE recycling, up to 2011 less than 1% of the REEs were actually recycled[52]. This is mainly due to inefficient collection, technological problems and, especially, a lack of incentives.

3.6. Retained values for the environmental assessment

Based on the previous subchapters, the following esitmates have been retained for later analysis under Task 5 :

Table 18: Inputs in the end-of-life phase of enterprise servers

	Plastics	Metals	Electronics	Misc.
Re-Use	50%			
Material Recycling	5%	45%	36.5%	43%
Heat Recovery	44%	0%	12.5%	1%
Non-recovery incineration	0.5%	0%	0.5%	5%
Landfill	0.5%	5%[53]	0.5%	1%
Total	100%	100%	100%	100%

Table 19: Inputs in the end-of-life phase of the storage system

	Plastics	Metals	Electronics	Misc.
Re-Use	25%			
Material Recycling	5%	70%	50%	68%
Heat Recovery	69%	0%	24%	1%
Non-recovery incineration	0.5%	0%	0.5%	5%
Landfill	0.5%	5%[54]	0.5%	1%
Total	100%	100%	100%	100%

Parallel to the Lot 9 preparatory study, the JRC-IES was working on a study called "Environmental Footprint and Material Efficiency Support for product policy - Analysis of material efficiency requirements for enterprise servers". This study contains further and more detailed material efficiency and end-of-life aspects for enterprise servers and should be publicly available shortly after publication of the Lot 9 preparatory study.

[51] Bunge, R., 2013. Recycling von Neodym aus Elektronikschrott. Projekt E-Recmet. HSR Hochschule für Technik Rapperswil, Institut für Umwelt- und Verfahrenstechnik UMTEC. Available at: www.umtec.ch/uploads/tx_hsrpm/Factsheet_E-Recmet.pdf [Accessed December 8, 2014].
[52] Reck, B.K. & Graedel, T.E., 2012. Challenges in metal recycling. Science, 337(6095), pp.690–5. Available at: http://www.ncbi.nlm.nih.gov/pubmed/22879508 [Accessed December 1, 2014].
[53] This value cannot be changed in the EcoReport tool.
[54] This value cannot be changed in the EcoReport tool.

4. Local Infrastructure

This section has the objective to identify, retrieve and analyse data, report on barriers and opportunities related to the local infrastructure.

The technical system (see section 1.2) is providing the “local infrastructure” for enterprise server and data storage equipment. In order to make the best purchasing decision and optimising the data centre infrastructure, the user (e.g. data centre operator) needs precise information (data) about the technical and environmental performance of the product. He needs exact specifications in terms of how (under which conditions) to operate the equipment. Furthermore, the operator will require more performance monitoring options and the possibility to integrate real-time performance data obtained from the IT equipment into his existing datacentre infrastructure management (DCIM).

4.1. Energy

Reliability, availability and nature (source) of electricity will depend on the actual location and service contracts of the data centre. Data centre operators in the northern parts of Europe have a considerable advantage due to lower annual temperatures or access to cold water. This allows for “free-cooling” (less cooling capacity necessary), higher thermal exchange efficiency, and more renewable energy sources including water and wind power. According to one industry stakeholder, the effective utilisation of free-cooling is, however, not limited to northern countries; it can be practiced effectively in a range of climate zones, albeit with lower levels of utilisation of the free-cooling system. Free-cooling utilisation rates of over 50% can be achieved in temperate climates where raised floor temperatures are moved to the ASHRAE A2 Standard and the cooling system is run with optimisation software. Energy consumption and related energy costs are a highly important business factor for data centre operators. The data centre operator might also choose to buy or otherwise produce and utilise renewable energy sources.

Depending on the equipment ownership and business model (e.g. co-location data centre) the transparent metering of energy consumption is a business necessity. More detailed energy metering is encouraged by the EN 50001.

The electricity supply for enterprise servers and data storage equipment is usually ensured through uninterruptable power supply units (UPS). Mainstream UPS use batteries. However, there also exist more efficient rotary or dynamic UPS which store kinetic energy through a flywheel which can be provided in the case of commercial power failure.

The power supply and distribution on floor and rack level is usually done with alternating current (AC). Nevertheless, direct current (DC) with considerable higher voltages (12V to 480V) is a possible option as well. The utilisation of DC would require that the data centres employ certified maintenance personal that can handle higher voltages.

4.2. Water

It is possible (but not necessary) that water or another cooling liquid is used for cooling both on the product level and on the technical system (infrastructure) level:

- On the product level, liquid cooling including water is an advanced technology for products that feature very high energy density. The necessity for liquid cooling depends on various factors including power dissipation, junction temperature, thermal resistance, ambient temperature, form factor, etc. The water or cooling liquid typically contains additives for anti-corrosion, anti-algae growth, anti-limes (chalk), etc.
- On the system level, the utilisation of water in specific cooling systems (infrastructure) is common. The availability will depend on the actual location and service contracts of the data centre.

4.3. Telecom

Broadband fixed-line network access is a basic condition for the operation of a data centre. Telecommunication infrastructure is locally available and part of the service contracts of the data centre.

Industry sources indicate that wireless networks have not been implemented in the past due to data security and interference reasons. It is however expected, that with further implementation of thermal sensors and power monitoring equipment, wireless communication within the data centre might become an option in the future.

4.4. Installation

The installation of enterprise servers and data storage equipment is usually part of service contracts between the customer and the equipment vendor. The contracts include installation and service for the duration of typically 3 years (see Task 2).

4.5. Physical environment

Enterprise servers and data storage equipment are usually installed and operated in special servers rooms or data centres supported by a complex infrastructure. Fully functional and autonomous operable container data centres are also available.

The physical environment is defined by maximum energy density that can be safely handled. The location of the data centre is an important distinction criterion. The access to cold air, water, ice for cooling and renewable energy sources for power supply will influence the overall energy and resource efficiency of the data centre.

5. Recommendations

5.1. Refined product scope from the perspective of consumer behaviour and infrastructure

The investigation of the functional and technical aspects of the products use phase indicated a considerable complexity and variety. Given the lack of statistical/average data on some use parameters, important assumptions are required to make the environmental and economic assessment feasible from a practical point of view.

Regarding the scope, the use phase analysis of server- and storage-related network equipment underlined the following aspects:

- **Different application environments**: The utilisation of network equipment in different application environments including telecommunication facilities, enterprise data centre, office and commercial buildings, and private homes result in extreme variety of product configurations. Performance, interoperability, scalability, security, electromagnetic compatibility, multi-functionality, and modularity are only a few aspects that distinguish these products.
- **Quality of service requirements**: Availability and performance dictates the technology, configuration and resulting product costs. The intended quality of service is setting the parameters for the products design including its options for power management and efficient resource utilisation.
- **Privacy and security:** Because communication is the foundation of modern life it is a highly sensitive topic in terms of privacy and security. Ensuring these critical aspects in product and network system designs has highest priority.

Given these considerations – and the resources necessary to assess this complex product spectrum – **the project team recommends investigating the ecodesign aspects of network equipment in a separate preparatory study.**

5.2. Barriers and opportunities for Ecodesign from the perspective of consumer behaviour and infrastructure

Energy efficiency and resource consolidation have been recognised by the industry as key performance aspects in data centres. Electricity costs are increasingly important and dominate in many instances the operational expenditures (OPEX). However, service availability, scalability of performance and security are still having priority over energy and resource consumption. Server and storage equipment are only tools in the much more complex system of a data centre and it is this larger system that needs to be optimised. The existing product variety and the offered options for individual product configurations are reflecting the diversity of the market demand.

Against this background, there are understandable barriers preventing some ecodesign measures on a product level. For instance, in applications and use environments with high availability and security requirements, it is obviously more difficult to implement a consequent power management (influencing latency) or reduce redundancy. The location, structural conditions, and given support infrastructure of an actual data centre will determine the physical system design, network architecture, and operating conditions (settings). Quite often legacy equipment is still in use for very special purposes. Finally, factors such as the budget for new equipment, including to a great extent software license fees, determine the type of product and which configuration will be installed.