Preparatory study on Smart Appliances

Task 3 Users

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

AC	Air Conditioning
ADSL	Asymmetric Digital Subscriber Line
BAT	Best Available Technology
BRP	Balancing Responsible Parties
CFL	compact fluorescent light
CHP	Combined Heat and Power
DHW	Domestic Hot Water
DOCSIS	Data Over Cable Service Interface Specification
DR	Demand response
DSO	Distribution System Operators
ETSI	European Telecommunications Standards Institute
EV	Electric vehicle
GLS	general lighting service 'incandescent'
GSM	Global System for Mobile Communications
GW	gigawatt
HEG	Home Energy Gateway
HID	high intensity discharge lamp
HVAC	Heating, Ventilation and Air Conditioning
LED	light emitting diode
LFL	linear fluorescent lamp
LTE	3GPP Long Term Evolution (4G)
M2M	Machine to Machine
NRVU	Non-Residential Ventilation Units
PLC	power line communication
PV	Photovoltaic
RES	Renewable Energy Sources
RVU	Residential Ventilation Units
SAREF	Smart Appliances REFerence ontology
SOC	State Of Charge
TSO	Transmission System Operators
TWh	TeraWatt hour
UMTS	Universal Mobile Telecommunications System
UPS	Uninterruptible power supply
VDSL	Very-high-bitrate Digital Subscriber Line
VRF	variable refrigerant flow

1 TASK 3 - USERS

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

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

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

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

1.1 END-USER PERSPECTIVE

1.1.1 DRIVERS AND BARRIERS FOR THE UPTAKE OF SMART APPLIANCES

Shifting loads in private households by using smart appliances may require behavioural changes and some adaptations of consumer's everyday routines. Consequently, the potential of smart appliances depends on the consumer acceptance and the use of smart appliances, which are among the most crucial key factors to make this new technology being successful.
The degree to which consumers tend to implement smart appliances will depend on technical, behavioural and economic drivers and barriers and their interaction. In the following, this report gives a general overview of the current state of consumer acceptance in view of smart appliances. It points out major barriers and provides strategies to overcome these objections, to raise the consumer acceptance and for a successful market penetration of smart technologies. Economic drivers/ barriers linked to business models are discussed more in detail in section 2.2.4 in Task 2 of this report.
The S3C project[1], which aimed at research of "best practice end-user engagement strategies and tools", took both, a theoretical and an empirical approach to gain information on drivers and barriers for implementing smart appliances. From a theoretical point of view, the S3C project analysed the process of behavioural changes, which is required for the implementation of smart appliances. As

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

most energy –related processes (e.g. operating dishwasher or washing machine, cooking etc.) are rather habitual processes, the project concluded that consumers first have to be activated to become engaged in load shifting and using smart appliances. At the beginning of this process, the behaviour is no longer habitual, existing routines have to be reconsidered and the behaviour is changed towards a higher consciousness ('disruptive phase'). The next phase targets at an active participation of consumers. They should explicit reflect their old and new practices ('activation phase'). In the third phase ('continuation phase'), new practices and routines are already adapted and the new behaviour becomes more and more habitual. However, new practices have to be supported and reinforced. According to the findings of the S3C project[1], drivers and barriers play a decisive role in the 'activation' and 'continuation phase'. The drivers and barriers identified in the framework of this project are discussed in the respective subsections.

Current available information from empirical studies implies that consumer acceptance in view of smart appliances and related to this, smart home technologies, is relatively high. Except for one study[2], preliminary findings indicate that consumers are willing to shift loads to off-peak hours by rescheduling certain household activities[3,4,5,6,7,8,9]. However, it is important to note that the results of these studies are mainly based on questionnaires or interviews and not on consumer experiences. Thus, they reflect the expected and not the real consumer behaviour and acceptance. This means that the figures should be treated with caution.

Consumer studies carried out within the framework of the "Energy Intelligent Europe" project „Smart Domestic Appliances in Sustainable Energy Systems (Smart-A)"[10], which was conducted in five European countries (Austria, Germany, United Kingdom, Slovenia and Italy) revealed that about 90 % of the respondents would accept different options of smart appliances. However, the acceptance is dependent on the respective device and smart operation mode and could not be generalized for all appliances. In terms of willingness, the highest load shifting potential was found for washing machines and dishwashers, whereas the willingness to shift cooking or entertainment applications or the operation of appliances ensuring comfort is vanishingly low[4,5,6,7,8,11]. For more detailed information, refer to subtasks 3.2.1-3.2.7.

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

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

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

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

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

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

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

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

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

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

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

Economic and ecological drivers
In a study by Paetz et al.[11], a total number of four test-residents lived in a fully equipped smart home laboratory to assess smart home technologies (feedback systems, automated energy management system, dynamic pricing) in everyday life. The study revealed that dynamic pricing and related to this, monetary savings, are the main drivers for shifting loads. Because of the complexity and variability of the dynamic prices, the study participants preferred an automated energy management system. Reasonable pay-back periods for investments were identified as crucial preconditions for consumer's acceptance of smart home technologies.
In the same smart home laboratory, focus group interviews were conducted with 29 participants to get an insight into consumer perceptions in view of smart appliances, smart metering, variable tariffs and home automation[12,13]. The results show again the importance of monetary savings.
A questionnaire-based survey and focus group interviews in several European countries as part of the Smart-A project[3,6] produced similar results. Also here monetary savings were the most important requirement for buying and using smart appliances. The second point is the reduction of the environmental burden.

Product related drivers
Besides economic and ecological benefits, also some product related drivers could be identified in former studies. The maturity of smart technologies, maintenance or enhancement of comfort (e.g. making housework less time consuming), good usability and higher security were found in the Smart-A consumer studies to play a decisive role for consumers to accept smart appliances. Expert interviews conducted within the framework of the Smart-A project additionally identified monitoring features (e.g. diagnosis of correct function of appliances) or "all power off"-switches as potential benefits.
In the S3C report[1], five major categories of drivers were identified besides economic and ecological benefits: increase in comfort, increase in control (e.g. advances control of appliances via smart phone or tablet, further possibilities to participate in energy market), knowledge and information (e.g. on energy use, more frequent billing), improved security (e.g. improved reliability of energy supply) and social process (e.g. social role, community feeling or fun).
In other studies[14,15], new services (e.g. monitoring of or support for elderly people) were named as a further motivators to buy and use smart appliances.
According to Mert et al.[10], the majority of consumers would only buy a smart appliance if they need to replace their old one anyhow.
Even though financial incentives (for instance through a dynamic pricing scheme) seems to play an important role as a driver, it can be concluded that they are not sufficient to establishing a structural change in consumer behaviour[16].

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[12] Paetz, Dütschke, Fichtner (2012): Smart Homes as a Means to Sustainable Energy Consumption: A Study of Consumer Perceptions. Journal of Consumer Policy. 2012; 35:23-41.
[13] Paetz, Duetschke, Fichtner, Wieschtel (2011): Tomorrow's households: How do consumers react to a smart-home environment? In: Bertoldi P, editor. Energy Efficiency in Domestic Appliances and Lighting. Copenhagen, Denmark 2011. p. 657-69.
[14] Balta-Ozkan, Davidso, Bicket, Whitmarsh (2013): Social barriers to the adoption of smart homes. Energy Policy. 63:363-74.
[15] Balta-Ozkan, Amerighi, Boteler (2014): Comparison of consumer perceptions towards smart homes in the UK, Germany and Italy: reflections for policy and future research. Technology Analysis & Strategic Management. 2014; 26:1176-95.

Barriers to buy/ to use smart appliances

Although results of customer research have shown that consumers have a positive attitude towards smart appliances and would be willing to adopt them, there are many objections which have to be solved before a market penetration is possible (Mert et al., 2008[10]). In the following, two main categories of barriers are distinguished: barriers in view of economic aspects and regulatory framework and product/service-related barriers.

Barriers in view of economic aspects and regulatory framework

The rollout of smart meters and informing about smart functions are definitely main barriers to uptake smart appliances (cf. Task 2, subtask 2.1.2 for more information on rollout of smart meters). A Forsa study[17] showed that even 91 % do not know the term "smart meter".

In 2010, more than 9,000 individuals in 17 countries across the globe were surveyed by Accenture[18] to get consumers attitudes and opinions toward electricity management programs. According to this survey, the three major barriers, which discourage consumers from adopting smart appliances, are costs, mistrust in providers and concerns about data privacy.

In view of the costs, consumers are in general willing to accept higher initial prices for smart appliances, but some of them fear hidden costs (e.g. costs for installation or repairs) as well as unreasonable and excessive pay back periods (Mert et al., 2008[10]).

This mistrust in energy providers represents the next major barrier in adopting smart appliances. On average, only 29 % of the consumers trust in utilities or energy providers. Nearly the same percentage has no trust and about half of the consumers are undecided. Environmental associations, academics/ schools/ scientific associations as well as consumer associations in contrast have the highest trust level. (Guthridge, 2010[16])

Consumers have the impression that economic goals of electricity providers are hidden behind a "green washing" attitude (Mert et al., 2008[10]). Because of that, they prefer independent institutions like governmental institutions at national and European level and consumer organisations to inform them.

Changes in electricity prices and programs by energy utilities reduce the level of trust in them. From the users view, there is also a lot of scepticism about the motivation of energy suppliers to promote smart appliances. As the knowledge of consumers about renewable energies and the energy system in principle is limited, consumers often fear that economic goals are hidden behind the aforementioned "green washing" attitude and energy suppliers use the ecological benefit as a sales argument. Combined with growing doubts about control, data privacy and data protection, consumers trust in energy providers is further minimised. (Mert et al., 2008[10])

Product/ service-related barriers

A further objection of consumers is an expected loss of control[1]. Consumers have certain mistrust in high tech solutions. In most cases, they lack knowledge about energy grids and the underlying concept of smart appliances, and consequently have concerns in view of technical failures and

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

[17] Forsa (2010): Erfolgsfaktoren von Smart Metering aus Verbrauchersicht, Berlin.

[18] Guthridge (2010): Understanding Consumer Preferences in Energy Efficiency - Accenture end-consumer observatory on electricity management, Amsterdam.

system reliability. On the one hand, many consumers are afraid of dependency on technology and on the other hand they do not like the idea of energy providers having control over their devices. This could be deeply rooted in the fact that consumers are accustomed of available electricity all the time and they can operate their appliances whenever they want. Consumers do not want to be restricted on electricity usage because for them, this means a loss of comfort. Another point is that consumers fear a certain stress to change their behaviour and daily routines. In the case of automatic regulation, consumer favour solutions that tie to existing platforms like smartphones and tablets[19] and they want to maintain control over their devices. Thus, it appears consumers prefer to have the possibility to override the smart operation mode any time they want (for example with an option to operate their appliances manually). (Mert et al., 2008[10])

The safety of smart appliances is also questioned by some consumers and plays a big role for their adoption as well. Users might be afraid of break-downs for example in case of fire or flooding. Doubts about leaving the appliances switched on during absence exist in the consumers mind. Among others, this is why manuals of traditional electrical appliances often warn consumers not to operate the devices unattended and sometimes even recommend unplugging it from mains after usage. To make things worse, insurances usually do not cover damages in absence. So consumers worry that they have to cover the costs of possible damages by themselves. (Mert et al., 2008[10])

In other studies[3,12,13,14,15], concerns expressed include a lacking interoperability, a too complicated handling (especially important for elderly and people with disabilities), error-proneness of appliances because of additional technical components and shorter life times of appliances due to short interruptions during operation. It has to be mentioned at this point that upgradeability and the length of manufacturer's support might also be decisive factors in view of product life time (even though not named in the aforementioned studies). Additionally, the reparability of the product might be affected as more complex technology such as electronics becomes part of the product design.

According to the S3C report[1], social processes (e.g. free-rider effects or job losses) and lack of information and knowledge (e.g. perceived health risks) may be named as an additional barriers.

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

Results from an online survey by Geppert and Stamminger[20] indicate that the probability of having concerns in view of smart appliances might be related to the degree of automation and technical complexity. Whereas only about 1/3 of participants stated to have concerns in view of a dishwasher, whose start is triggered by an external signal (e.g. via power line), half of all respondents expressed concerns in view of a remote control (e.g. interruptions or altered consumption pattern in the case of refrigerators, freezers, air condition, heating pumps or electric water heaters).

Additional costs and expected financial gains

Studies by Mert et al.[10] as well as Geppert and Stamminger[20] revealed that almost all consumers are in general willing to pay a slightly higher price (up to 50 €) for smart appliances than for conventional ones when buying an appliance. An absolute statement about additional costs accepted by consumers is not possible as these costs much depend on the absolute price of the appliance, the

[19] Panasonic, IFA 2015

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

expected payback time, the expected gain in comfort, potential additional costs (e.g. installation and upgrading) and potential future savings.
According to Mert et al. (2008)[10], the majority of consumers would certainly not approve a payback time of 5 years and some of them might not accept even 3 years.
The online study by Geppert and Stamminger[20] has shown that almost 80 % of participants would buy a smart appliance under the precondition of getting incentives from their utilities (e.g. cheaper energy tariff). A reduced purchase price for the appliances would only convince about 16 %. When asked about their expected reduction in energy price, most participants stated a percentage in the range of 1 to 30 (mostly 11 to 20 percent). By trend, the expected reductions are higher in the case of remote control (e.g. interruptions of appliances, altered consumption patterns) than in the case of external signals, which trigger a delay in start time (e.g. frequency control).
A point-of-indifference analysis by Paetz et al.[12] determined savings of 80 € per year as the point at which changes in behavioural patterns start to be worthwhile for consumers.

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

Major concerns are related to safety aspects and the technology. Consumers are afraid of fire or flooding or any failures if appliances are operated during absence. Potential measures to overcome these objections include additional safety mechanisms in view of appliances (improved protection against fire or flooding), the possibility to remotely monitor different operation parameters (e.g. temperatures) and an alert via smartphone or email in the case of failures. But also the insurance can plays a decisive role to overcome the safety barrier by covering damages occurring during unattended operation (for instance manufacturers offering own insurances for aqua-stop etc.). (Mert et al., 2008[10])

As consumers also fear error-proneness of appliances and a shorter life span due to interrupted operation and more technical components, realistic life time and fatigue tests should provide information for consumers. Extended warranties could be a further possibility to overcome this concern.
Another aspect to increase the consumer acceptance is that providers need to build trust and credibility before they see a broad adoption of smart appliances. So first they have to improve their customer relationships. In order to create trusted advisor relationship, providers need to be more transparent in their activities. In addition to that they need to match consumer's requirements for a good data protection and should also delete consumer's data after some time. As many consumers remarked that they are afraid to lose control over their devices, consumers should have the possibility to override the smart operation mode any time they want (for example with an option to operate their appliances manually) and should have access to their own data. Further it will be necessary for energy providers to build relationships with governments, regulators and associations,

which are able to push the energy-efficiency agenda forward (Guthridge, 2010[18]). Alternatively, a regulated or government body could undertake the management of the smart appliances and the interaction with end consumers.

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

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

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

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

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

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

1.1.2 End-use parameters and user requirements of appliances

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

1.1.2.1 Periodical appliances

1.1.2.1.1 Usage Behaviour

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

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

In view of periodical appliances, energy is mainly needed for heating processes. In the case of washing machines, dishwashers and washer-dryers, water is heated up for cleaning purposes. In view of tumble dryers and washer-dryers, hot air is produced, which is required for drying wet laundry. The temperatures vary according to the respective programmes. The rated power of the heating devices is shown in Table 1.

Table 1: Rated power of heating devices (source: Stamminger et al., 2009[32])

Appliance	Rated power of heating device
Dishwashers	1,800-2,500 W
Washing machines	1,800-2,500 W
Tumble dryers	2,000-2,500 W (1,000 W for heat-pump)
Washer-dryers	2,000-2,500 W

Additional energy is needed to operate circulation pumps, motors, fans and displays/ user interfaces. During spin-drying, motors of washing machines and washer-dryers reach power peaks of up to 950 W, whereas their typical operational power input is about 100 W. The rated power input of water circulation pumps is about 15-30 W. (JRC, 2015[21])
Periodical appliances have a relatively high volume of installed base in EU-28 (some of them still growing).
For dishwasher, penetration rates vary extremely between different countries with ownership rates of 40-50 % in EU-15 (2012) and 10-15 % in new member states. For EU-28, this results in 46 %. According to estimations, ownership rates in EU-28 will increase during the next decades reaching 60-70 % in 2030. (VHK, 2014[22])
The average ownership rate of washing machines (EU-27) is about 90 % with only marginal differences between countries (Bertoldi et al., 2012)[34].
According to estimations in 2010, the stock of tumble dryers in Europe was about 54 million appliances (Bush, Damino, Josephy, 2013[23]) corresponding to an average ownership rate of about 32 %. In 2015, estimations indicate an amount of about 63 million appliances in stock (VHK, 2014[24]) and a corresponding penetration rate of 29 %. Penetration rates are much higher in Western than in Eastern European countries (Lefèvre, 2009[25]).

[21] JRC (2015): Ecodesign and Energy label revision: Household Washing machines and washer-dryers. Draft. Available online: http://susproc.jrc.ec.europa.eu/Washing_machines_and_washer_dryers/docs/Prepstudy_WASH_20150601_FINAL_v2.pdf
[22] VHK (2014): "Omnibus" Review Study on Cold Appliances, Washing Machines, Dishwashers, Washer-Driers, Lighting, Set-top Boxes and Pumps. Final report
[23] Bush et al. (2013): Heat Pump Tumble Driers: New EU Energy Label and Ecodesign requirements in Europe, MEPS in Switzerland, Initiatives in North America. Available online: http://www.topten.eu/uploads/File/EEDAL_heat_pump_driers_2013.pdf
[24] VHK (2014): ECODESIGN IMPACT ACCOUNTING Part 1 – Status Nov. 2013
[25] Lefèvre, 2009: Ecodesign of Laundry Dryers, Preparatory studies for Ecodesign requirements of Energy-using-Products (EuP) – Lot 16

Washer-dryers are a small category of wet appliances. Because they are relatively new on the market, their ownership rate is only about 4 % in Europe, but still increasing (Euromonitor 2014, cited by JRC, 2015[21]).
For more information on stock data, please refer to Task 2.
Given the comparatively high power consumption and the large installed base volumes, the potential of periodical appliances for load shifting is assessed to be high. Therefore, appliances of this category are described more in detail in this chapter.

1.1.2.1.2 User behaviour concerning periodical appliances

DAILY AND ANNUAL USE PATTERN

Dishwashers

According to an online survey in 10 European Countries (EUP LOT 14[26]), the average number of dishwashing cycles per week is 4.06, corresponding to 211 cycles per year. The same average number was reported for German households by Bichler et al. (2014)[27].
The European Commission estimated the total electricity consumption of dishwashers in Europe to be around 25.3 TWh in 2010 (Bertoldi et al., 2012)[34]. Dishwashers with a capacity of 13 settings currently available on the European market consume between 194 and 290 kWh/year (http://www.topten.eu). Stamminger et al. (2009)[32] reported on an average consumption of 241 kWh/year corresponding to 1.19 kWh/cycle.

Assuming a normal cleaning programme and an energy consumption of 1.19 kWh per cycle, the power demand curve of a current average dishwasher follows the pattern shown in Figure 1.

[26] Preparatory Studies for Eco-design Requirements of EuP’s, LOT 14: Domestic Washing Machines and Dishwashers, Task 3: Consumer Behaviour and Local Infrastructure.
[27] Bichler S. (2014): Verbraucherakzeptanz von Energieeinsparpotentialen an automatischen Geschirrspülmaschinen. Shaker Verlag, Aachen.

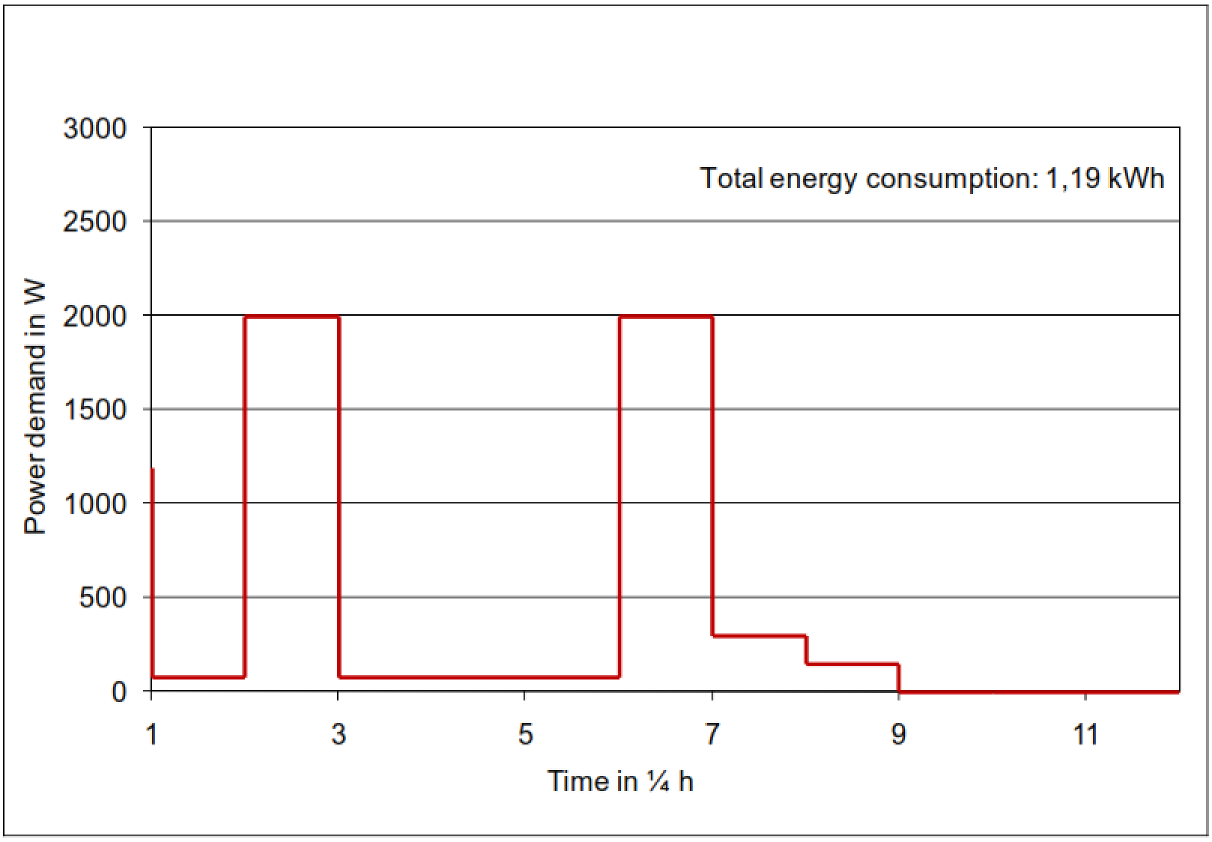

Figure 1: General pattern of a power demand curve of an average dishwasher operating in a normal cleaning programme (source: Stamminger et al., 2009[32])

Due to the Energy Label and other political measures, the total energy consumption of dishwashers in Europe is expected to further decrease within the next years. Assuming lower cleaning and rinsing temperatures, the power demand curve of an average dishwasher in 2025 may change towards a lower power demand in the cleaning and rinsing phase and increased cycle times.

It is assumed that use patterns of dishwashers vary on a daily, but not on a seasonal basis. According to results of an online survey in ten European countries in 2007 (n=2500), dishwashers are preferably switched on in the afternoon/ evening period after dinner (Figure 2). At present, there is no reason per se to expect that the daily use pattern of dishwashers will change in the near and medium-term future.

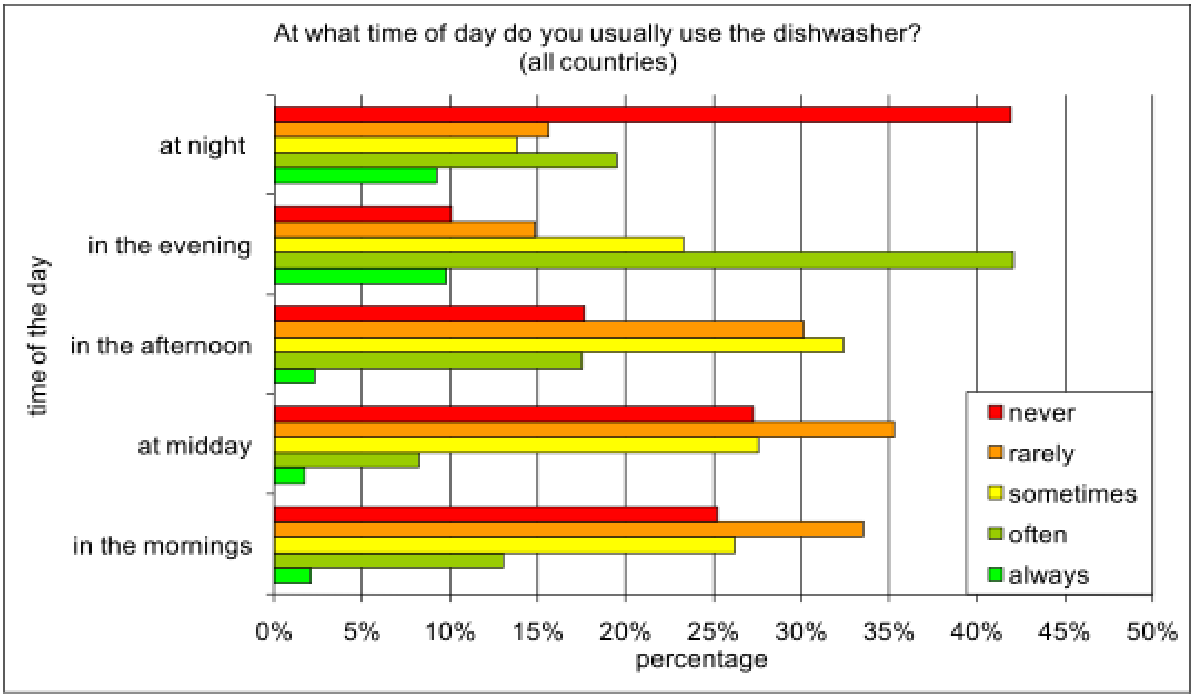

Figure 2: Frequency of operation of dishwashers during the day (Source: EUP LOT 14[26])

Within the framework of the Smart-A project (Stamminger et al., 2009)[32], this information was used to deduce the probability of start time of dishwasher operation for the ten European countries investigated (cf. Figure 3).

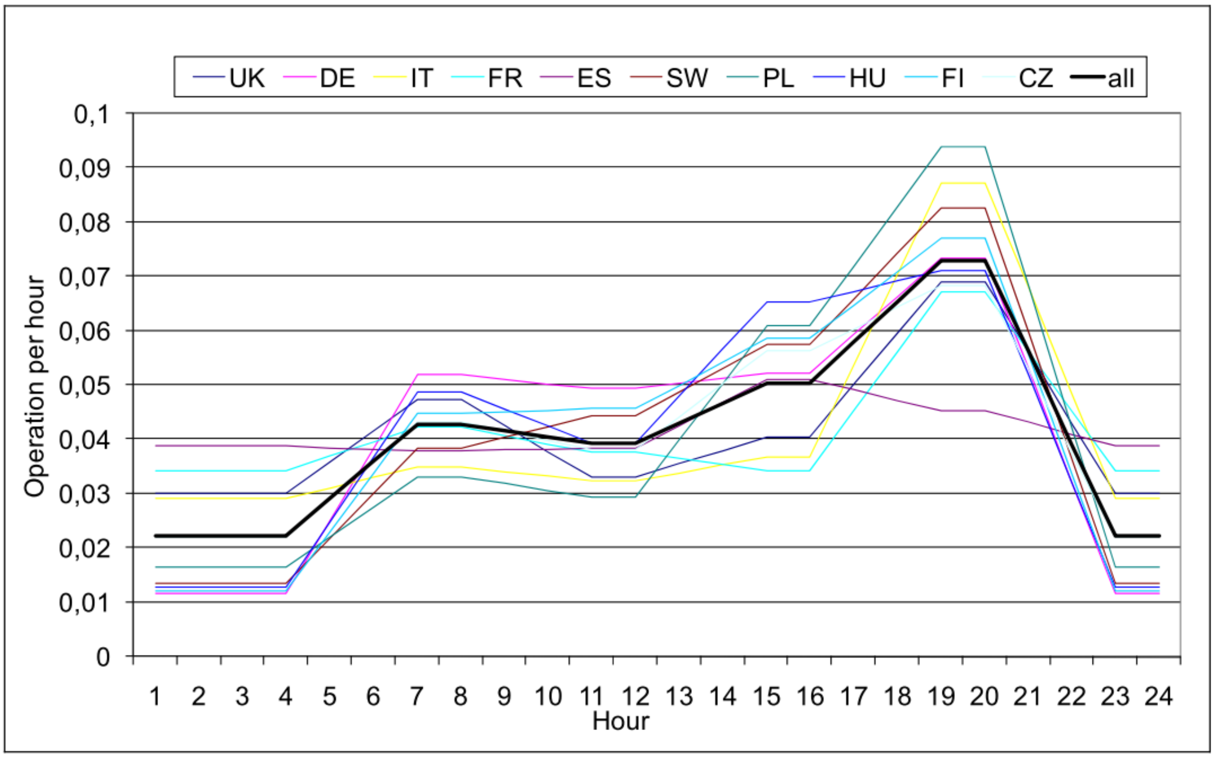

Figure 3: Probability of start time of the dishwasher operation for the ten European countries investigated (source: Stamminger et al., 2009[32])

In view of dishwashers, just one major scheduling period can be identified in the late afternoon/ evening (about 5 PM-8 PM). For Spain, this peak is not as pronounced as for other countries. The probability curve is rather flat, showing that dishwashers in Spain are operated all over the day with roughly the same probability.

If the general pattern of a power demand curve of a current average dishwasher (cf. Figure 1) is aggregated with the average probability of start time (cf. Figure 3) and an appliance-specific usage factor, which takes into account the average number of cycles per year, the general pattern of a daily load curve depicted in Figure 4 can be derived. It has to be noted that this daily load curve is based on data representing the user behaviour of only ten European countries, which are named in Figure 3. As the countries investigated cover a major part of the population of EU-28 and the user behaviour appears to be similar in these countries, it seems to be reasonable to assume that the consumer behaviour and this general pattern of a daily load curve is also valid for all EU-28 countries. If the total energy consumption of dishwashers will further decrease as expected for the next years, the power demand curve will change, which will have an impact on the daily load curve.

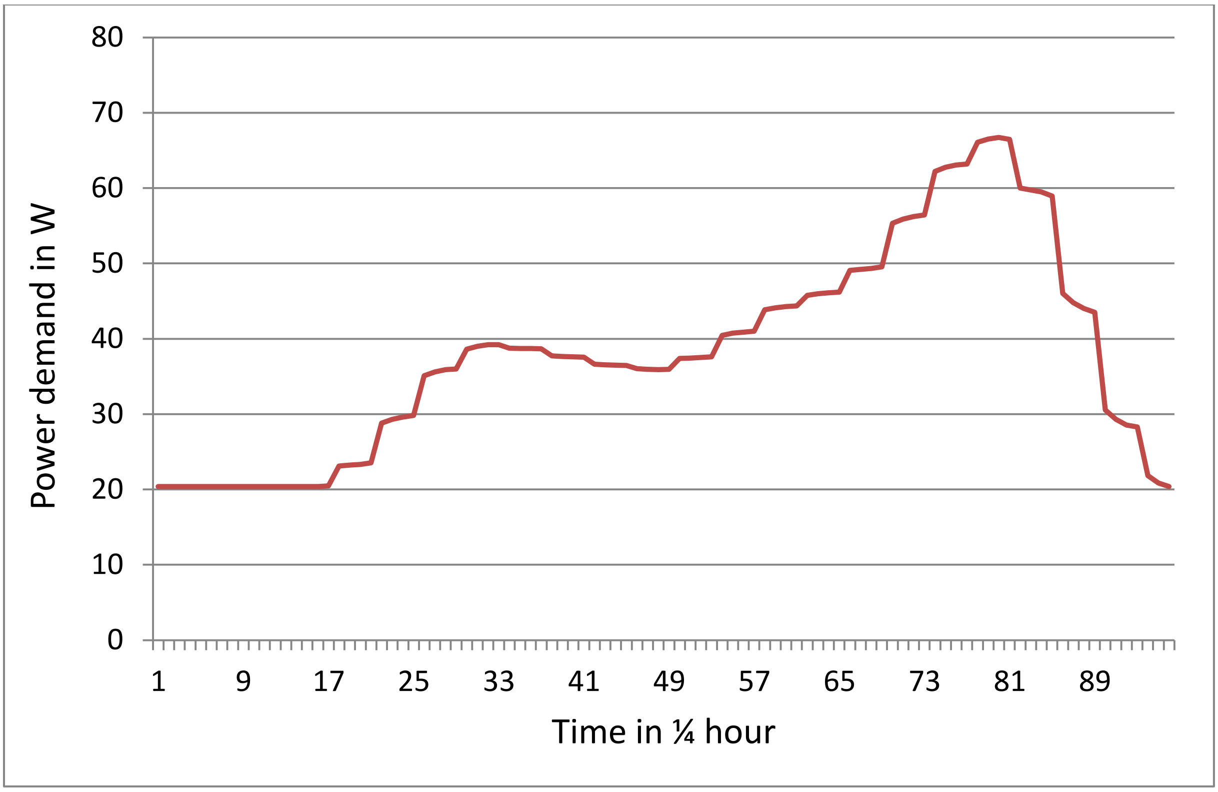

Figure 4: General pattern of a daily load curve of a current dishwasher (source: modified according to Stamminger et al., 2009[32])

Washing machines

In Europe, a trend towards decreasing household sizes and increasing capacity of washing machines from an average capacity of 4.8 kg in 1997 to 6.0 kg in 2008 can be observed (VHK, 2014[22]). In 2011, an average number of 3.8 cycles per household and week was determined by Schmitz and Stamminger (2014)[28], corresponding to 198 cycles per year. The International Association for Soaps,

[28] Schmitz and Stamminger (2014): Usage behaviour and related energy consumption of European consumers for washing and drying. Energy Efficiency, 7, 937-954.

Detergents and Maintenance Products (A.I.S.E) reported an average wash frequency of 3.2 per household and week (166 cycles per year) across Europe in 2011 (A.I.S.E., 2013[29]).
In view of the energy consumption per household per year, large differences between the countries could be registered, which can be explained by different washing temperatures and frequencies (Figure 5).

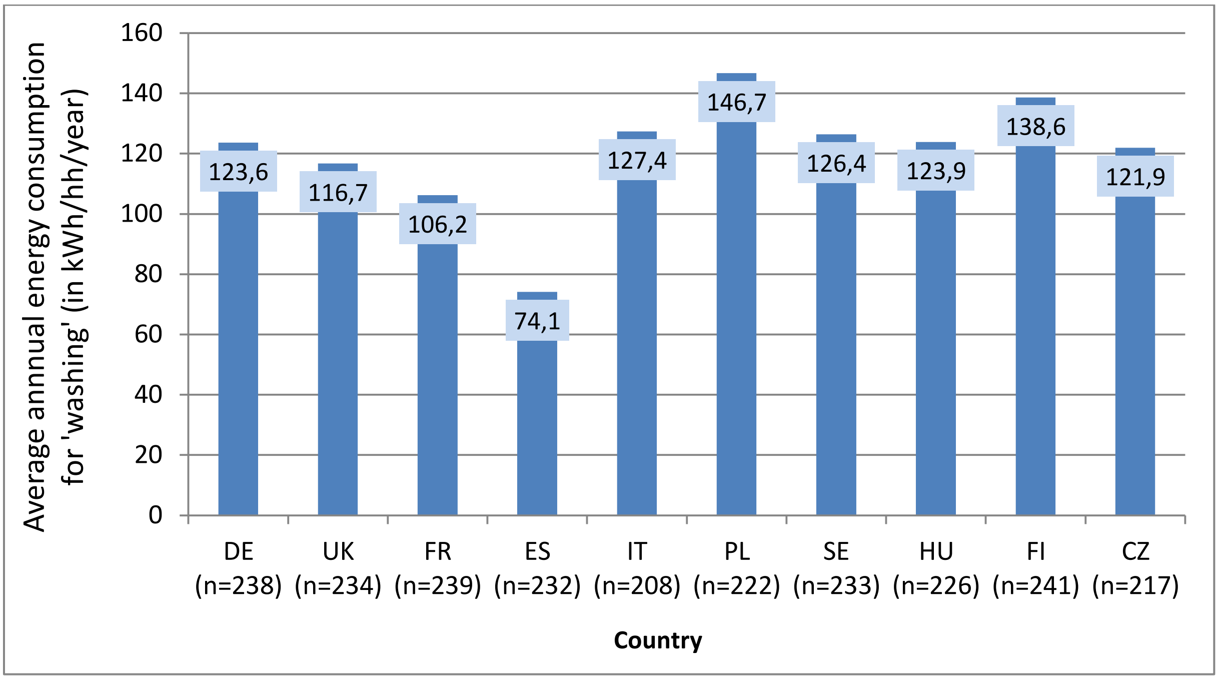

Figure 5: Average energy consumption for 10 European countries in 2011 (Source: Schmitz and Stamminger, 2014[28])

Assuming a normal cotton programme and an energy consumption of 0.89 kWh per cycle, the power demand curve of a current average washing machine follows the pattern shown in Figure 6.

As the power demand is dependent on the washing temperature and also the amount of water needed for the washing process, this pattern may change according to the programme chosen and the capacity of the machine.

Due to the Energy Label and other political measures, the total energy consumption of washing machines in Europe is expected to further decrease within the next years. Assuming lower washing temperatures, the power demand curve of an average washing machine in 2025 may change towards a lower power demand in the heating phase and increased cycle times.

[29] A.I.S.E. (2013). The case for the "A.I.S.E. low temperature washing" Initiative.

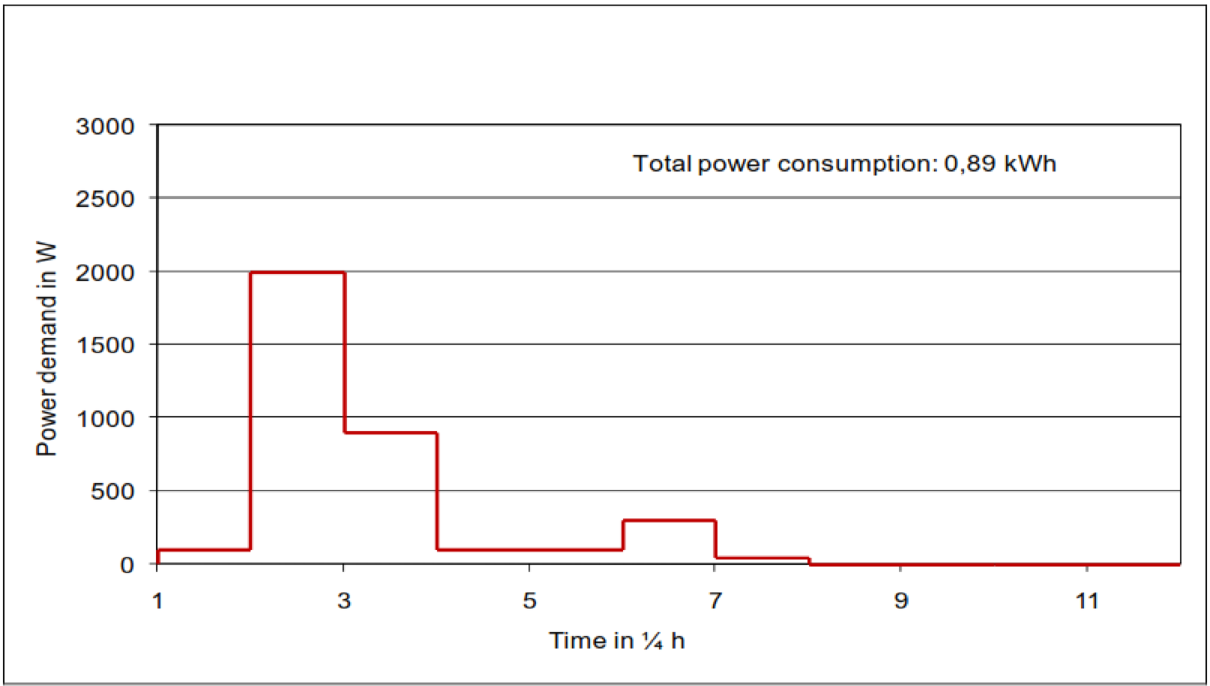

Figure 6: Typical pattern of a power demand curve of an average washing machine operating in a normal cotton programme (source: Stamminger et al., 2009[32])

It is assumed that use patterns of washing machines vary on a daily, but not on a seasonal basis. In 2007, about 2500 consumers from ten European countries were asked about the time of the day they usually use their washing machines (EUP LOT 14[26]). When looking at the results showing the frequency of operation of washing machines during the day (Figure 7), two preferred time slots can be identified, one in the morning and the second in the afternoon/ evening.

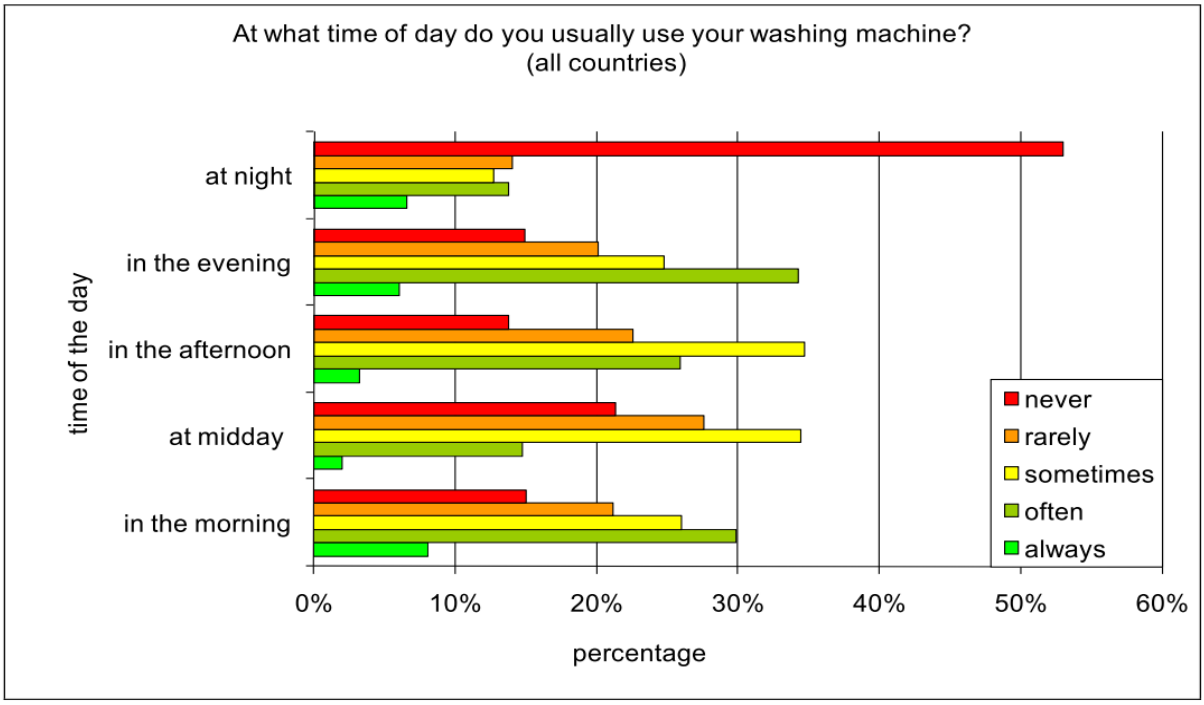

Figure 7: Frequency of operation of washing machines during the day (Source: EUP LOT 14[26])

Within the framework of the Smart-A project (Stamminger et al., 2009[32]), this information was used to deduce the probability of start time of the washing machine operation for the ten European countries investigated (Figure 8). Two major time periods can be identified for the initiation of the washing machine operation, one in the morning between 7 AM and 9 AM and one in the late afternoon/ evening period (about 4 PM-8 PM). The daily use pattern is similar for all countries investigated with the exception of Spain, where the morning peak is more pronounced, as well as Sweden and Finland, where machines are predominately operated in the afternoon/ evening hours. At present, there is no reason per se to expect that the daily use pattern of washing machines will change in the near and mid-term future.

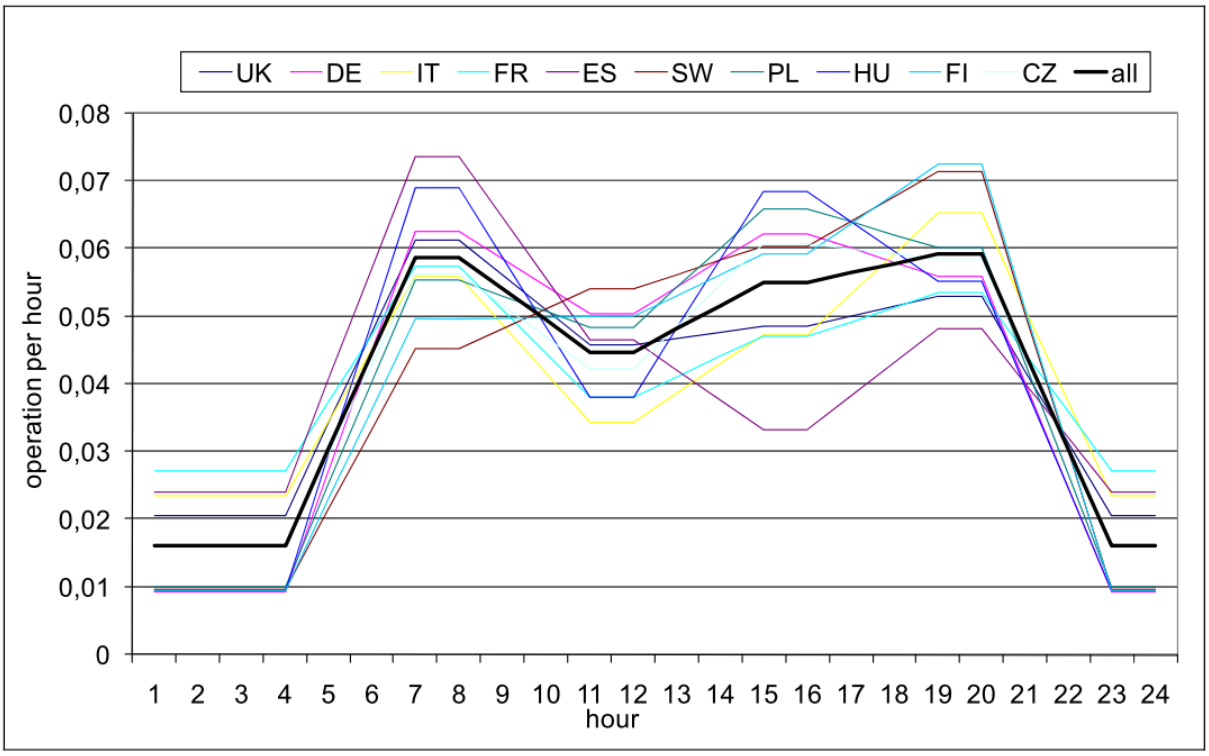

Figure 8: Probability of start time of the washing machine operation for the ten European countries investigated (source: Stamminger et al., 2009[32])

If the general pattern of a power demand curve of a current average washing machine (cf. Figure 6) is aggregated with the average probability of start time (cf. Figure 8) and an appliance-specific usage factor, which takes into account the average number of cycles per year, a general pattern of a daily load curve can be derived (Figure 9). It has to be noted that this daily load curve is based on data representing the user behaviour of only ten European countries, which are named in Figure 8. As the countries investigated cover a major part of the population of EU-28 and the user behaviour appears to be similar in these countries, it seems to be reasonable to assume that the consumer behaviour and this general pattern of a daily load curve is also valid for all EU-28 countries. If the total energy consumption of washing machines will further decrease as expected for the next years, the power demand curve will change, which will have an impact on the daily load curve as well.

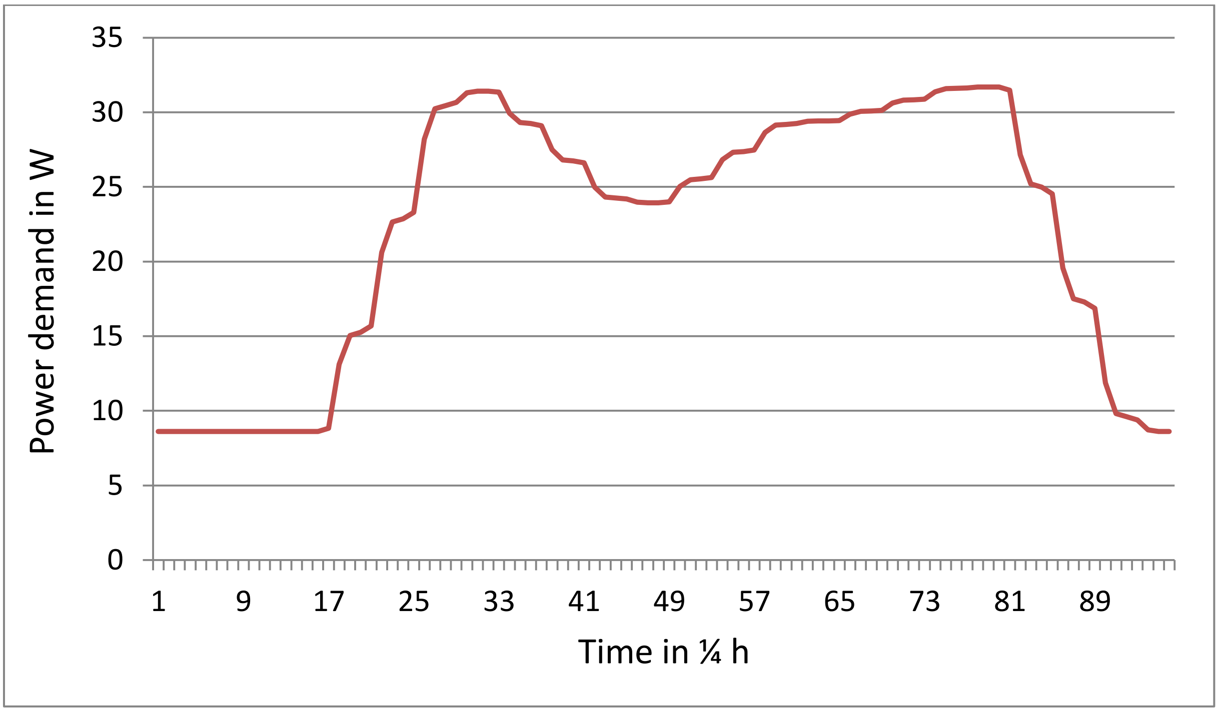

Figure 9: General pattern of a daily load curve of a current washing machine (source: modified according to Stamminger et al., 2009[32])

Tumble dryers

The usage of tumble dryers is highly dependent on the season. According to a survey conducted within the framework of the EUP LOT 16 study (Lefèvre, 2009[25]), 50 % of consumers owning a tumble dryer use it always or often during the winter season. For the summer period, less than a quarter of the consumers (24 %) gave this statement. In the same study, an average frequency of 3.6 cycles per household and week (1.1 cycles/ person/ week) was calculated for the winter and 2.3 cycles per household and week (0.7 cycles/ person/ week) for the summer season. Assuming a duration of 26 weeks per season, this corresponds to an average of 153 cycles per household per year.

A study conducted in ten European countries by Schmitz and Stamminger (2014)[28] indicates that a share of about 16 % of all drying cycles of all households are done using a tumble dryer in winter. During summer, this share is about 9 %.

Based on data published by the European Commission (2003)[30], Stamminger et al. (2009)[32] calculated an average electricity consumption of 2.46 kWh/ cycle (251 kWh per household per year). For this calculation, an annual average of 102 drying cycles per household owing a tumble dryer was assumed.

Considering a normal cotton programme and an energy consumption of 2.46 kWh per cycle, the power demand curve of a current average tumble dryer follows the pattern shown in Figure 10.

As the power demand is dependent on the process temperature and also on the amount and type of load, this pattern may vary between machines and according to the programme chosen.

Due to the Energy Label, other political measures and the increasing availability of more efficient technologies (heat pump dryer), the total energy consumption of tumble dryers in Europe is expected to further decrease within the next years. This may result in a lower power demand during the whole cycle.

[30] European Commission (2005): Green Paper on Energy Efficiency or Doing More with Less. COM (2005) 265 final.

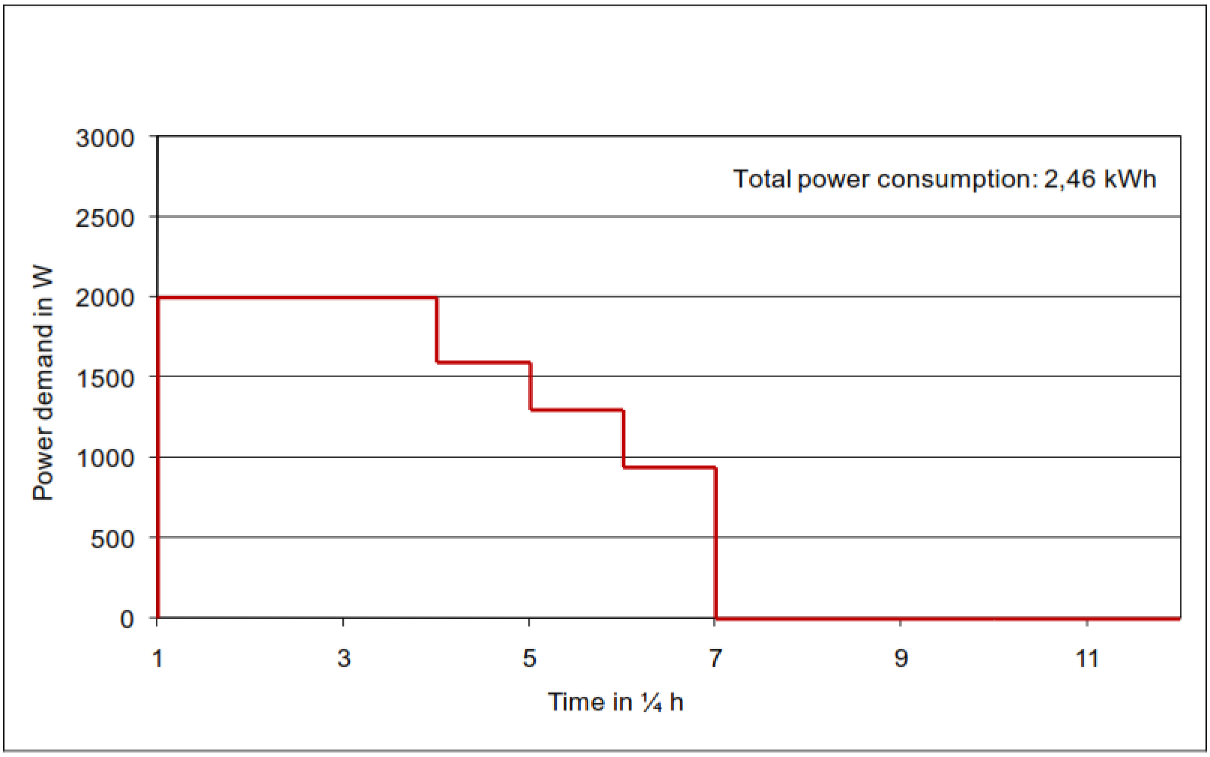

Figure 10: Typical pattern of a power demand curve of an average tumble dryer operating in a normal cotton programme (source: Stamminger et al., 2009[32])

Use patterns of tumble dryers vary both, on a daily and on a seasonal basis. According to Stamminger et al. (2009)[32], the probability of the start time of the tumble dryer operation can be derived from the respective information about washing machines (Figure 8) by simply adding two hours to the time the washing cycle is started. Normally, the washing and drying process are done consecutively. The offset of two hours is seen as an average time span between the start of these two devices. Against the background of increasing cycle times of washing machines, this offset is expected to become larger in the near and mid-term future.

If the general pattern of a power demand curve of a current average tumble dryer (cf. Figure 10) is aggregated with the average probability of start time (cf. Figure 18) and an appliance-specific usage factor, which takes into account the average number of cycles per season, a general pattern of a daily load curve can be derived (Figure 11). It has to be noted that this daily load curve is based on data representing the user behaviour of only ten European countries, which are named in Figure 18. As the countries investigated cover a major part of the population of EU-28 and the user behaviour appears to be similar in these countries, it seems to be reasonable to assume that the consumer behaviour and this general pattern of a daily load curve is also valid for all EU-28 countries. If the total energy consumption of tumble dryers will further decrease as expected for the next years, the power demand curve will change, which will have an impact on the daily load curve as well.

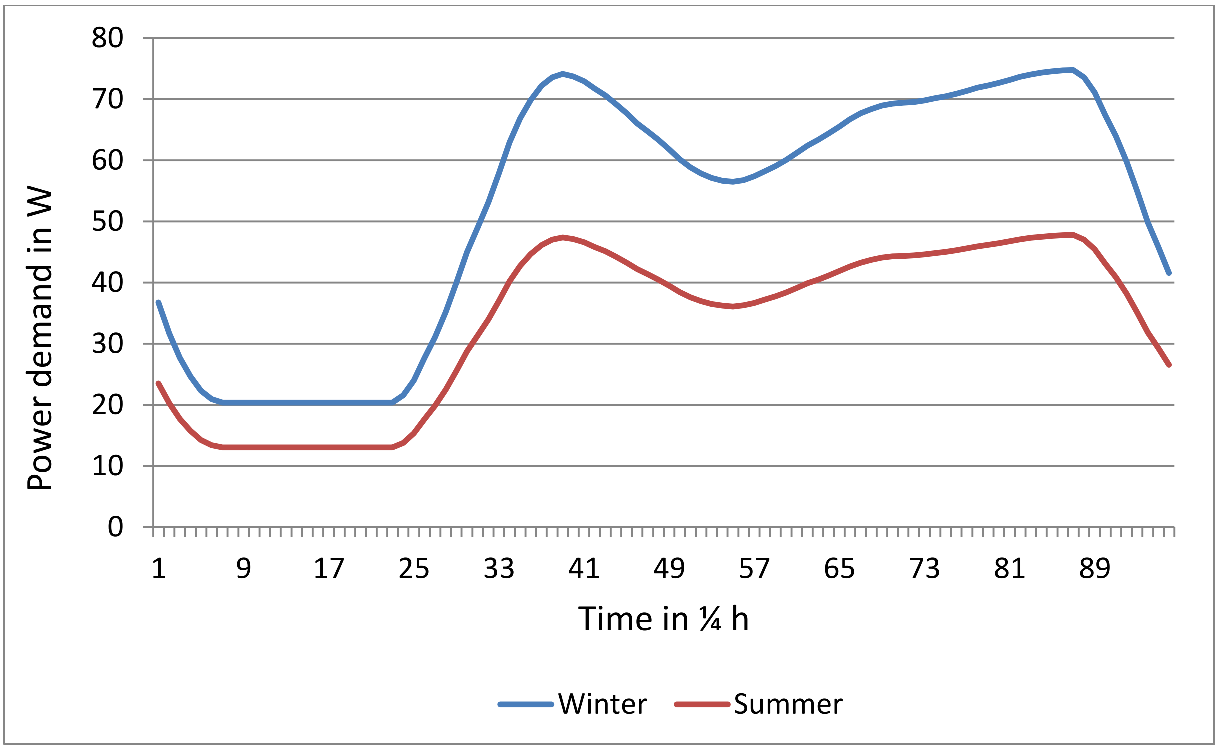

Figure 11: General pattern of a daily load curve of a current tumble dryer for winter and summer season (source: modified according to Stamminger et al., 2009[32])

Washer-dryers

According to a study by Schmitz and Stamminger (2014)[28] conducted in ten European countries, the average number of washing cycles per week and household is 4.3. This corresponds to an annual number of 224 cycles. The aforementioned study also revealed that washer-dryers are mainly used for washing purposes. The integrated drying function is only used in 29 % of all wash cycles. This means an average frequency of 1.3 times a week. Even though the majority of appliances in this study were equipped with a 'wash and dry in a row' function (no consumer interaction is needed between the washing and the drying cycle as far as the load capacities for washing and drying are respected), this function is only chosen for 24 % of all wash cycles (corresponding to 1.1 cycles per week). This might be explained by the fact that the capacity for drying is often smaller than for washing, which means that either consumer interaction would be needed to remove wet clothes partly before drying or alternatively the washing capacity cannot be used to the full extent. Another reason is the fact that not all fabrics and items are suitable for tumble drying and therefore have to be removed after the washing process.

The energy consumption of washer-dryers currently available on the market varies between 3.7 kWh and more than 6 kWh (http://www.topten.eu) for a washing and drying cycle. This wide range can be explained by the fact that only the efficient appliances are equipped with a heat pump, while the inefficient once are lacking this technology.

It is assumed that use patterns of washer-dryers vary both, on a daily and on a seasonal basis. The study by Schmitz and Stamminger (2014)[28] has shown that in summer, owners of washer-dryers predominately prefer to dry their laundry outside. About 60 % of participants in this study stated to use the drying function of the washer-dryer rarely or never during the summer season. For the winter season, only about half of the households gave this statement. Even though no data are available, it might be assumed that the probability of start time of the washer-dryer operation is equivalent to the probability pattern of washing machines (cf. Figure 8).

1.1.2.1.3 Lifespan

The average life span of periodical appliances may vary depending on the manufacturer, the model, the equipment, the use conditions and the maintenance. However, calculations and estimations from GfK and experts from industry suggest an average life span of 10 to 15 years for appliances of this category. Information that is more detailed is given in Table 2.

Table 2: Average life span of periodical appliances (Source: [a] VHK, 2014[22]; [b] EUP LOT 14[26]; [c] Lefèvre, 2009[25])

Type of appliance	Average life span
Dishwashers:	13 years[a]
Washing machines:	14 years[b]
Tumble dryers:	13 years[c]
Washer-dryers:	n.a.

1.1.2.1.4 Possibilities for consumers to engage in smart periodical appliances

In view of periodical appliances, two different possibilities to shift energy or modulate power could be identified.

1. Remote activation: the user selected program is remotely activated before the user deadline is reached.
2. Altered electricity consumption pattern: while the appliance is activated, the consumption patterns changed through pausing the operation, changing the temperatures, etc.

In the first case, the machines are remotely started, e.g., when a surplus of (renewable) energy is available on the grid. For this case, user's involvement is limited to the activation of the respective mode and the definition of a desired deadline. As the operation of a single appliance is only shifted in time, the sequence of the programme and with this, the power demand curve of a cycle, remain unchanged. In the case of washing machines or washer-dryers, the drum should be reversed after the end of the cycle until switching the machine off to avoid the laundry going mouldy or sticking together (additional energy is needed for this function, in average 10 W[31]). Appliances in this category offer a high energy shifting capacity. Studies indicate that around 30 % of the configurations of washing machines and tumble dryers can be operated with remote activation. For dishwashers this is 56 %. The average length of the time window for remote activation varies from 3 to 8 h (Mert et al. 2008[10]).

In the second case, machines may change their operation if they are triggered by an external signal, e.g., showing a shortage of energy available on the grid. Possible changes include short-term interruptions, changes in temperatures or spinning speed or shifts of single programme phases (e.g. heating or spinning phases). This may change the power demand curve of a single appliance and the overall duration of a cycle. For periodical appliances, short-term interruptions might be critical if they occur during the heating phase. Depending on their duration and the actual process temperature, heat energy may be lost to the surroundings and additional energy is needed to recover the process temperature. Investigations by Stamminger et al. (2009)[32] recommend interruptions not exceeding a time of 10 minutes in order to avoid significant losses in heat energy. A further aspect, which has to be taken into account in view of short-term interruptions, is the performance. If the operation of washing machines or tumble dryers is interrupted, for instance, the laundry may go mouldy or stick together or fading of colours may occur. In order to avoid such textile damages, the drum should be moved in regular intervals during interruptions longer than 5 minutes.

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

[31] Based on measurements of University of Bonn, not published

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

1.1.2.1.5 Comfort constraints and consumer objections

Several studies (e.g. Kobus et al., 2015[4], Saele and Grande, 2011[5], Mert et al., 2009[6], Paetz et al., 2011[11], D'hulst et al., 2015[45], Vanthournout et al., 2015[46]) have shown that the willingness of consumers to shift loads to off-peak hours is rather high for washing machines and for dishwashers. Pilot studies, however, revealed significant inter-personal differences.

In view of washing machines, concerns expressed include safety aspects (e.g. fear of flooding or fire if appliances are operated unattended or during the night). Additionally, consumers are afraid of noise during operation at night. Although the willingness to postpone wash cycles is generally high (77 % of consumers asked in the framework of the Smart-A Study would accept shifts of at least 3 hours), the fear of textile damages (e.g. getting mouldy) is becoming a critical factor for shifting operation (Mert et al., 2008[10]). Also short term power interruptions may cause textile damages like colour fading or getting mouldy and should therefore not exceed 5 minutes without tumbling (Stamminger et al., 2009[32]).

For dishwashers, consumers' acceptance of shifting loads or short term interruptions is markedly high. According to findings of the Smart-A project (Mert et al., 2008[10]), the majority of consumers would be willing to shift their operation at least for 3 hours. Since many consumers already use their dishwasher during night or absence from home, only a few of them are afraid of unattended operation, flooding, fire or noise.

In view of tumble dryers, consumer's acceptance of load shifts demand might be lower than for other periodical appliances. Normally, their operation immediately follows the washing process. If the start is postponed, consumers are afraid of textile damages and wrinkles. In the case of washer-dryers, the level of acceptance is assumed to be higher than for separate tumble dryers as no additional consumer interaction is required if the load capacity of the washing and drying function is respected. (Mert et al., 2008[10])

In a pilot study in the framework of the LINEAR project focussing on the flexibility potential of washing machines, dishwashers and tumble dryers and other wet appliances, significant shares of the flexible electricity consumption were shifted to lower price periods, whereas the dishwasher outperformed the other wet appliances in flexibility. User fatigue couldn't be observed during the project. The participants of this pilot study reported on a small impact in view of the comfort, which is not further specified. (Vanthournout et al., 2015[46])

1.1.2.2 Continuous appliances

1.1.2.2.1 Usage Behaviour

Continuous appliances are appliances that provide a capacity to store thermal energy in a form ready to be delivered to the user without any further transformation. These appliances require no interaction with the user after initial set up, although user actions can impact the appliance's operation. In this category we need to distinct between the following appliances destined for private use:

- Refrigerators
- Freezers
- Electric storage water heaters

Residential refrigerators and freezers are mostly based on a closed vapour-compression system. Besides a compressor, they consist of three main components, an evaporator, a condenser and an expansion valve. A fluid refrigerant circulates inside a closed piping system. By absorbing the heat inside the refrigerator or freezer and cooling down the air, the refrigerant evaporates to a gas and flows to the compressor, where it is compressed. The compression causes the temperature and the pressure of the refrigerant to rise. After that, the refrigerant passes the condenser, where it releases heat (equivalent to the heat absorbed inside the refrigerator/ freezer and the thermal equivalent of compressor's work) to the surroundings and becomes liquid. The expansion valve is used to expand the refrigerant and control its flow back to the evaporator. In this process, electrical energy is mainly needed to operate the compressor. Additional energy may be required for the internal light, fans, displays and automatic defrosters.

In the case of electric storage water heaters (hot water buffers), cold water is heated up by one or two direct immersion heating elements, which are located near the bottom and in the upper part of an insulated storage tank. The tank is connected to a cold water supply and has an outgoing insulated pipe for hot water, which normally supplies different taps. Wattage and voltage of electric storage water heaters vary depending on their storage capacity and the temperature range. Whereas the usual residential voltage current (230 V, 16 A) is sufficient for devices with a small storage capacity up to 30 litres, water heaters with larger tanks are frequently connected to high voltage current (~ 400 V). Besides the energy needed for heating up the water, electric storage water heaters may consume stand-by energy to maintain the desired water temperature (about 1.8-2.6 kWh per day; Stamminger et al., 2009[32]). However, water heaters and hot water storage tanks are now subject to Ecodesign requirements (COMMISSION REGULATION (EU) No 814/2013 of 2 August 2013), which regulate a decrease of standing losses. Consequently, the stand-by energy consumption to maintain a desired water temperature will reduce within the next years.

The rated power of the aforementioned appliances is shown in Table 3.

Table 3: Rated power of devices (source: Stamminger, 200918)

Appliance	Rated power of devices
Refrigerators/ freezers	50-300 W
Electric storage water heaters	2000-6000 W

For refrigerating appliances, the market penetration is extremely high reaching 1.4 appliances per EU households in 2015. This corresponds to a total of 303 million appliances in stock. (VHK, 2015[33]) During the last years, refrigerator-freezer-combinations account for the highest share of refrigerating appliances (60 % in EU-15, about 80 % in New member States; Bertoldi, Hirl, Labanca, 2012[34])

According to estimates by JRC, the installed stock of electric storage water heaters in EU-27 in 2007 was 90 million units. Electric storage water heaters with a capacity of more than 30 litres represent 27 % of the installed base of primary water heaters. (Bertoldi and Anatasiu, 2009[35])

For more information on stock data, refer to Task 2.

[32] R. Stamminger (2009): Synergy potential of smart domestic appliances in renewable energy systems. Shaker Verlag, Aachen.

[33] VHK (2015): Ecodesign & Labelling Review Household Refrigeration. Preparatory/review study Commission Regulation (EC) No. 643/2009 and Commission (Delegated) Regulation (EU) 1060/2010. Interim report

[34] Bertoldi, Hirl, Labanca (2012): Energy Efficiency Status Report 2012, Electricity Consumption and Efficiency Trends in the EU-27.

[35] Bertoldi, Atanasiu (2009). Electricity Consumption and Efficiency Trends in European Union – Status Report 2009, European Commission DG Joint Research Centre

Given the high power consumption of electric water heaters and the large installed base volumes of refrigerating appliances, the potential of this category for smart applications is assessed to be high. Therefore, these appliances are described more in detail in this chapter.

1.1.2.2.2 User behaviour concerning continuous appliances

DAILY AND ANNUAL USE PATTERN

Refrigerators

In view of refrigerators energy consumption, only limited data are available. In the preparatory study in 2005, a total energy consumption of 82 TWh/a for refrigerators (190.6 million appliances in 2005) and 40 TWh/a for freezers (54.3 million appliances in 2005) was calculated (EUP LOT 13[36]). This is corresponding to an annual consumption of about 430 kWh per appliance for refrigerators and 737 kWh for freezers. In the meantime, refrigerators have become substantially more efficient. According to latest data from Topten.eu (2015)[37], the average declared energy consumption for refrigerators sold in 2014 was 231 kWh.

Besides technical factors, the user behaviour and environmental factors determine the energy consumption of refrigerators (Geppert and Stamminger, 2013[38]). These factors include:

- Ambient temperature and humidity
- Exposure to external heat sources (direct sunlight, ovens, dishwashers, washing machines)
- Capacity
- Temperature setting
- Insertion of warm load
- Frequency and duration of door openings
- Installation (freestanding or built-in)

Previous studies have shown that the user behaviour (e.g. temperature settings, insertion of load) as well as environmental factors like ambient conditions vary largely in European countries, making it difficult to predict the energy consumption of refrigerators in real life (EUP LOT 13[36], Geppert and Stamminger, 2010[39]).

Depending on their capacity, the actual power demand of refrigerators is between 50 and 300 W, whereas Stamminger et al. (2009)[32] calculated an average of 138.2 W. Although the efficiency of compressors is still increasing, it can be assumed that this average power demand remains constant over the next years due to a trend towards higher capacities. Under normal conditions, the compressor is working intermittently with a total operation time of about 1/3. However, this operation time may increase up to 100 % under extreme conditions (extremely high ambient temperatures, large amount of hot load). Figure 12 shows a typical pattern of a power demand curve of a refrigerator.

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[36] Preparatory Studies for Eco-design Requirements of EuPs. LOT 13: Domestic Refrigerators & Freezers. Final Report

[37] Topten.eu (2015): Energy efficiency of white goods in Europe: monitoring the market with sales data. Available online: http://www.topten.eu/uploads/File/WhiteGoods_in_Europe_June15.pdf (latest 10-03-2015)

[38] Geppert and Stamminger (2013): Analysis of effecting factors on domestic refrigerators' energy consumption in use Energy Conversion and Management, Volume 76, December 2013, Pages 794-800.

[39] Geppert and Stamminger (2010): Do Consumers Act in a Sustainable Way Using Their Refrigerator? The Influence of Consumer Real Life Behaviour on the Energy Consumption of Cooling Appliances International Journal of Consumer Studies, 34(2), 219-27

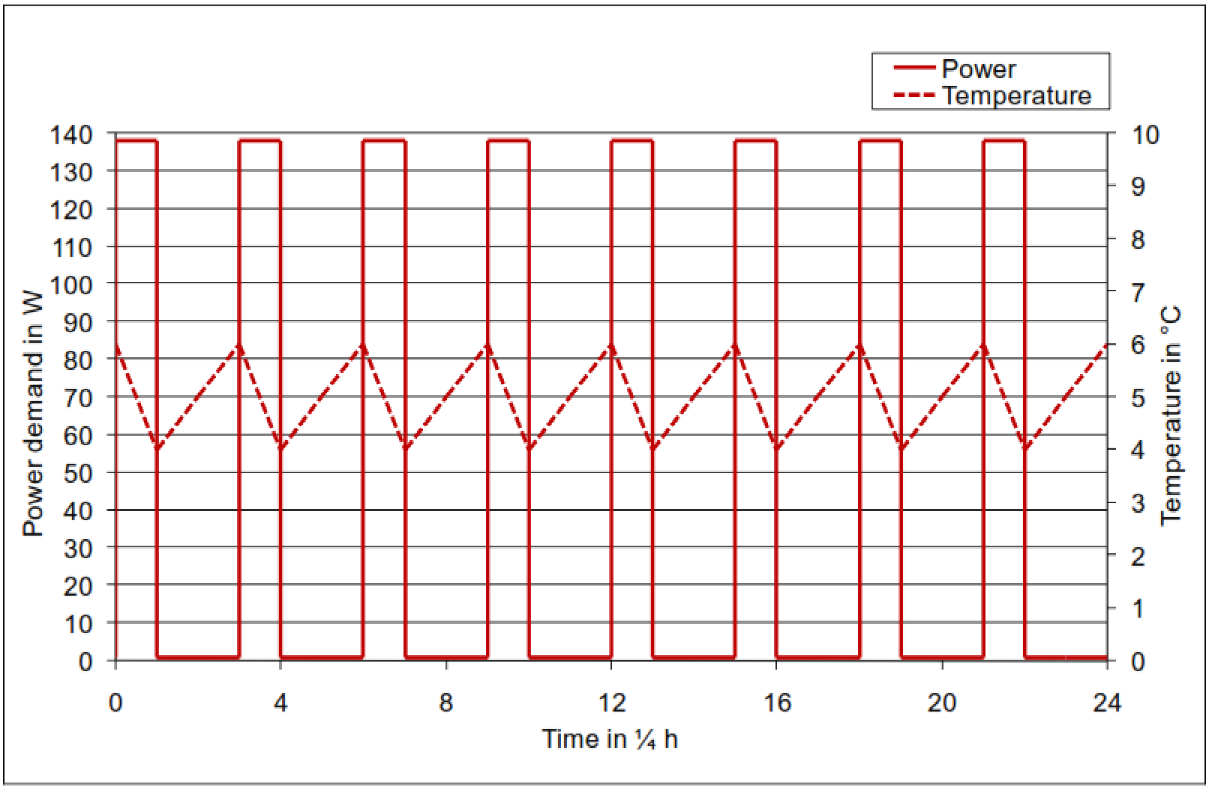

Figure 12: Typical pattern of a power demand curve of a refrigerator (Source: Stamminger et al., 2009[32])

It is assumed that use patterns of refrigerators mainly vary on a daily basis. Seasonal variations due to differences in ambient temperatures are only weak and may be neglected as refrigerators are normally located inside closed rooms where the temperature is nearly constant all over the year. In view of daily variations, results of a study in different European households by Thomas (2007)[40] suggest an increased use in the afternoon/ evening period (Figure 13). It seems reasonable to assume that this usage pattern will not change within the next decade.

[40] Thomas S. (2007): Erhebung des Verbraucherverhaltens bei der Lagerung verderblicher Lebensmittel in Europa. Shaker Verlag, Aachen.

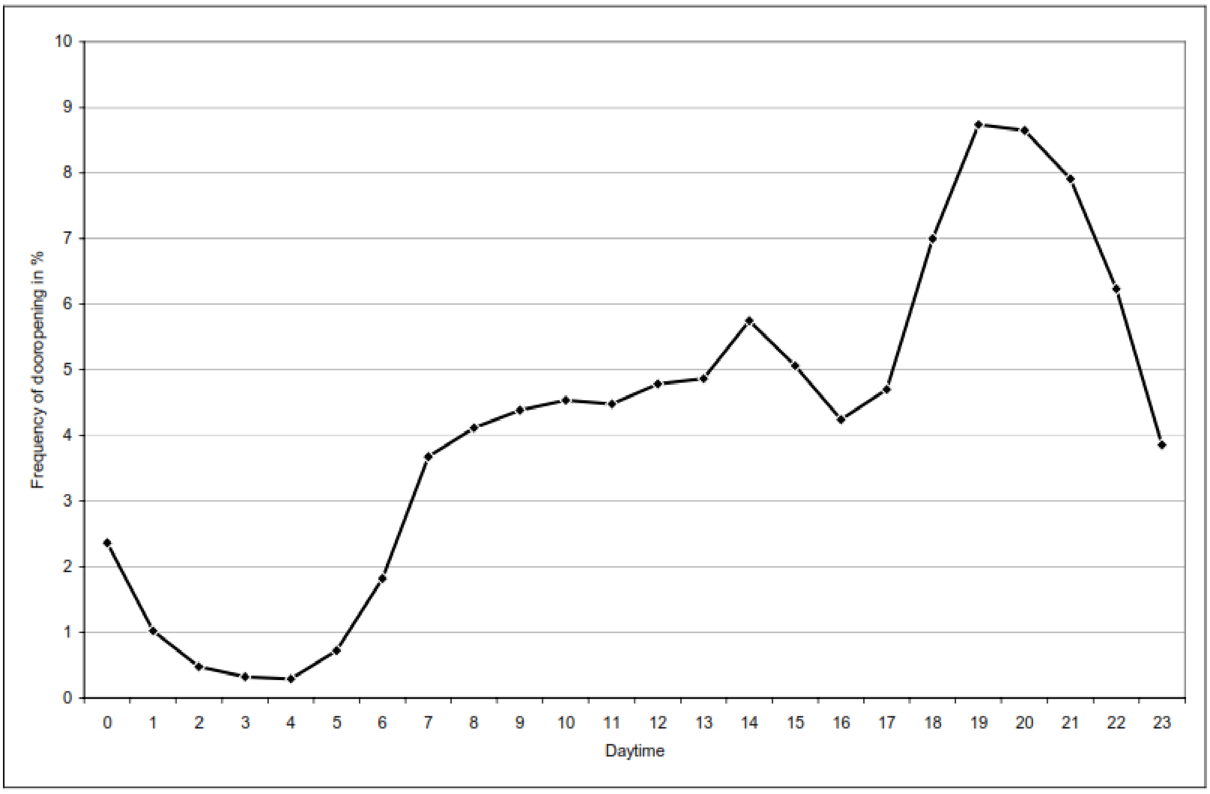

Figure 13: Frequency of door openings during the day (source: Thomas, 2007[40])

If the typical pattern of a power demand curve of a refrigerator (shown in Figure 12) as well as the daily usage pattern (cf. Figure 13) are taken into account and it is assumed that 25 % of the total energy consumption is caused by this usage (e.g. door opening, placing of warm food), a typical daily load curve of an average refrigerator in Europe will follow the pattern shown in Figure 14. (Stamminger et al., 2009[32])

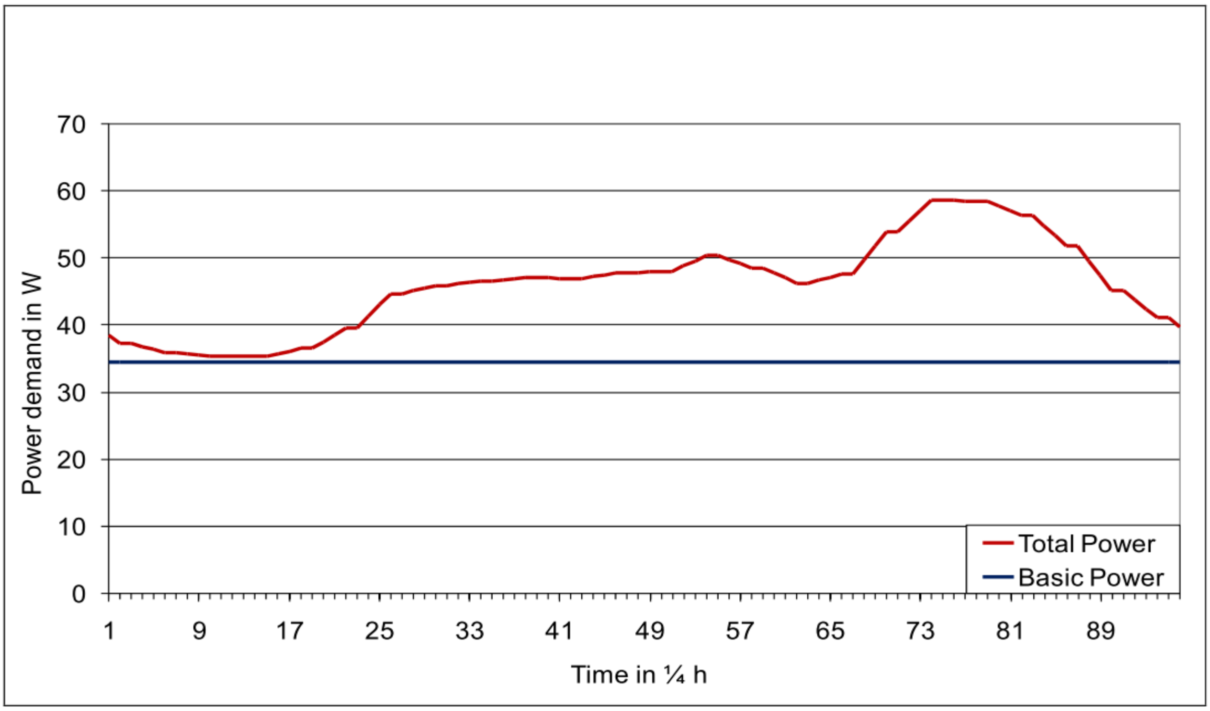

Figure 14: General pattern of a daily load curve of an average refrigerator (source: Stamminger et al., 2009[32])

Freezers

In view of freezers energy consumption, only limited data are available. In most cases, no distinction is made between refrigerators and freezers. In the preparatory study in 2005, a total energy consumption of 40 TWh/ year for freezers (54,292 million appliances in 2005) was calculated (EUP LOT 13[36]). This is corresponding to an annual consumption of about 737 kWh per appliance. In the meantime, freezers have become substantially more efficient.

As described for refrigerators, user behaviour and environmental factors determine the energy consumption of freezers (Geppert and Stamminger, 2013[38]). These factors include:

- Ambient temperature and humidity
- Exposure to external heat sources (direct sunlight, ovens, dishwashers, washing machines)
- Chest vs. upright freezers
- Capacity
- Insertion of frozen load
- Insertion of load to freeze
- Frequency and duration of door openings
- Installation (freestanding or built-in)
- Activation of “super frost” function

Previous studies have shown that the user behaviour (e.g. temperature settings, insertion of load) as well as environmental factors like ambient conditions vary largely in European countries, making it difficult to predict energy consumption of freezers in use (EUP LOT 13[36], Geppert and Stamminger, 2010[39]).

Depending on their capacity, the actual power demand of freezers is between 50 and 200 W, whereas Stamminger et al. (2009)[32] calculated an average of 105.5 W. Under normal conditions, the compressor is working intermittently with a total operation time of about 1/3. However, this operation time may increase up to 100 % under extreme conditions (extremely high ambient

temperatures, large amount of unfrozen load). The typical pattern of a power demand curve of a freezer without any consumer interaction is similar to that of refrigerators shown in Figure 12.
It is assumed that use patterns of freezers vary on a daily and on a seasonal basis. Ambient temperatures are often higher during the summer (EUP LOT 13[36]), resulting in an increased operation time of compressors. The most common temperature setting is -18 °C and this setting remains unchanged in the majority of households (EUP LOT 13[36]). On a daily basis, consumer's interaction with freezers is normally very limited. According to estimations by Stamminger et al. (2009)[32], consumers open their freezers about one to two times per day to take out frozen food (mostly in the afternoon/ evening period) and one to three times per week to place unfrozen food. Opening the freezer's door once and taking out frozen food doesn't have a significant impact on the energy consumption. However, the operation time of the compressor and consequently the energy consumption will increase if new goods have to be cooled down and frozen. To avoid excessive rises in temperature and defrosting of frozen food after storing new goods, consumers can activate a "super frost" function in preparation. This function forces the freezer to cool down to a lower than the normal temperature. Nevertheless, the temperature inside the freezer will increase as soon as unfrozen food is placed, and the compressor operates non-stop until the heat is removed. After switching off the "super-frost" function, the temperature raises back to the initial one, accompanied by a pause in compressor's operation. These changes in power demand curve are illustrated in Figure 15.

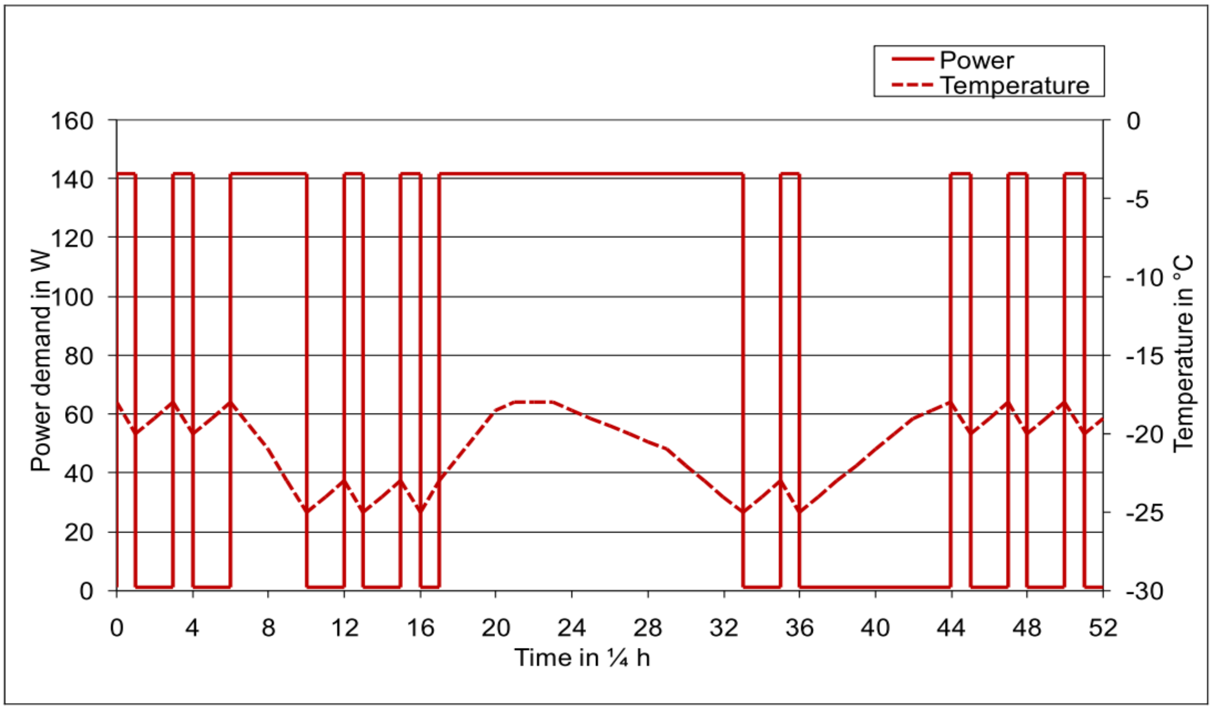

Figure 15: Typical pattern of a power demand curve of a freezer during storage of new goods to be frozen (source: Stamminger et al., 2009[32])

If the consumer behaviour is taken into account and it is assumed that 10 % of the total energy consumption is caused by this consumer behaviour (e.g. placing unfrozen food), a typical daily load curve of an average freezer in Europe will follow the pattern shown in Figure 16. (Stamminger et al., 2009[32])

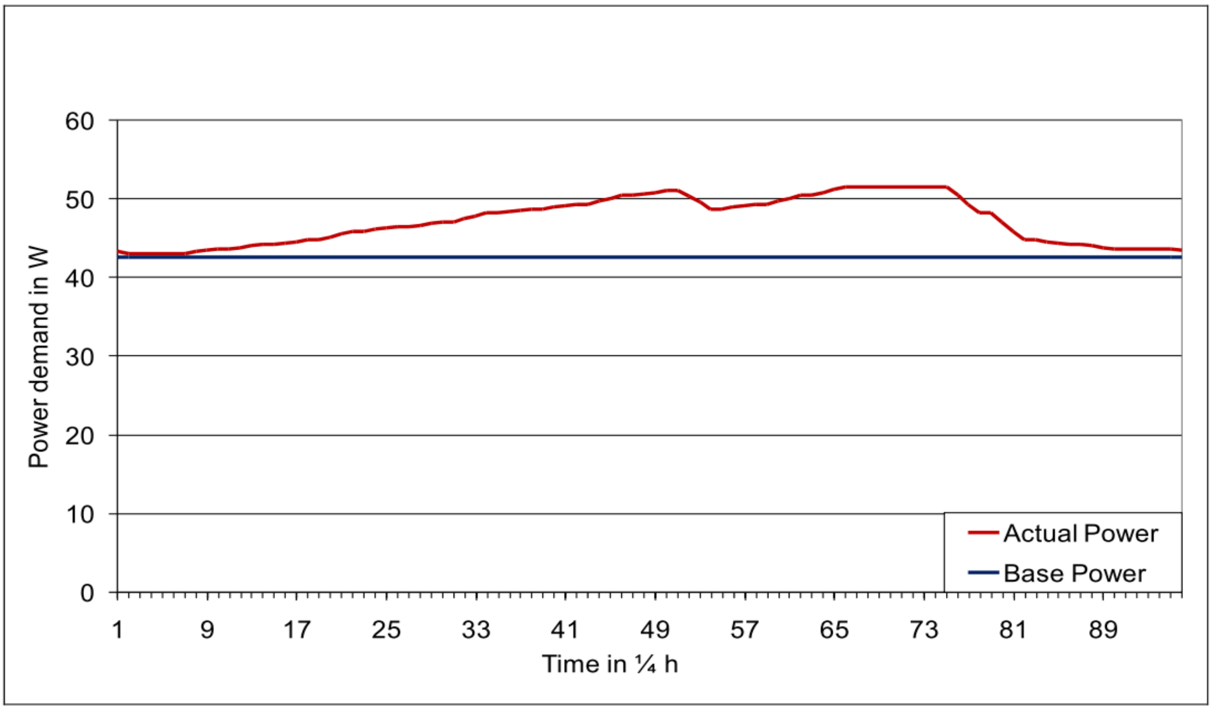

Figure 16: General pattern of a daily load curve of an average freezer (Source: Stamminger et al., 2009[32])

Electric water heaters

According to Bertoldi et al. (2012)[35], electric water heaters consumed 8.7 % of total residential electricity consumption in 2007, corresponding to 73.0 TWh/ year. Taking into account the installed stock in EU-27 in 2007 (in total 119 million devices[*]), an average annual consumption of about 613 kWh per appliance can be calculated.

As described for refrigerators and freezers, the energy consumption of electric water heaters is also significantly affected by user's behaviour and environmental factors:

- Number of people per household
- Frequency, duration and timing of showers or baths per person
- Number and usage of appliances connected to hot water supply (e.g. dishwashers, washing machines)
- Manual dishwashing habits
- Use of hot water for cooking

In 2007, the preparatory study on water heaters (EUP LOT 2[41]) calculated an average hot water consumption of 24 litres per person per day for EU-25, corresponding to an average of 59 litres per household per day. However, there are considerable differences between different member states as shown in Figure 17.

[41] Preparatory Study on Eco-design of Water Heaters. Final report.

[*] Includes storage and instantaneous appliances

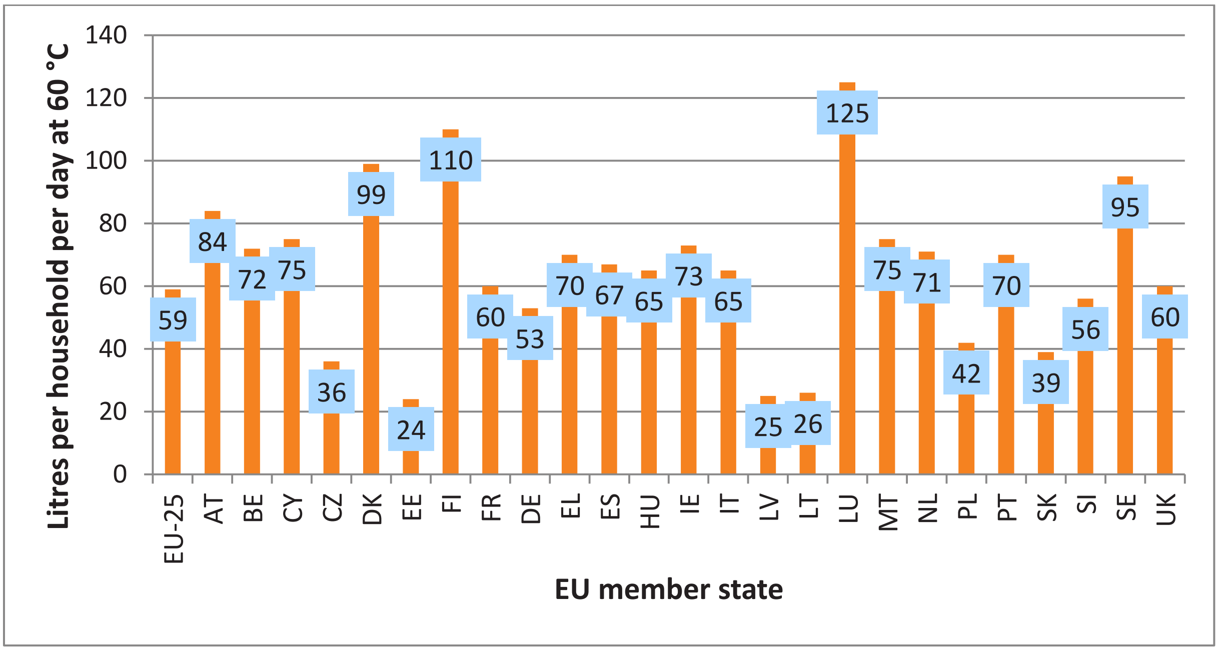

Figure 17: Hot water consumption per household per day for EU-25 (source: own illustration based on EUP LOT 2[41])

Due to changes in consumer behaviour and variations in temperature of the incoming (cold) water, seasonal variations in use pattern of electric water heaters can be assumed. In-home measurements of water temperature and water consumption in 20 multi-family houses in Switzerland in 1993 have shown that the hot water temperature remained unchanged at about 60 °C all year. Concerning the hot water consumption per day, the study revealed significant seasonal effects. Additionally, a dependency on the weekdays could be observed (Figure 18).

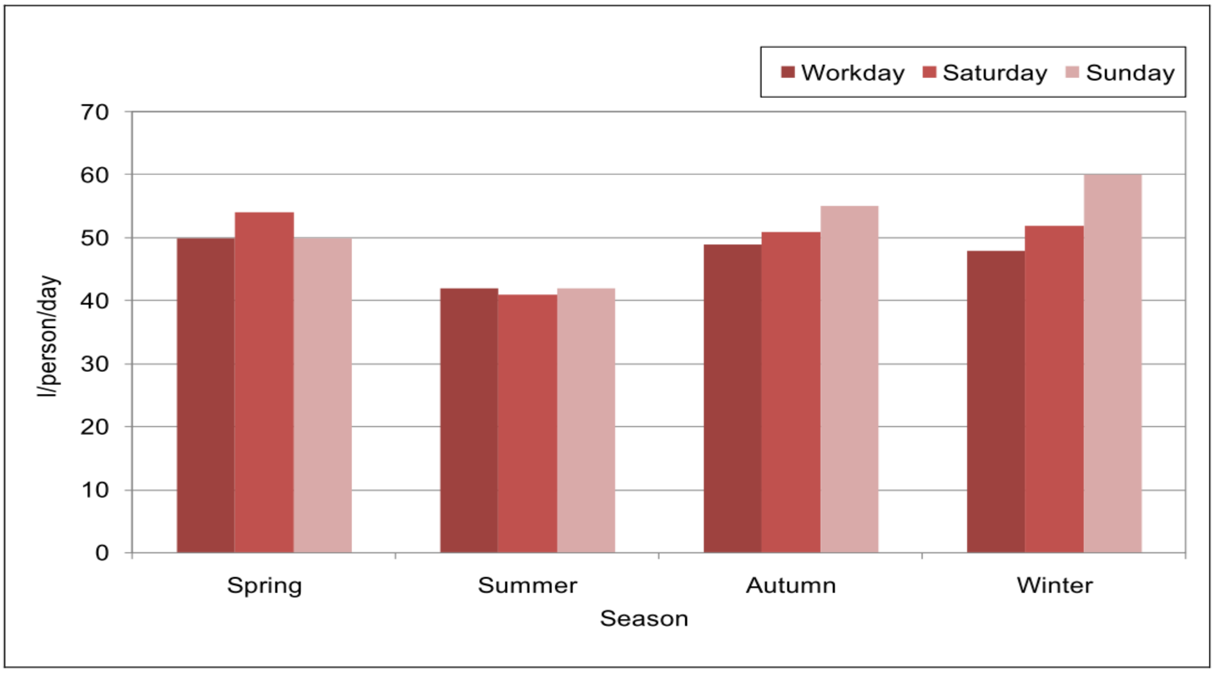

Figure 18: Daily hot water consumption by season and weekday (source: BfK, 1993; taken from Stamminger et al., 2009[32])

Besides seasonal variations, use pattern of electric water heaters also varies on a daily basis.

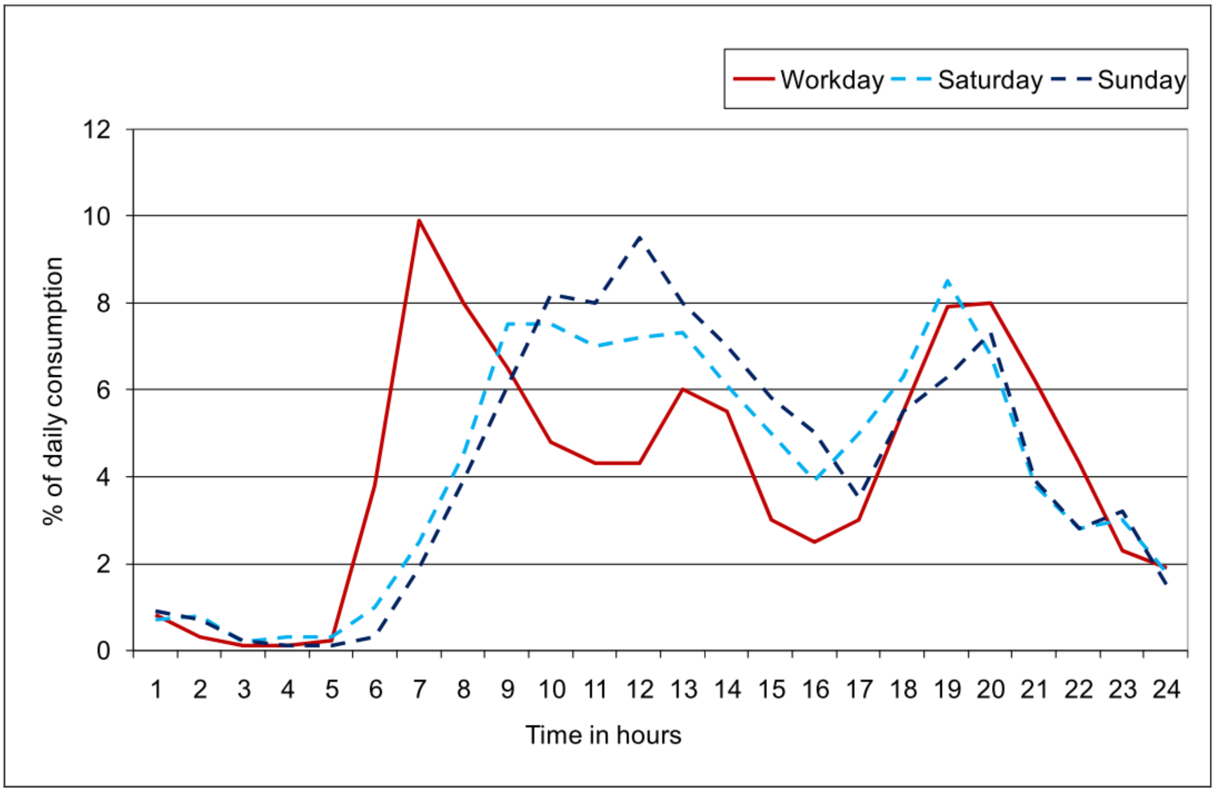

Figure 19: Profile of daily hot water consumption (source: BfK, 1993[42]; taken from Stamminger et al., 2009[32])

On working days, two peaks can be observed, one in the morning between 6 a.m. and 9 a.m. and one in the evening period between 7 p.m. and 10 p.m. (Figure 19). Whereas the morning peak is postponed by about 4 hours (between 10 a.m. and 2 p.m.) during the weekend, the evening peak almost remains unchanged. Defra (2008)[43] more recently published a similar daily profile measured in UK. For this reason, it seems to be reasonable to assume that the daily profile shown in Figure 19 is still valid today.

In view of power demand curves of storage water heaters, it has to be distinguished between three main types: storage heaters, which heat during the night only, storage heaters, which heat during the night and maintain the water temperature during the day and continuous water heaters, which heat continuously (hot water buffers). Information about the distribution of these three types of storage water heaters is scarce. According to estimations by a manufacturer, water heaters heating during the night are the prevailing type in France and Germany, whereas continuous storage water heaters are predominately used in Spain, Italy, Hungary, Czech Republic and Poland. In UK, both types are common. Data on the distribution in other European Countries are currently not available. (Stamminger et al., 2009[32])

General patterns of power demand curves for all three types of storage water heaters are given in Figure 20. The orange line shows a typical power demand curve of a heating device with a storage

[42] Bundesamt für Konjunkturfragen, 1993: Blatter, Borel, Hediger, Simmler: Materialien zu RAVEL. Warmwasserbedarfszahlen und Verbrauchscharakteristik. Bern.

[43] Defra, 2008: Measurement of Domestic Hot Water Consumption in Dwellings. URL: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48188/3147-measure-domestic-hot-water-consump.pdf

capacity of 300 l and a rated power of 4 kW. The blue graph depicts the power demand curve of the same device. However, the water temperature is maintained during the day. For continuous storage water heaters (green graph), a rated power of 2.7 kW, a hot water consumption of 160 l and a temperature difference of 28 K was assumed and the profile of the daily hot water consumption (Figure 19) was taken as a basis. The power demand curve needs to fit the respective total energy consumption, which is dependent, amongst others, on the amount of water to be heated. (Stamminger et al, 2009[32])

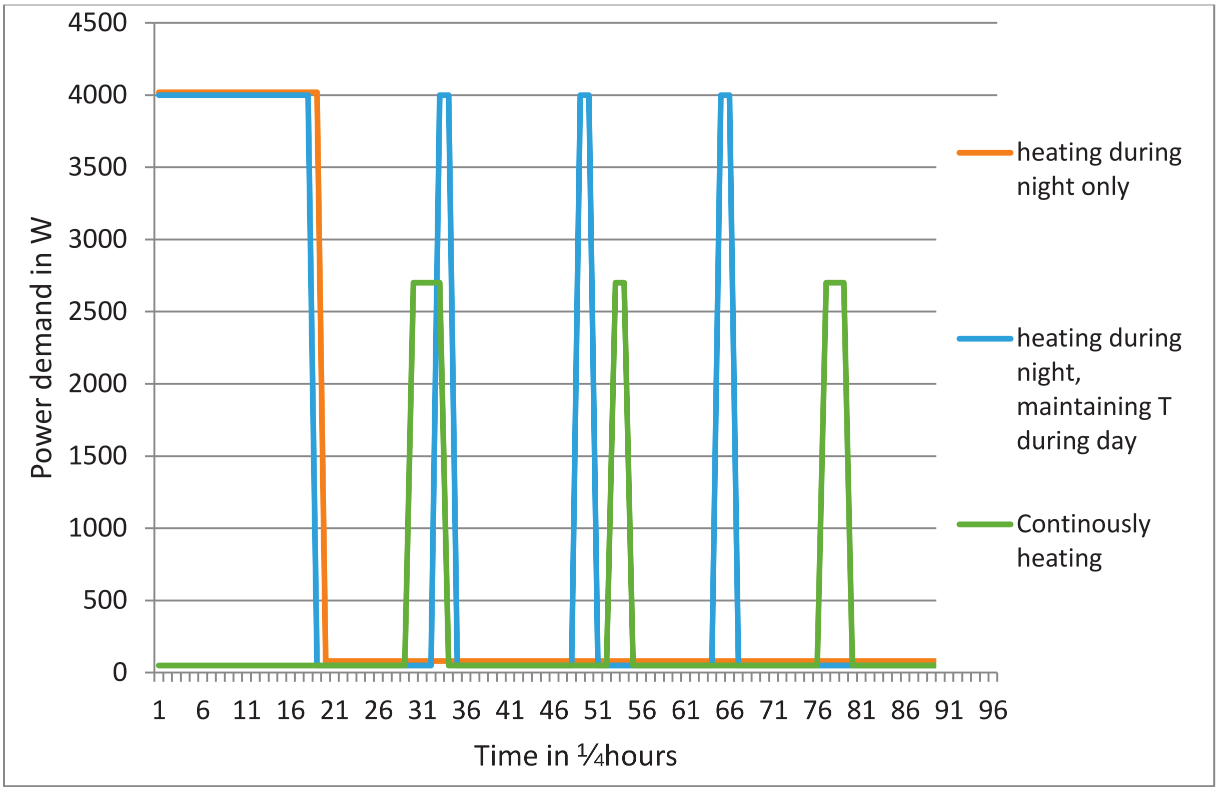

Figure 20: General pattern of a power demand curve for different types of storage water heaters (source: own illustration based on Stamminger et al., 2009[32])

If the profile of the hot water consumption during weekdays (cf. Figure 8) is combined with the general pattern of a power demand curve of a 2.7 kW continuous storage water heater heating up 160 l (Δ T= 28 K; cf. Figure 9), a typical pattern of a daily load curve (Figure 10) can be derived. It has to be noted that this daily load curve is just an example. As the pattern is dependent on the total amount of water to be heated, the temperature difference and the rated power, it is only valid under the conditions specified before. Due to huge variations in conditions between different countries and even between households in the same country, it is impossible to give a general pattern of a daily load curve of storage water heaters.

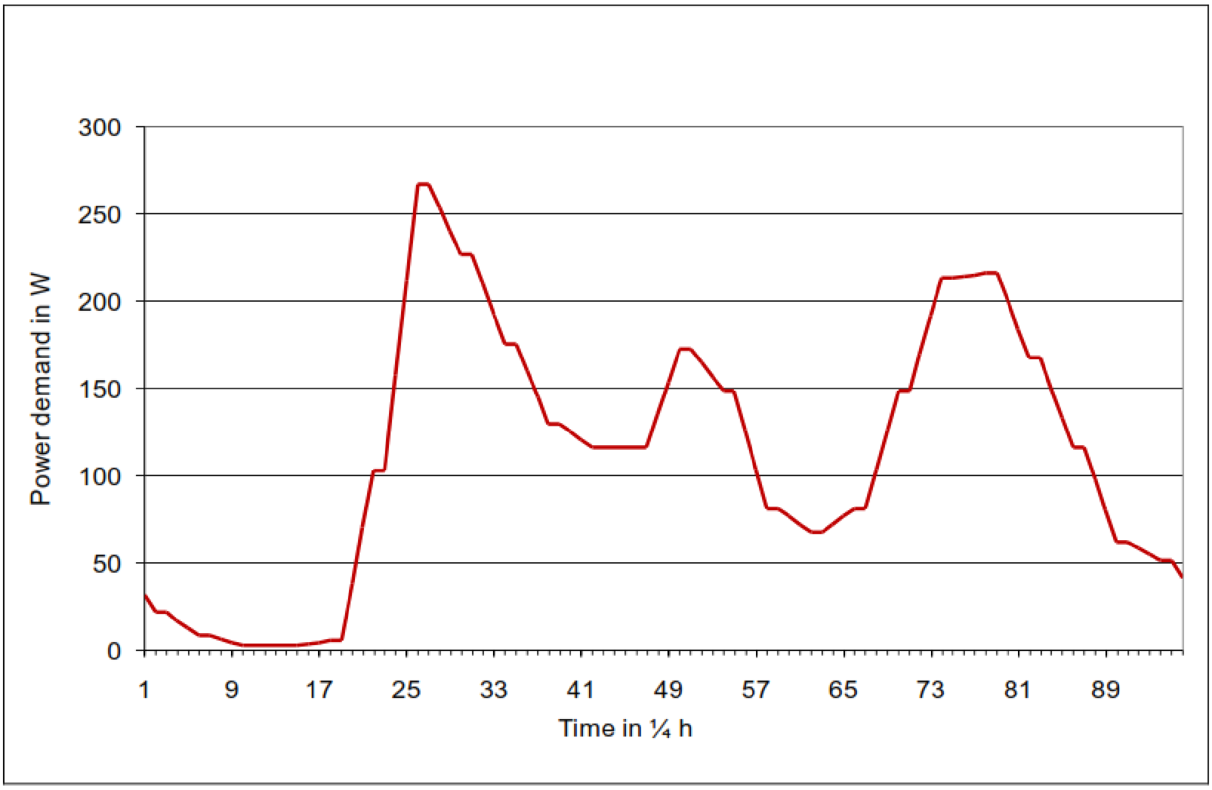

Figure 21: Typical pattern of a daily load curve of a 2.7 kW storage water heater continually heating (source: Stamminger et al., 2009[32])

1.1.2.2.3 Lifespan

The average life span of continuous appliances may vary depending on the manufacturer, the model, the equipment, the use conditions and the maintenance. Average data are given in Table 2.

Table 4: Average life span of continuous appliances (Source: [a] CECED, 2006[44]; [b] EUP LOT 2[41])

Type of appliance	Average life span
Refrigerators:	13 years[a]
Freezers:	17 years[a]
Storage water heaters:	15 years[b]

1.1.2.2.4 Possibilities for consumers to engage in smart continuous appliances

In view of continuous appliances, two different possibilities to shift energy or modulate power could be identified.

1. Power line triggered operation (e.g. frequency control): changes in frequency are detected by appliances and transferred into action (activation or delay of cooling or heating).
2. Altered electricity consumption pattern: changes in the operational parameters of the appliance (motor speed, temperature settings, etc.) allow modification of the consumption pattern.

[44] CECED, 2006: Energy Efficiency, A shortcut to Kyoto Targets. The Vision of European Home Appliance Manufacturers.

In the first case, the appliances are activated when a surplus of energy/ renewable energy is available on the grid, communicated e.g. via power line frequency or other control signals. In the following, the procedure is explained taking the example of frequency control.

Both, surplus and shortage of energy have an impact on the total load on the grid and thus the frequency. These changes in frequency can be detected by appliances of this category and transferred into a respective action.

If power shortage is for example indicated during the operation of a refrigerator's compressor, the compressor will stop its operation even if the temperature, at which the thermostat normally switches off, is not reached. On the other hand, if there is a surplus of energy available on the grid, the compressor will start to operate even if the maximum temperature, at which the thermostat normally switches on, is not reached yet. In this way, the upper and lower temperature limits will not be exceeded. The hysteresis rather gets smaller and as a consequence, the food quality will not be compromised. For freezers, the same scenario is applicable. In the case of storage water heaters, a surplus of energy may prepone the start of the heating process and a power shortage may interrupt it for a short period of time. In the case of frequency control, appliances operate fully automatic so that no consumer interaction is required. In response to the load on the grid, frequency control may change the on-off cycle of refrigerators and freezers and may prepone or delay start of electric storage heaters or interrupt their operation by seconds or minutes.

In the second case, the appliances are remotely controlled and may change their operation. For refrigerators and freezers, possible changes include pre- or postponed start of the compressor, changes in temperature hysteresis or motor speed/ power level. In view of water heaters, the following changes are possible: delay in start or interruption of heating phase, preponing operations for storing energy in anticipation of future use in the coming hours, reducing water temperature desired. In order to enable remote control of appliances, a bidirectional communication is needed. This may change the power demand curve of a single appliance (e.g. shift in operation by seconds or minutes or changes in motor power) and the overall duration of a cycle.
The complexity of technical adjustments and redesign needed is higher for the second than for the first option.
For appliances in this category, flexibility depends on the thermal storage capacity. Flexibility is mainly situated in the afternoon (refrigerators and freezers) and in the early morning (electric water heaters). The flexibility of hot water buffers remains to a great extent stable during the day (D'hulst et al., 2015[45]). Whereas for refrigerators and freezers, seasonal effects are only weak, water heater loads are highly seasonal with highest potential occurring in winter.

1.1.2.2.5 Comfort constraints and consumer objections

In order to prevent microbial growth and quality losses of food, the temperature inside the compartment of refrigerators has to be kept constant within narrow ranges. As a result, delays in start time, short term interruptions and changes in temperature hysteresis are only feasible to a limited extent. Whereas it is possible to store energy by cooling to lower than normal storage temperatures in the case of freezers, this possibility is limited in the case of refrigerators because of the risk of freezing sensitive food and loosing food quality.
Although the acceptance for smart operation of refrigerators and freezers is generally high (96-98 % of consumers asked in the framework of the Smart-A Study would accept shifts), the fear of food spoilage or deterioration is becoming a critical factor (Mert et al., 2008[10]). Additionally, consumers raised doubts concerning a safe operation of the technology. To provide failure –resistant

[45] D'hulst, Labeeuw, Beusen, Claessens, Deconinck, Vanthournout (2015): Demand response flexibility and flexibility potential of residential smart appliances: Experiences from large pilot test in Belgium. Applied Energy 155: 79-90.

technologies and the possibility to monitor easily the storage temperatures might help to overcome these concerns (Mert et al., 2008[10]).
In view of electric storage water heaters, it is essential for a high consumer acceptance to always ensure a sufficient amount of hot water. Consequently, shifts in operation are limited, especially for water heaters with small storage capacities. In terms of devices with large storage capacities, operation shifts are possible without comfort or user impact. Operation of water heaters may also be adapted to shortages of power on the grid by reducing the desired water temperature (at present about 60 °C). However, this scenario might be critical from a hygienic point of view as the growth of microorganisms such as *Legionella* can only be reliably prevented at higher water temperatures of about 60 °C. In the framework of the LINEAR project, user acceptance with smart domestic hot water buffers was examined (Vanthournout et al., 2015[46]; Linear[47]). In order to avoid losses in comfort, some measures were used in the aforementioned study. So, a minimum state of charge was defined determining that the state of charge may not be less than 30 %. If the state of charge comes below this value, the buffer is automatically recharged until reaching a value higher than 30 %. These measures proved effective during the study as none of the participants complained about comfort losses. Due to the fact that no further consumer interaction is required once the comfort settings are done, consumer's acceptance for smart operation of domestic hot water buffers was high. Also in the study by Mert et al., 2008[10], participants predominately stated to accept smart operation of water heaters as long as there is no loss of comfort.

1.1.2.3 Behavioural appliances

1.1.2.3.1 Usage Behaviour

Behavioural appliances are appliances where the operation is linked to its functionality and whose operations require the active involvement of consumers. In this category there are the following appliances destined for private use:

- Electrical hobs
- Electric ovens
- Range hoods
- Vacuum cleaners
- Instantaneous water heaters

Regarding **electric hobs,** three main types may be distinguished: sealed hobs using solid plates made of cast iron, ceramic hobs heated with a halogen heating element and induction hobs. In the case of sealed hobs, heat is transferred via thermal conduction. In view of ceramic hobs, a halogen heating element is producing the heat, which is transferred to the cooking ware by radiation and conduction. Induction hobs create heat energy inside the cookware itself by inducing turbulent electric flow in its bottom. In all three cases, electrical energy is mainly needed for heating processes. Additional energy may be required for displays.
In the case of **electric ovens**, a variety of heating methods can be used including top and bottom heat, fan heat, grill and combinations of them. The heat is mainly transferred via radiation and, to a minor degree, by convection. Normally, temperatures can be set between 50 and 300 °C. Besides the energy needed for heating processes, electric ovens may consume stand-by energy (e.g. display, clock, and programme). Additional to single ovens, combinations of hobs and ovens (called cookers) are available and very common in the European market. (Stamminger et al., 2009[32])

[46] Vanthournout, Dupont, Foubert, Stuckens, Claessens (2015): An automated residential demand response pilot experiment, based on day-ahead dynamic pricing. Applied Energy 155: 195-203.
[47] Linear (local intelligent networks and energy active regions): www.linear-smartgrid.be

In view of electric **range hoods**, a variety of types and sizes are available on the market, including wall-chimney-hoods, island hoods, under-cabinet hoods or downdraft hoods. Their main function is to remove airborne grease, combustion products, smoke, fumes and odours coming from cooking processes. Range hoods can either be vented or ductless. Vented hood exhaust the air to the outside of the house by using a fan. On its way to the outside, the air passes one or more grease filters. Ductless hoods use several filters (e.g. activated charcoal) to clean the air and recirculate it back to the kitchen. Energy is mainly consumed by the fan. Additional energy may be required for lighting, displays and for stand-by losses.

Vacuum cleaners are appliances that suck up dust and particles from the floor and other surfaces by creating a partial vacuum. The main components are a fan, which is driven by a motor, different filters and nozzles. There are many different designs and technologies available on the market, e.g. canister, drum, upright, hand-held, robotic, cyclonic, bag less, bagged, wet-and-dry vacuum cleaners. Energy is mainly needed to operate the motor/ to create the partial vacuum.

In view of **instantaneous water heaters**, water is instantly heated up by passing the device. Heater rods of bare wire are often preferred for these devices. Due to their high wattage, instantaneous water heaters need to be connected to high voltage current (~ 400 V). In contrast to electric storage heaters, hot water is not stored and consequently no stand-by energy is required to maintain water at a desired temperature.

The rated power of the aforementioned appliances is shown in Table 5.

Table 5: Rated power of devices in stock (source: [a]Schätzke[48], 1997; [b]HEA[49]; [c]EUP LOT 17[50], [d]Stamminger et al., 2009[32])

Appliance	Rated power of devices
Electric hobs	100-2,000 W (per plate)[a]
Electric ovens	Up to 3,500 W
Electric cookers	8,000-13,000 W[b]
Range hoods	120-1,000 W[b]
Vacuum cleaners	1,000-2,700 W[c]
Instantaneous water heaters	2,400-27,000 W[d]

Since September 2014, vacuum cleaners are subject to Ecodesign requirements, which regulate a progressive decrease of rated input power (European Commission, 2013[51]). Consequently, the average rated power will reduce within the next years.

According to the EUP LOT 23[52] report, 145.7 million electric hobs (solid plates, radiant and induction hobs, mixed hobs, electric cooker tops) were in stock in 2007, corresponding to a penetration rate of 71 % (assumption: 205 million households). The overall trend shows that the share of electric hobs (especially induction hobs) will increase during the next years with slightly decreasing shares of gas fuelled hobs. However, there are variations between the member states with some favouring electric (e.g. Germany and Sweden) and some gas fuelled hobs (e.g. Italy).

[48] Kutsch, Piorkowsky, Schätzke (1997): Einführung in die Haushaltswissenschaft. Haushaltsökonomie, Haushaltssoziologie, Haushaltstechnik. Stuttgart 1997

[49] HEA (2015): Fachwissen Elektroherde. Available online: http://www.hea.de/service/fachwissen/elektroherde/

[50] Work on Preparatory Studies for Eco-Design Requirements of EuPs (II). Lot 17 Vacuum Cleaners. Final report

[51] European Commission (2013): COMMISSION REGULATION (EU) No 666/2013 of 8 July 2013 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for vacuum cleaners

[52] Preparatory Studies for Eco-design Requirements of EuPs (III) Lot 23 Domestic and commercial hobs and grills, included when incorporated in cookers. Final report

The penetration rate (EU-15) for electric fuelled ovens in 1998 was 61 % (Kasanen, 2000[53]). Sales figures from 2006 (96 % of all build-in units were electric ovens) admittedly show a trend towards an increasing share of electric ovens (EUP LOT 22[54]). There are differences across the member states with some preferring electric ovens (e.g. Scandinavian countries) and some preferring gas fuelled appliances (e.g. Spain and Ireland).
In view of range hoods, the EUP LOT 10[55] report on ventilation indicates about 36 million hoods in stock in 2005 and about 39 million in 2010. Consequently, the penetration rate is about 19 % but is estimated to increase within the next years.

According to the EUP LOT 17 report[50], the European market for vacuum cleaners is already oversaturated meaning that on average, every household has such an appliance and some households even have more than one.

According to estimates by JRC, the installed stock of instantaneous water heaters in EU-27 in 2007 was 29 million units. Instantaneous water heaters (> 12 kW) represent a share of 6.6 % of the installed base of primary water heaters. In view of secondary installations, instantaneous water heaters have a share of 7 %. (Bertoldi and Anatasiu, 2009[35])

For more information on stock data please refer to Task 2.

As all behavioural appliances require an active involvement of consumers during operation and cooking and cleaning activities are time-bound in the majority of households, the acceptance of consumers for shifts in operation are presumably low. In view of instantaneous water heaters, smart operation would lower consumer's comfort significantly and is therefore considered as improbable. Concerning hobs and ovens, however, the potential of short term interruptions can be assessed as rather high as far as the cooking or baking results are not compromised. In contrast, short term interruptions are improbable for range hoods and vacuum cleaners as their power demand remains also constant during operation and interruptions in power supply would interrupt their operation. A reduction of their power would decrease their performance (lower air change rate, a loss of suction power or a reduction of heating power, respectively), and will presumably not be accepted by consumers.
Because of the reasons mentioned before, the focus is on electric hobs, ovens and cookers in the remainder of this chapter.

1.1.2.3.2 User behaviour concerning behavioural appliances

DAILY AND ANNUAL USE PATTERN

Electric hobs and ovens

Data on energy consumption of electric hobs, cookers and ovens are limited and often only available for one of the aforementioned appliances. Bertoldi et al. (2012)[35] reported on a total consumption of 63.1 TWh for electric hobs and ovens together (40.1 TWh for hobs, 23.0 TWh for ovens). Considering stock data as shown above, an average energy consumption of about 206 kWh per appliance and year can be calculated for hobs (including mixed hobs and cooker tops). According to the SAVE II final

[53] Kasanen, P. (2000): Save II study, efficient domestic ovens, Final report, TTS Institute

[54] Preparatory Studies for Eco-design Requirements of EuPs (III) Lot 22 Domestic and commercial ovens (electric, gas, microwave), including when incorporated in cookers. Final report

[55] Preparatory study on the environmental performance of residential room conditioning appliances (airco and ventilation). Study on residential ventilation - Final report

report on efficient domestic ovens (Kasanen, 2000[53]), the average energy consumption per electric oven per year in Europe is 138 kWh with large variations between different member states.
Besides technical factors, the user behaviour and environmental factors determine the energy consumption of hobs. These factors include:

- Choice of cooking utensils (pots and pans)
- Use of lids
- Type of hob (solid plate, radiant, induction)
- Temperature setting
- Duration of the cooking or baking process
- Use of synergistic effects
- Frequency of cooking or baking
- Frequency and duration of door openings (ovens)
- Heating mode of the oven (top or bottom heat, convection, grill, combinations)
- Use of pyrolytic function (ovens)

In a study by Sidler (1999)[56Error! Bookmark not defined.], the operation time for different hobs varied between 26 and 58 minutes per day. Data by Sidler (2009)[57] suggest seasonal effects of cooking showing that more energy is consumed in winter than in the summer period.
In view of electric ovens, Kasanen (2000)[53] reported on an average use frequency of 110 times per year, whereas the frequency is higher in Scandinavian countries and France and much lower in Italy and the Netherlands. The average operation time is 55 minutes per cycle (EUP LOT 22[54]).
Sidler (1999)[Error! Bookmark not defined.] has published daily power demand curves of hobs and ovens, which are given in Figure 22 and Figure 23, respectively.

[56] Sidler et al. (1999): An experimental investigation of cooking, refrigeration and drying in 100 households. Programme SAVE, Project ECUEL.
[57] Sidler, O (2009): ENERTECH. “Notes techniques: Connaissance et maîtrise des usages spécifiques de l’électricité dans le secteur résidentiel”

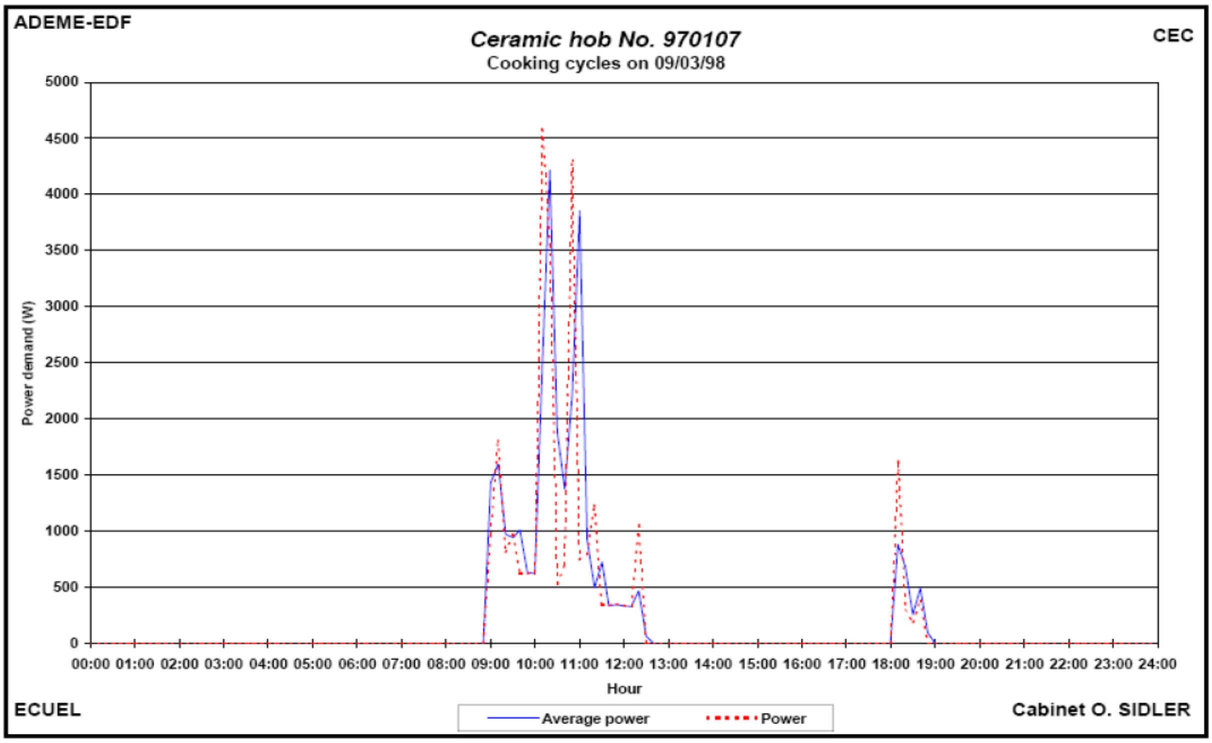

Figure 22: Daily power demand curve of an electric hob (source: Sidler, 1999[56Error! Bookmark not defined.])

In view of daily variations of electric hobs, the results suggest an increased use late in the morning (between 9 a.m. and 11 a.m.) and in the evening period (between 6 p.m. and 7 p.m.).
For electric ovens, only one main use period was found in the morning (between 8.30 a.m. and 11 a.m.)

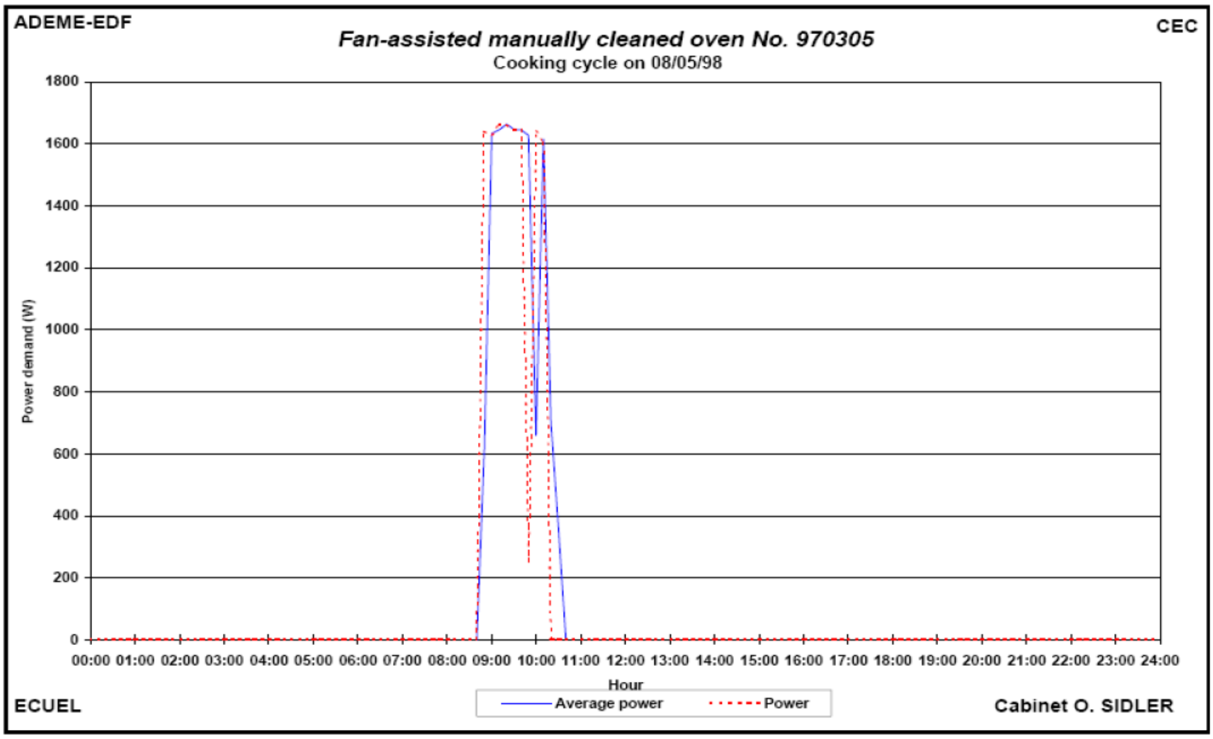

Figure 23: Daily power demand curve of an electric oven (source: Sidler, 1999[56Error! Bookmark not defined.])

Depending on the type of hob, the size of the plate and the temperature chosen, the actual power demand of hobs will vary between about 100 and 2,000 W. During operation of a hob, a typical pattern of power demand can be identified, independent on the actual power. This typical pattern is given in Figure 24. In the starting phase, the hob normally uses its full power to heat itself up. After that, the heating element of the hob is working intermittently, whereas the phases in power on mode are much shorter than the first (heating up) phase.

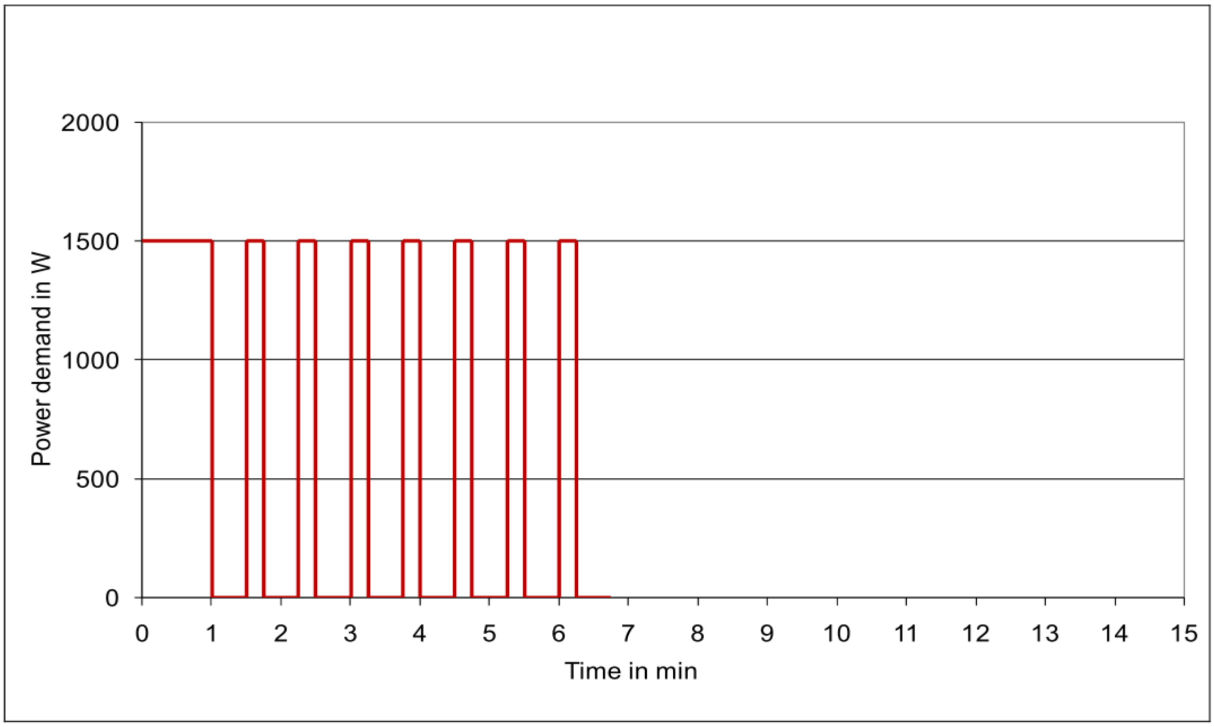

Figure 24: Typical pattern of a power demand curve of an electric hob (Source: Stamminger et al., 2009[32])

A typical power demand curve of an electric oven (Figure 25) looks similar to that of a hob. However, the heating up phase is much longer than for hobs. Electric ovens are also working intermittently, whereas the total operation time of the heating element depends on the heating method as well as on the temperature setting.

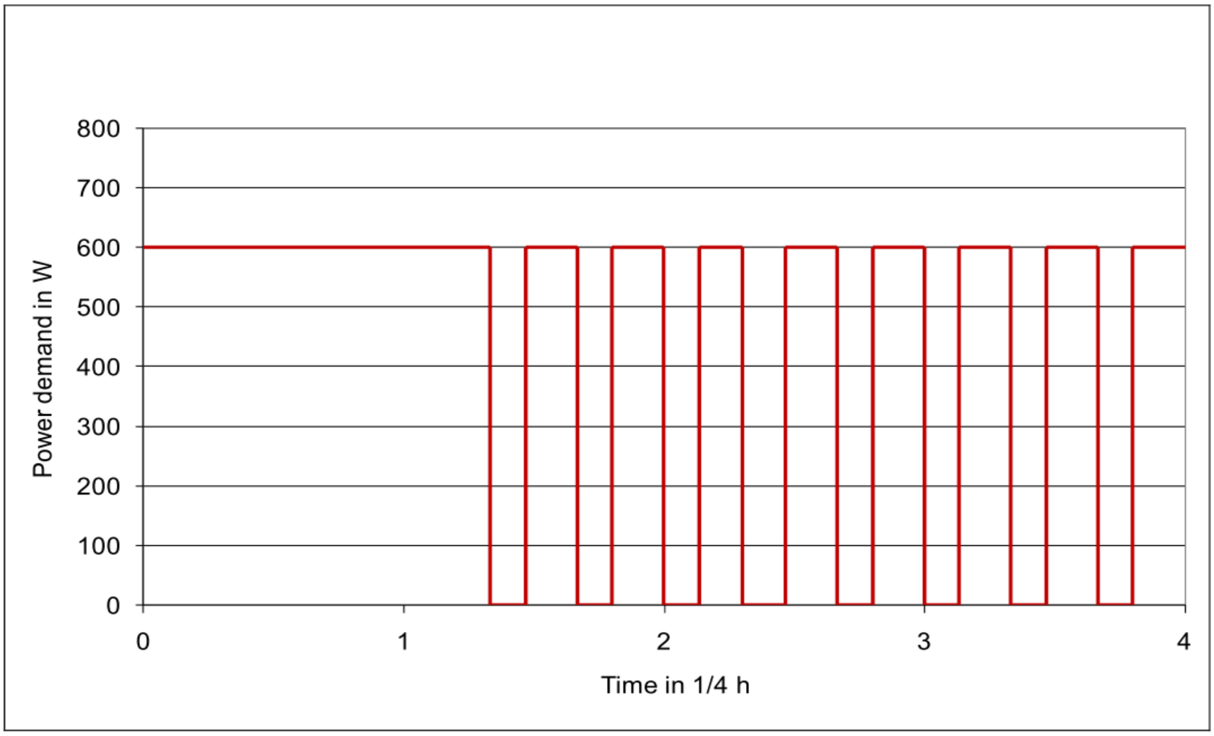

Figure 25: Typical pattern of a power demand curve of an electric oven (Source: Stamminger et al., 2009[32])

If the daily cooking behaviour is taken into account, a typical daily load curve of an electric oven in an average European household will follow the pattern shown in Figure 26. (Stamminger et al., 2009[32])

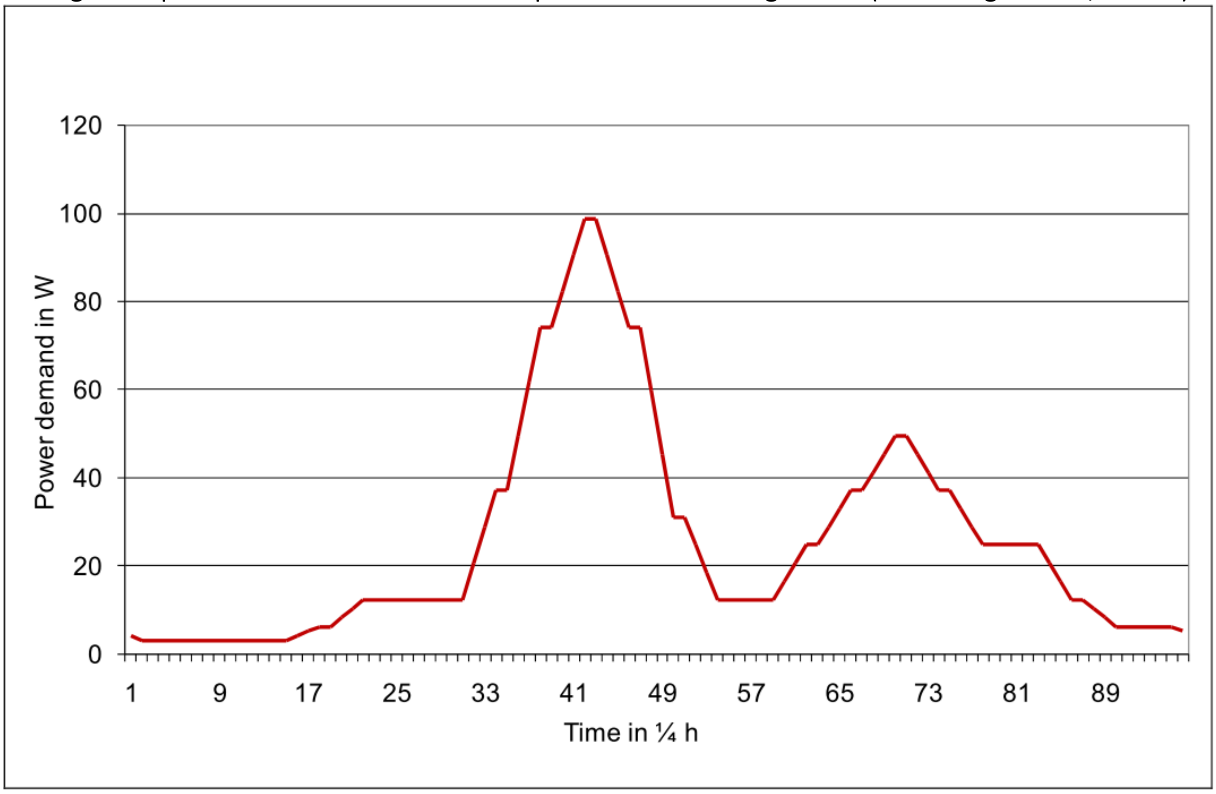

Figure 26: General pattern of a daily load curve of an electric oven in an average European household (source: Stamminger et al., 2009[32])

1.1.2.3.3 Lifespan

The average life span of behavioural appliances may vary depending on the manufacturer, the model, the equipment, the use conditions and the maintenance. Average data are given in Table 6.

Table 6: Average life span of behavioural appliances (Source: [a] EUP LOT 23[52]; [b] EUP LOT 22[54])

Type of appliance	Average life span
Electric hobs (except induction):	19 years[a]
Electric hobs (induction):	15 years[a]
Electric ovens:	19 years[b]

1.1.2.3.4 Possibilities for consumers to engage in smart behavioural appliances

In view of hobs and ovens, one possibility to shift energy or modulate power could be identified.

1. Altered electricity consumption pattern: pause between heating cycles, interrupt the heating phase, etc.

In this case, appliances may change its operation if they are triggered by an external signal showing a shortage of energy available on the grid. Possible changes include prolongation of intervals between two heating phases, interruption of a heating phase or changes in heating power. The external signal should include information on the shortage of energy and how long it will last and the appliance will answer with an appropriate action. Power demand curve of a single appliance can be changed in different ways, e.g. shift in operation or reduction of power by seconds or minutes. As such changes must not compromise the performance of the cooking process, it has to be ensured that they are limited in time (up to a few seconds) and don't take place during the first heating phase. (Stamminger et al., 2009[32])

Flexibility is typically situated especially in the late morning and, to less extent, in the evening. As described before, there are week seasonal effects of cooking resulting in maximum energy consumption during winter and minimum consumption during the summer period.

1.1.2.3.5 Comfort constraints and consumer objections

As described above, the operation of behavioural appliances requires an active involvement of the consumer and thus is time-bound in narrow ranges. For this reason, the acceptance of consumers for shifts in operation is presumable low. However, short term interruptions for a few seconds or postponed heating phases will hardly be recognised by the users so that these scenarios will rather be accepted. In order to prevent losses in the performance of the cooking process, interruptions or shifts in heating phases have to be strictly limited in time. Data on the maximum tolerable duration of interruptions are lacking so far. If the cooking process is compromised in any way, consumers will not accept the aforementioned changes in operation. (Stamminger et al., 2009[32])

1.1.2.4 HVAC

The following task contemplates to incorporate HVAC equipment through DR technology to the basic balancing mechanisms/ancillary services of the electrical grid. In order to do so, the main grid-stabilizing mechanisms used in most European deregulated markets will be taken into account: e.g. frequency containment, Automatic Frequency restoration, Manual frequency restoration.

Concerning HVAC technologies (heating, ventilation and air conditioning), use patterns must match the timing of the balancing grid mechanisms (instantaneous, short term, long term…) so that the incorporation of a DR technology will allow the grid operator to adjust their operability without interrupting a defined cycle or jeopardizing occupants' comfort.

1.1.2.4.1 *User behaviour concerning HVAC appliances*

HVAC appliances are installed to ensure thermal comfort and air quality to buildings' occupants. The main constraints regarding energy shifting HVAC appliances are the consequences on thermal comfort, humidity, CO_2 and other pollutants that these actions may cause. The points to be covered in this section are: comfort constraints, seasonal periods, occupation schedules, lifespan of HVAC appliances.

1.1.2.4.2 *Comfort constraints*

Heating: During the winter, the inside temperature for occupation periods (which could be specified by end-users) should not fall below 18 °C (19 °C for tertiary buildings). As well as the variation of temperature should not be higher than 2°C/h according to the standard EN 15251.

Cooling: During summer, the inside temperature for occupation periods (which could be specified by end-users), shall not exceed 27°C according to EN 15251. As well as the variation of temperature should not be higher than 2°C/h according to EN 15251 standard.

Air treatment: Ventilation assures air quality for building occupants; the standard EN 15251 gives guidance regarding standard air flow rates by person and admissible pollutant concentration in buildings.

SEASONAL PERIODS

Europe can be divided into three main climate types: oceanic, continental and Mediterranean. These different climates will modulate the potential for DR HVAC appliances within the continent. Nevertheless, an average climate could characterize the whole continent and may be used as a reference for this study. The following Table 7 indicates extreme climate conditions within Europe as well as the mean climate.

Winter

Table 7: Heating season for EU27 (Bio Intelligence Service, 2012[58]) (values are weighted by dwelling stock)

Member State	Heating Degree-hours	Group by heating season average	Heating Season (months)	Number of days in heating season	Days in heating season (group mean)
Finland	5849	Group 1	10,8	323	288
Sweden	5444		10,2	306	
Estonia	4445		8,8	265	
Latvia	4265		8,6	257	
Lithuania	4094	Group 2	8,3	250	214
Poland	3616		7,7	231	
Austria	3574		7,6	229	

[58] BIO Intelligence Service (2012) Preparatory Studies for Ecodesign Requirements of EuPs (III), ENER Lot 20 – Local Room Heating Products - Task 3: Consumer behavior and local infrastructure. Prepared for the European Commission, DG ENER.

Czech Republic	3571		7,6	229	
Denmark	3503		7,5	226	
Slovakia	3453		7,5	224	
EU 27 Average	3254		7,2	216	
Germany	3239		7,2	215	
Luxembourg	3210		7	214	
Romania	3129		7	211	
United Kingdom	3115		6,9	210	
Slovenia	3053		6,7	208	
Hungary	2922		6,7	202	
Ireland	2906		6,7	202	
Netherlands	2902		6,7	201	
Belgium	2872		6,7	200	
Bulgaria	2687		6,4	193	
France	2483		6,1	284	
Italy	1970		5,4	163	
Spain	1842		5,3	158	
Greece	1663	Group 3	5	151	138
Portugal	1282		4,5	135	
Cyprus	782		3,8	114	
Malta	560		3,5	105	

Regarding the cooling season, the following Table 8 shows the different potentials within the European Union (EU27).

Summer

Table 8: Cooling season for EU27 (VHK, 2014[22]), (Ecodesign LOT 10, TASK 2 Final Report, 2008[59])

Member State	Cooling degree-days	Population Share (EU28) (2)	Penetration Rate (%) (3)	Pondering (1) (2) (3)
	Total (1)			
EI	5	1%	7%	0,00
DK	57	1%	7%	0,05
NL	75	4%	6%	0,17
EE	78	0%	7%	0,02
SE	81	2%	6%	0,10
BE	84	2%	7%	0,12
UK	94	13%	7%	0,84
FI	97	1%	6%	0,07
LT	102	0%	8%	0,03
LU	103	0%	7%	0,01
LI	105	1%	7%	0,05

[59] Ecodesign LOT 10, TASK 2 Final Report, 2008. URL: http://www.eup-network.de/fileadmin/user_upload/Produktgruppen/Aircon_Final_report_of_Task_2.pdf

CZ	116	2%	1%	0,03
FR	138	13%	7%	1,22
DE	168	18%	2%	0,49
SI	187	0%	24%	0,14
AT	213	2%	5%	0,17
PL	216	7%	1%	0,08
SK	260	1%	30%	1,02
BG	275	1%	28%	1,07
HR	277	1%	n/a	n/a
HU	282	2%	1%	0,07
PO	324	2%	3%	0,16
RO	379	3%	29%	3,75
IT	420	12%	43%	22,22
ES	652	7%	42%	19,28
MT	714	0%	29%	0,21
GR	893	2%	73%	12,41
CY	972	0%	100%	0,97
EU 27 Mean	**263**	**100%**	**18%**	

Table 7 and Table 8 summarize the total seasonal demand for HVAC appliances (EU 27). The heating demand is on average 10 times more important than the cooling demand and it has a more homogenous behavior within the member states (group 1 and group 2 are in the same order of magnitudes). On the contrary, for the cooling seasons the total is not only climate dependent, but furthermore population-climate dependent. Regarding the table above, it can be seen that the highest shifting potential according to the “cooling degree-days indicator” regards Mediterranean countries (Cyprus, Greece, Italy, Spain and Malta) and Eastern Europe countries (Romania, Poland, Hungary, Bulgaria). Nevertheless, when this factor is weighted with the population factor and the penetration rate per country, the highest potential occurs in Spain, Italy, Greece, Romania and way behind Bulgaria and Slovakia (see Figure 27).

In conclusion, it seems plausible to evaluate a case study for different heating technologies using an average climate due to the fact that it is a representative sample. However, for cooling technologies, DR appliances only seem interesting (high potential) for countries in Mediterranean climates (Italy, Spain, Cyprus, Malta, Greece) or continental climates in Eastern Europe (Romania, Bulgaria, Slovakia).

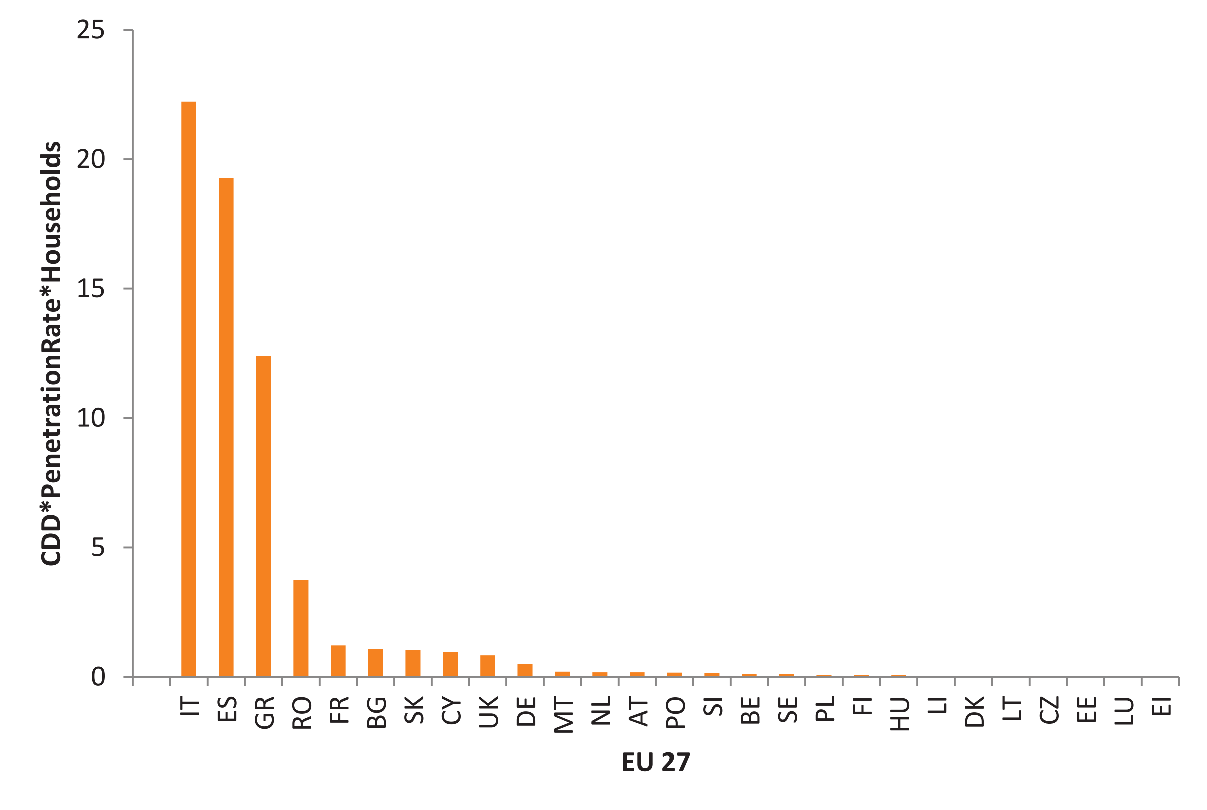

Figure 27: Cooling degree-days weighted by the population factor and the penetration rate per country

1.1.2.4.3 Occupation Schedules

Possible use patterns and energy shifting scenarios (cooling and heating) are as listed below, considering that energy can be shifted over those occupations periods (periods when energy is being consumed) without jeopardizing the occupants' comfort and health.

Residential occupation periods

- Residential (working population): From 5 pm to 8 am from Monday thru Friday. Weekend schedules are 24h except for those families that will be on a weekend trip and will not consume any energy at all over that period.
- Residential (full time): From Monday to Sunday the dwelling will be occupied 24h.

Tertiary occupation periods

- Tertiary: Occupation periods are between Mondays and Fridays from 8 am to 8 pm.

1.1.2.4.4 Lifespan

The lifespan of HVAC products may vary according to the equipment, but a good estimation is around from 10 to 15 years for boilers, air conditioners and heat pumps. Information that is more detailed is given in Table 9:

Table 9: Lifespan of HVAC appliances (Bio Intelligent Service, 2012[58]) *Source: (Eco-design Boilers, 2007)

Main Category	Type of heating appliance	Average lifespan
Fixed heaters	Convector panel heaters	12
	Radiators	20
	Fan heaters	12
	Ceramic heaters	12
	Radiant heaters	12
	Storage heaters (static)	20
	Storage heaters (dynamic)	20
	Under-floor heating	40
Portable electric heaters	Convector panel heaters	12
	Radiators	12
	Fan heaters	12
	Radiant heaters	12
	Ceramic heaters	12
Boilers	Gas Fired	12*
	Oil Fired	12*

Energy consumption and shifting potential per appliance per day / per season (refer to task 1 for more information) for 27 EU member states.

Heating:

- Peak power: up to about 95 GW (2010)
- Energy consumption: about 280 TWh/a
- Potential energy to be shifted: about 30 TWh/a, about 100 GWh/day in the coldest winter months (heating off for one hour)

Cooling:

- Peak power: 160 GW
- Energy consumption: 80 TWh (2010)
- Potential energy to be shifted: 65 GWh/day (this corresponds a the mean demand over the summer for an off-period of one hour)

Air treatment:

- Peak power: 10 GW
- Energy consumption: 59 TWh (2010) or
- Potential energy to be shifted: 10 GWh/day (air treatment off for one hour)

CASE STUDIES (POSSIBILITIES FOR CONSUMERS TO ENGAGE IN SMART APPLIANCES)

2.1. Apartment in EU-27 average winter conditions using standard electric radiator
2.2. Apartment in EU-27 average winter conditions using built-in inertia radiator (refracting ceramic…)
2.3. Apartment in EU-27 average winter conditions using a heat pump
2.4. Apartment in Mediterranean climate using a residential air conditioner (<12 kW)

POSSIBILITY OF ADAPTATION TO GRID CONTROL MECHANISMS:

HVAC systems can be shut down and turned on without any built-in machine constraints (unlike washing machines for example), as well as their capacity can be adjusted (change the speed of the compressor - which would more efficient than turning the units off-, adapting the temperature set points or the fan speeds). Therefore, there is an important potential for all “grid balancing mechanisms” in order to shift the energy consumed by HVAC in different times of the day.

Australian case for example: the Demand-Response project began in 2005 due to the fact of the increasing energy demand caused by the growing penetration rate of AC (air conditioning is a peak coincident load in Australia). It is projected that the proportion of Australian households that would be equipped with an AC unit will increase from 56% in 2010 to 70% in 2020. In order to avoid peak demands, the regulation AS4755 mandates to incorporate DR mechanisms to AC units, so a third party actuator can modulate the load. Encouragements include a low price of the DR platform (10 AUS$, around 1% of the retail cost for a residential unit), and Payments of $250 are offered to customers who buy an AS/NZS 4755 compliant air conditioner and have it activated on installation, and to customers who have their existing air conditioner connected to the Energex communications system (Wilkenfeld, 2011[60]).

EXPERIENCE WITH DEMAND RESPONSE MECHANISMS IN HVAC EQUIPMENT

- Daikin has implemented DR control in many countries over the world, allowing them to control remotely HVAC equipment. More precisely, they have participated in **Open ADR** trial by Japanese government, university and companies, in order to carry out cooperative operation with smart cities and aggregators in wide areas. Mainly speaking, the control consisted in a “Power Measurement Unit” which sends only information about the difference of total demand and target current. HVAC equipment (air conditioners, heat pumps) will power down automatically depending on established difference and pre-settled priority.

- The EcoGrid project carried out by Sintef Energy Research and other partners in Bornholm (Denmark), evaluated the potential of DR appliances (mainly heat pumps and electric heating) based on a real-time market approach. This DR program lets distributed energy resources and flexible electricity demand, receive and respond to variable electricity prices. Different control systems and interfaces were used along the project: Ecohome (present in 60% of the studied homes, remote control of the heating system), Greenwave Reality (electric radiators and heat pump control), Siemens Synco Living (consists of a central unit/control panel that is connected to the internet, the control of the electric heating and/or domestic hot water boiler is done via contactors installed in the fuse box of the participants and thermometer probe in the boiler). The final conclusions of this project are not yet available, but preliminary results regarding the tests and adjustments done in 2013/2014 winter show that: For the IBM Greenwave reality solutions, based on a maximum of 90 minutes of heating off-time is now guaranteed, with no single off time period longer than 60 minutes and with a few hours in between off periods. In addition some

[60] Wilkenfeld (2011): Smart appliances for smart grids: flexibility in the face of uncertainty 2011.

recommendations and preliminary conclusions for further analyses and deployment of demand-response mechanisms are:

- Low data quality: The system must receive reliable temperature readings to ensure that heating is regulated in accordance with the comfort preferences of the customer
- Internet connection must be stable
- The nature of the individual heat pumps' own optimization system limits regulation possibilities
- Comfort setting of the households gives little room for "down or up" regulation for consumption. (www.ecogrid.eu)

1.1.2.5 Battery operated rechargeable appliances

1.1.2.5.1 Usage Behaviour

This category comprises the following segments:

- Multimedia :
  - Smartphones
  - Tablets
  - Laptops
  - (Video) cameras
  - Personal navigation
  - etc.
- Household appliances
  - Electric toothbrushes
  - Fans
  - Vacuum cleaners
  - Clocks
  - Shaving products
  - etc.
- Power tools
  - Drill machines
  - Screwdriver
  - Garden trimmers, mowers & edgers
  - etc.

Given the low power consumption in the charging process, only appliances with large installed base volumes and frequent charging patterns will have enough potential for load shifting.
Household appliances have smaller installed base volumes than smartphones and tablets and it is presumed that they have a lower and less predictable charging frequency. On top of that many have such low consumption that the charging energy is too small to be relevant, even in large numbers.
For power tools, the charging power is higher compared to multimedia devices, but the charging frequency is usually lower and these appliances have a 'charging when going to be used' pattern, making it hard to provide flexibility. Also the amount of 'active' appliances is much lower.
Personal navigation devices and digital cameras have smaller installed base volumes than smartphones and tablets and it is presumed that they have a lower and less predictable charging frequency.
Smartphones and tablets have low charging power consumption, but have a very large volume (and still growing) installed base.

Laptops have also a smaller installed base then smartphones and almost similar to tablets but a higher charging power consumption.
Therefore only laptops, smartphones and tablets appliances will be taken into account in the remainder of this chapter.

1.1.2.5.2 User behaviour concerning charging

It is clear that if the devices are smartly charged, it is essential for a good user acceptation, to always guarantee sufficient State of Charge (SOC).

1.1.2.5.3 Comfort constraints

From studies by the J.D. Power and Associates 2012[61] it is shown that satisfaction with battery performance is becoming a critical factor in overall satisfaction as well as brand loyalty. It is clear that if the devices are smartly charged, it is essential for a good user acceptation, to always guarantee sufficient State of Charge (SoC). This puts a constraint on the smart charging to be able to predict very accurately and reliably the next usage of the multimedia device in order to guarantee the expected comfort on next usage. [62]

1.1.2.5.4 Occupation Schedules

A 4-week study[63] with more than 4000 attendees, which assessed their smartphone charging habits, was performed by Ferreira et al.. From this, an insight on charging behaviour could be retrieved. It has been observed that many charging instances happen overnight, with connection to power supply units typically for periods > 14 hours (See Figure 28). They also noticed that the majority of charging events during the day are for short periods (< 3 h).

[61] J.D. Power and Associates Reports. Denzil Ferreira, Anind K. Dey, Vassilis Kostakos. Understanding Human-Smartphone Concerns: A Study of Battery Life. Has Become a Significant Drain on Customer Satisfaction and Loyalty. March 2012. Pervasive Computing. June 2011.
[62] Sasu Tarkoma, Matti Siekkinen, Eemil Lagerspetz, Yu Xiao, Aalto University, Finland. Smartphone Energy Consumption - Modeling and Optimization. August 2014.
[63] Denzil Ferreira, Anind K. Dey, Vassilis Kostakos. Understanding Human-Smartphone Concerns: A Study of Battery Life. Pervasive Computing. June 2011.

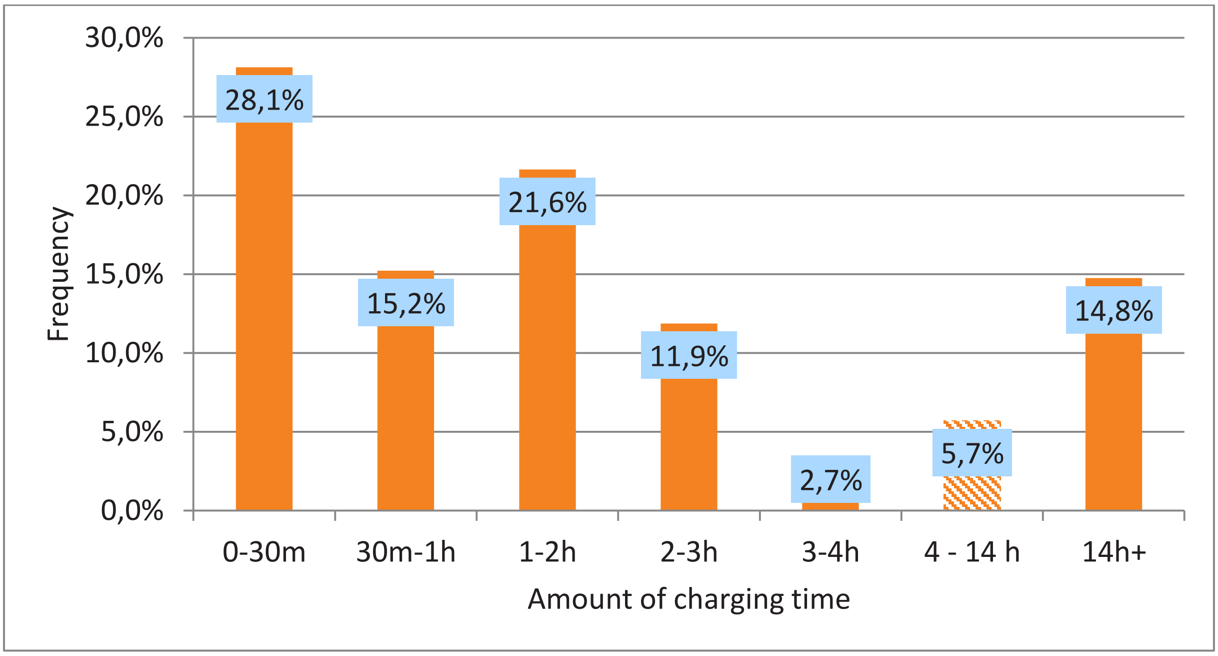

Figure 28 : Time plugged in

When looking at the time slots, it is seen that 2 major scheduling periods can be identified for the initiation of the charging, one between 6 PM and 8 PM and another between 1AM and 2 AM.

1.1.2.5.5 Lifespan

The lifespan of approximately 5 years for smartphones and tablets is rather short compared to other consumer electronics (Figure 29).

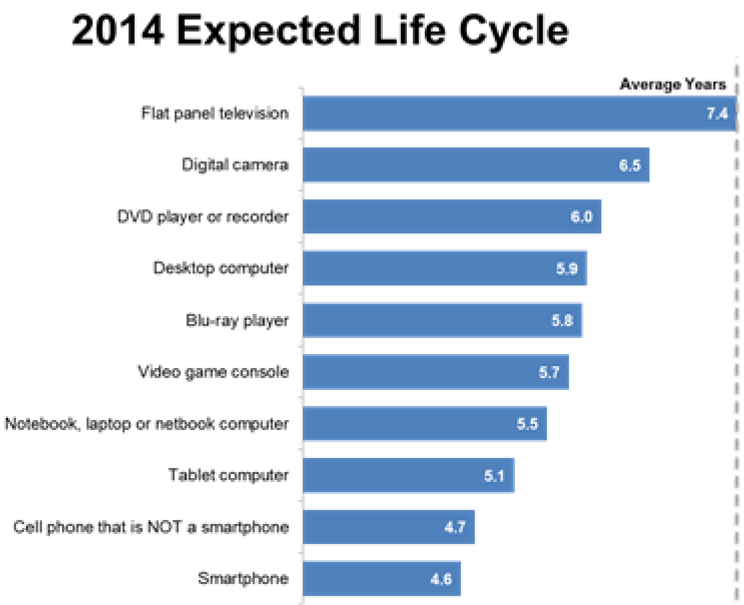

Figure 29: Source: Consumer Electronics Association (CEA), 2014 CE Product Life Cycle. Base: U.S. Adults (n=1,013)

Energy consumption and shifting potential per appliance per day/ per season for 28 EU member states.

As stated in Task 1, the potential per appliance and day is very low. The main benefit needs to come from the large volume of appliances:
For smartphones only, the sales figures (IDC[64] and Gartner[65]) worldwide have gone from 300 million in 2010 to more than 650 million in 2012 and grew to above 1 billion in 2014. The situation is similar for tablets worldwide, with sales growing from 200 million in 2013 to an expected 260 million in 2016 (Gartner, January 2015)[66]. Estimates of laptop sales vary between 200 and 180 million.
For Europe (EU28), the sales of all mobile phones (smartphones and regular mobile phones) range from 227 million in 2009 to 213 million in 2013.

Table 10: Mobile subscriptions in Europe

	2014	2020
Mobile subscriptions (million)	1,135	1,280
Smartphone subscriptions (million)	475	815

The figures for Europe*[67] on the installed base show almost half a billion of smartphone subscriptions in 2014 and an expectation of more than 800 million subscriptions by 2020.

When looking at the total energy consumption of these appliances of

- Smartphone: 3 to 5 kWh/year
- Tablet: 12 kWh/year
- Laptop: between 150 and 300 kWh/year.

it can be concluded that a flexibility capacity would derive from the large number of appliances, rather than from the individual power consumption.

A first calculation of the authors is based on the assumption that in 14.8% of the charging session appliances are plugged in long enough to provide flexibility (as stated in Figure 28). Taking into account the values for smartphones this could lead to 14.8% * 4 kWh (average) * 475 million = 281 GWh per year or 0.77 GWh/day and for tablets 14.8% * 15kWh * 200 million: 444 GWh shifting potential per year or 1.2 GWh/day, but here the assumption is made that the 14.8% of sessions also corresponds to the same amount of charging power. It's however clear that for correct calculations, there is still a general lack of available and reliable studies on this. For laptops the calculations were not done, since no info is found on the charging (duration) patterns for these devices. These charging patterns will probably be different to that of the smartphones by the nature of the usage pattern and the fact that laptops are often connected to mains power supply while being used.

<u>Important note:</u>
It has to be taken into account that the energy (demand) shifting potential is a balance between flexibility and energy saving.

[64] IDC Press Release : Worldwide Smartphone Growth Expected to Slow to 10.4% in 2015, Down From 27.5% Growth in 2014, According to IDC, August 2015, http://www.idc.com/getdoc.jsp?containerId=prUS25860315
[65] Gartner Press Release : Gartner Says Smartphone Sales Surpassed One Billion Units in 2014, March 2015, http://www.gartner.com/newsroom/id/2996817
[66] Gartner, Press Release : Gartner Says Tablet Sales Continue to Be Slow in 2015, January 2015, http://www.gartner.com/newsroom/id/2954317
[67] Ericsson, Europe Ericsson Mobility Report Appendix, November 2014
* From the report it is not clear which countries are included, but since also Russia is mentioned it will be broader than EU28.

From a flexibility point of view, the longer the charger is connected, the more shifting potential is (theoretically) available. However from an energy saving point it is important to disconnect the charger ASAP after the battery is fully charged since it also consumes (little, but present) power when devices are connected.
Given the evolution and regulation on the requirements for standby, off mode electric power consumption of electrical and electronic household and office equipment[68], the issue will become less important.

1.1.2.6 Residential energy storage system

1.1.2.6.1 Usage behaviour

Differentiation
Grid-connected battery-based electric energy storage systems are a recent development for dwellings. Two different set-ups exist:

- back-up power
- electric energy storage

The first one is similar to uninterrupted power supply systems that are used in industry, data centers and hospitals. For households they can be an alternative for noisy generators and can take over the power supply in a household immediately if necessary. In countries with a questionable electricity grid or where fear exists that a power outage can happen, there are several companies who sell such 'home battery backup systems'. These batteries have to always be fully charged until a power outage happens, so they cannot be used as a smart appliance in the context of this study.
The second set-up is the fast growing market: storing cheaper (renewable) electric energy to avoid buying expensive electricity at a later period. The stored electricity is often generated by a PV installation. For this new product category, there is no unique and universal definition so far. Therefore, the following terms are used (amongst others):

- storage battery for home use
- residential energy storage system
- solar-energy storage unit
- solar battery
- home battery

In off-grid dwellings batteries are already common practice, often powering a DC-grid. This is however out of scope of this document.

Basic use of a home battery
A home battery is usually used together with a PV installation. It avoids that more expensive electricity has to be bought back in the evening whereas own solar electricity flows into the distribution grid in the daytime. Storage is a way to increase the self-consumption of solar energy and therefore a residential energy storage system is a DR/DS compatible smart appliance, relieving

[68] COMMISSION REGULATION (EU) No 801/2013. Amending Regulation (EC) No 1275/2008 with regard to ecodesign requirements for standby, off mode electric power consumption of electrical and electronic household and office equipment, and amending Regulation (EC) No 642/2009 with regard to ecodesign requirements for televisions. 22 August 2013.

the distribution grid. The proof of attractiveness and the premises to be so are described in[69,70]. In Germany 25,000 home batteries have been installed up to 2015[71]. Some home battery sellers state explicitly that their storage systems can also be connected to small wind turbines and cogeneration units. Although buying electricity at the night tariff and to use it in the daytime would sound like another possibility, the spread between these tariffs is mostly small.

Distinction between different implementations

1. Residential energy storage systems combined with a separate PV installation. The installation consists of a battery storage system and additional convertors to connect the storage system to the house grid.
2. Fully integrated residential energy storage systems with PV (e.g. SMA Sunny Island). In these systems the battery storage is part of the PV installation and a single integrated controller takes care of the balancing between PV, grid and storage
3. Setup 2 combined with smart control of appliances, e.g. via controlled power plugs.
4. Standalone residential energy storage systems. The purpose here is, e.g., to use the electricity price differences (business case -> difference in prices) – communication tariffs or to provide, e.g., ancillary services with volume as a control signal.
5. Electric Vehicle (EV) To Home. In this setup, electric vehicles will be used as a (mobile) Battery Storage Systems, to store and extract electric energy. The setup is currently in use in Japan, but not yet popular in the EU.

1.1.2.6.2 User behaviour concerning charging

The main goal for setup 1, 2 and 3 is maximisation of self-consumption, in order to minimise the economic disadvantage due to feed in tariffs that are lower than the buying price.
Setup 4 focusses more on the difference in pricing in time. This can be due to Day/Night, Peak/Off peak pricing or in the future, variable pricing blocks during the day. Or to receive reservation and activation fees for other services.
Setup 5 (EV's) is out of scope of the study.
The systems taken into account for this chapter are focussed on residential usage and range between 2 to 10 kWh.
The biggest market for Battery Storage Systems in Europe is Germany with an installed base of 25,000 installed systems today[71]. For other European countries figures are very low and some only have some projects with experiment setups. No exact figures were found for these countries.

1.1.2.6.3 Comfort constraints

The modern residential energy storage systems operate fully automated. The systems can make use of advanced algorithms taking into account price variations, solar predictions based on regional weather information, self-learning techniques to predict expected consumption, etc. These algorithms need minimal or no user interaction. The capacity needed is dependent on consumption patterns and installed appliances (E.g. heat pump or not) and installed PV capacity.
An additional advantage, but certainly not the main goal, is that the residential energy storage system can provide in backup power when the grid is not available. The household can go in Island Mode, but first needs to disconnect physically from the grid. This might require extra hardware such as a grid feeding monitoring.

[69] Grietus Mulder, Daan Six, Bert Claessens, Thijs Broes , Noshin Omar, Joeri Van Mierlo. The dimensioning of PV-battery systems depending on the incentive and selling price conditions. Applied Energy. April 2013.
[70] Michael Fuhs, Shamsiah Ali-Oettinger. Storage has landed. PV Magazine. November 2012.
[71] „Die Sonne speichern“, Presse, 8 January 2015. [Online]. Web address: http://die-sonne-speichern.de/pressemeldungen/. [Latest: 4 May 2015].

1.1.2.6.4 Occupation Schedules

The usage and dimensioning is dependent on the targeted DR business case. More details on the different business cases are described in T2.3.

1.1.2.6.5 Lifespan

Most system manufacturers estimate the lifespan at 15 to 20 years. For modern Li-Ion batteries this is feasible if they operate within their designated operations conditions (Temperature, Charging and Depth of discharge limits). For Lead-Acid the maximum discharge depth is around 50 % while for Li-Ion this can vary between 50 and 100 % of nominal capacity, depending on the type. For some battery types, 100% is not possible, but we can state that the majority has a higher Depth of Discharge level then Lead-Acid [72].

The capacity of the batteries degrade over time dependent on type of battery, the number of cycles, depth of discharge and temperature as shown below (see Table 11 and Table 12).

Table 11: Cycle life as a function of depth of discharge (source: http://batteryuniversity.com/learn/article/how_to_prolong_lithium_based_batteries)

Depth of discharge	Discharge cycles	
100% DoD	300 – 500	A partial discharge reduces stress and prolongs battery life. Elevated temperature and high currents also affect cycle life.
50% DoD	1,200 – 1,500	
25% DoD	2,000 – 2,500	
10% DoD	3,750 – 4,700	

Table 12: Estimated recoverable capacity when storing Li-ion for one year at various temperatures

Temperature	40% charge	100% charge	
0°C	98%	94%	Elevated temperature hastens permanent capacity loss. Not all Li-ion systems behave the same.
25°C	96%	80%	
40°C	85%	65%	
60°C	75%	60% (after 3 months)	

For more technical details on the lifespan and constraints of batteries refer to Task 4.

[72] Jeff Dahn and Grant M. Ehrlich. Lithium-Ion Batteries. Linden's handbook of batteries. 2011.

1.1.2.6.6 Energy consumption and shifting potential per appliance per day / per season (refer to task 1 for more information) for 27 EU member states.

SHIFTING POTENTIAL

For the purpose of this report, a distinction is made between the overall shifting capacities independent of a business case and the "battery with PV" business case, since that is currently the most used and we have more detailed information on this.

The overall shifting capacity is dependent on the operating range of the installations. Parameters like maximal depth of discharge, maximal charge and discharge currents determine how much of the total capacity can be actually used for flexibility. The parameters differ for the used battery technologies (Lead-acid, Li-Ion, etc.).

For the battery with PV installations, the shifting potential will vary strongly in the different seasons as well as with geographical location (Figure 30). Below it is estimated what this would mean on a European level.

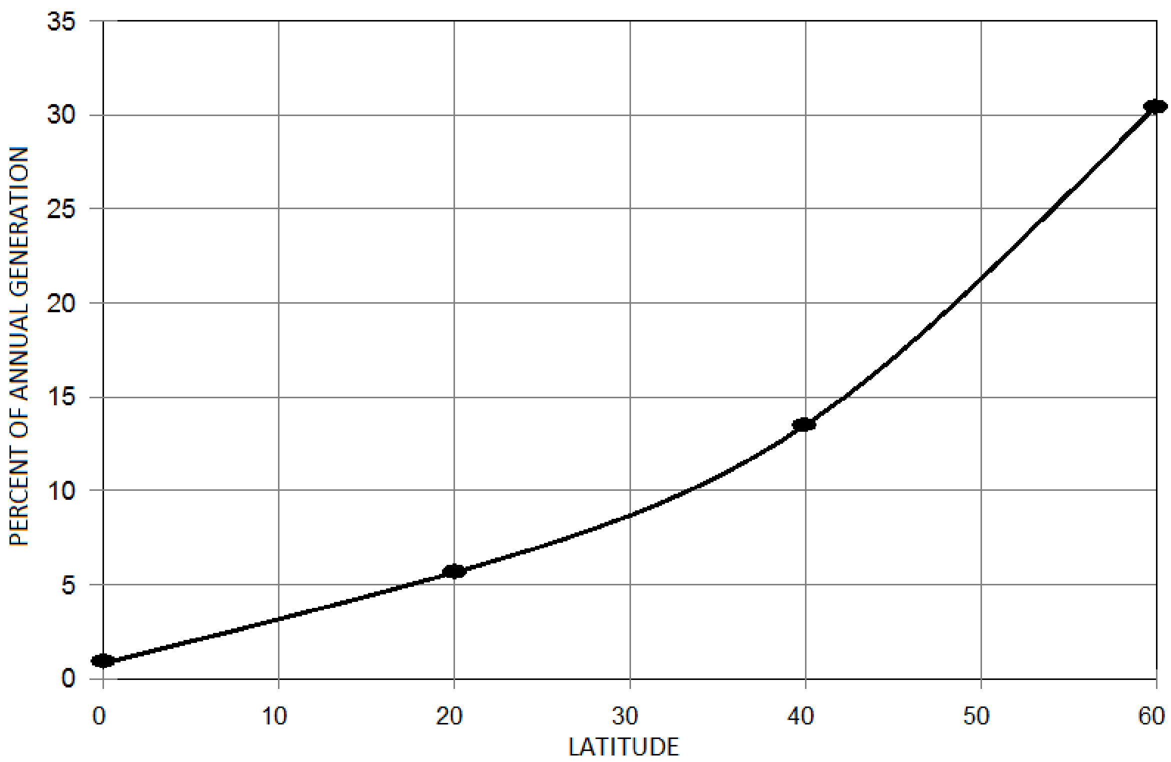

Figure 30: Battery storage requirements versus latitude. (http://euanmearns.com/how-much-battery-storage-does-a-solar-pv-system-need/)

By the end of 2013, in total 81 GW of PV was installed and in 2014 an additional 10 GW was installed77. IEA-RETD76 indicates that 20% of the installed PV capacity is situated in the residential sector, which results in a total of 18 GW of installed residential PV capacity in Europe.
The average capacity of residential installations is 4 kW[73], so translated to the number of installations 4.5 million existing installations can be assumed.

[73] Australian Energy Market Operator (AEMO). Ltd Rooftop PV Information Paper - National Electricity Forecasting. 2012

For each installation a self-consumption share without storage of 40% is estimated, when storage is integrated this is expected to be 70% with an average storage of 4 kWh (based on a conservative estimate which is a bit higher than the smallest installations (~2 kWh) but below the average (6 kWh) of the range of the residential installations (2 to 10 kWh).

- The average production of an installation would be 4 kW * 1,000 full load hours /year = 4,000 kWh.
- 40% self-consumption equals to 1,600kWh/year[70].
- The assumed 30% extra gained from the storage for later consumption, accounts for 1200 kWh.
- For the average consumption of a household figures from Germany were used[52]: 3,500 kWh/year. All together this applies that a household would need to retrieve 3,500 kWh – 1,600 kWh (PV) – 1,200 kWh (storage) = 700 kWh from the grid and 1,200 kWh (30%) of the PV production is sent back to the grid (feed-in).
- The total shifting potential can now be calculated twofold :
  - Shifting for self-consumption: 1,200 kWh * 4.5 million installations = 5.4 TWh
  - Additional shifting by using the remaining full load cycles. Since the objective is to store and extract from the residential energy storage on daily basis, 365 full load cycles per year can be assumed. The used 1,200 kWh used for self-consumption accounts for 300 full load cycles of 4 kWh, leaving additional storage capacity for 65 days resulting in 260 kWh/year. Based on the 4.5 million installations this provides a shifting potential of around 1.17 TWh.

All together this results in a shifting potential of about 5.5 TWh, which is 0.18% of the total electricity consumption (3,101.3 TWh) in EU28 in 2013[74].

1.1.2.7 Lighting

1.1.2.7.1 Usage Behaviour

This category comprises lighting in residential and commercial indoor areas and public street lighting by use of the following types of light sources:

- LFL: Linear fluorescent lamp
- CFL: Compact fluorescent light
- Tungsten
- GLS: General lighting service ('incandescent')
- HID: High intensity discharge lamp
- LED: Light emitting diode

The general usage is that the light is switched on when it is needed and switched off again after use. In offices and other commercial indoor areas, there is a high degree of automatic systems, either on/off or variable according to the incoming daylight.

There are the following possibilities to modulate capacities:

- For advanced LED light bulbs: There are already LED light bulbs on the market, which can be controlled by a smart phone over Wi-Fi – in some cases combined with a special hub for the bulbs. This can be further developed into a DR enabled system controlled by signals from the

[74] Net electricity generation, 1990–2013. Eurostat online.

power supply system. For LED systems there will be no technical problems in dimming and switching off the light.

- For CFLs: It is also possible to build in DR enabling, but in a less extent dimming compared to LEDs.
- Generally, for all light bulbs (LED, CFL, Tungsten, GLS) it is technical possible to mount an extra DR module for switching on and off the bulbs.
- For luminaires and lighting systems in commercial areas (mainly LFL): There are already advanced systems on the market, which can be controlled by local conditions in the lighted area through presence sensors and solar radiation sensors combined with the time of day. This can be further developed into a system controlled by signals from the power supply system.
- Public street lighting: Street lighting systems are already highly controlled from outside and it is possible to combine this with a DR module.
- Many light technologies can be dimmed (tungsten, halogen, fluorescent, LED etc.) resulting in reduction in power load and energy consumption. Lighting including street lighting is naturally mostly switched on in periods with no solar radiation apart from indoor areas with no or few windows such as basements, commercial centres etc. meaning that the energy consumption is higher in evenings and during nights, though also depending on time of year and geographical location within EU. For offices and some other commercial area, the energy consumption is reduced during weekends. The energy consumption is higher during these periods, which would be a basis for the flexibility potential.

1.1.2.7.2 Comfort constraints

The negative comfort impact by DR enabled lighting is naturally a serious constraint. Light is used when there is a need for light and only too little awareness or not correctly adjusted control systems will result in a potential for reducing light intensity or switching off without comfort impacts.

The comfort impacts will be large especially in the homes and commercial areas, which may include safety issues. Only very short periods of dimmed or switched off time would be accepted; we assume 5 minutes per day.

For public street lighting the comfort impact may be more limited, at least for shorter periods of time. On average, we assume half an hour per day.

1.1.2.7.3 Lifespan

Lifespan is measured in hours of light. The life varies from about 1000 hours for tungsten lighting sources up to around 50000 hours for LED lighting.

Energy consumption and shifting potential per appliance per day/ per season for 28 EU member states.
The estimated stock year 2013 based on the Ecodesign Preparatory Study on Light Sources (ENER Lot 8/9/19[75]:

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

[75] VITO. Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements (‘Lot 8/9/19’). Draft Interim Report, Task 2 (revision 1)

- LED: Light emitting diode: 144 million units

Separately, the estimated number of street lighting luminaires in EU-25 is about 60 million (2004 figures)[76].

Total calculated energy consumption year 2013 calculated on the basis of (Kemna, 2014):

- LFL: Linear fluorescent lamps: 126 TWh/year
- CFL: Compact fluorescent light: 33 TWh/year
- Tungsten: 57 TWh/year
- GLS: General lighting service ('incandescent'): 13 TWh/year
- HID: High intensity discharge lamp: 48 TWh/year
- LED: Light emitting diode: 1 TWh/year
- Total: 279 TWh/year

Total energy consumption (2020) of street lighting is 35 TWh/year (VITO, 2007).

Data on shifting or capacity modulating potential per appliance in a smart grid perspective are scarce. Instead, we have assessed the potential from available data on stock, lumen output, operating hours, and efficiency[77] combined with more details on street lighting.

Based on average data on lumen/unit and lumen/watt, the average wattage for each unit is:

- LFL: Linear fluorescent lamps: 29 watt
- CFL: Compact fluorescent light: 11 watt
- Tungsten: 50 watt
- GLS: General lighting service ('incandescent'): 51 watt
- HID: High intensity discharge lamp: 144 watt
- LED: Light emitting diode: 5 watt
- Tungsten stock: 36 watt

The technical potential for load shifting for each light bulb is of the same size assuming switching off. Modulating i.e. dimming potential is much less but naturally depends on the dimming level.

Based on data on the total amount of lumen for EU27 and the lighting efficiency, we have calculated the total power draw for each type of lighting technology assuming full simultaneous power draw:

- LFL: Linear fluorescent lamps: 56 GW
- CFL: Compact fluorescent light: 36 GW
- Tungsten: 49 GW
- GLS: General lighting service ('incandescent'): 8 GW
- HID: High intensity discharge lamp: 7 GW
- LED: Light emitting diode: 29 GW
- Total: 185 GW

This figure needs to be reduced with a simultaneity factor i.e. taking into account that all lighting devices are not switched on all the time. As a rough estimate, we assume a 30 % simultaneity factor and a 50 % comfort factor i.e. only 50 % would be possible to switch off without losing unacceptable comfort losses. The total shifting potential is therefore about 28 GW.

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[76] VITO. Preparatory Studies for Eco-design Requirements of EuPs. Final Report. Lot 9: Public street lighting. 2007.

[77] René Kemna (VHK). ECODESIGN IMPACT ACCOUNTING Part 1 – Status Nov. 2013. May 2014.

Of this total shifting potential, street lighting is estimated at about 5 GW (based on VITO, 2007) and residential and commercial indoor lighting is 23 GW.

If assumed maximum 5 minutes and 30 minutes of acceptable off time per day for residential and commercial indoor lighting and street lighting, respectively, then the switching potential would be about 4 GWh/day.

Functionalities supporting energy efficiency

For lighting in homes and commercial areas, information feedback on the level of consumption; when the consumption takes places in relation to the needs and efficiency and possibilities of impacting the consumption by behaviour changes and change of bulbs and lighting systems may provide substantial energy savings.
Street lighting is typically highly controlled and professional procured, and only few savings would be possible to achieve with more information feedback.

1.1.2.8 Conclusions

Periodical appliances

Periodical appliances are characterised by relatively long average lifespans (about 13 to 14 years) and relatively high power consumption. The numbers of installed base are high for washing machines reaching almost 200 million appliances. For dishwashers, tumble dryers and washer-dryers, these numbers are markedly lower with lowest ownership rates occurring in Eastern European countries. By trend, the penetration rates of these appliances are increasing in all the Member States. Periodical appliances offer a high flexibility, whereas the dishwasher outperforms the other periodical appliances in flexibility. Delay in start time as well as short term interruptions of operation or modulations in power consumption pattern (e.g. postponing single phases) are assumed to be accepted by consumers if the performance is not compromised. User's concerns mainly focus on safety aspects (e.g. flooding or fire during unattended operation). These concerns could be addressed by improving safety features and by offering relevant insurances.

Continuous appliances

Cooling appliances like refrigerators and freezers are characterised by high numbers of installed base in all the Member States and relatively low power consumption. Load shifting would be possible (e.g. changes of compressor on and off cycles, short term interruptions of compressor's operation) but strictly limited in time for reasons of food safety and quality (seconds to a few minutes). Flexibility could also be provided by modulating power consumption (e.g. changes in motor speed). As cooling appliances operate fully automatic, there is no impact on user's comfort. If food safety and quality is not compromised and the system is working reliably, consumers will rather accept smart operation.

Electric storage water heaters are available in relatively large numbers in the Member States with numbers of installed base ranging in about 90 million units. In comparison to other residential appliances, they are characterised by extremely high power consumption. However, electric storage water heaters represent a heterogeneous category with comprising appliances with different storage capacities and modes of operation. Whereas water heaters heating during the night are the prevailing type in France and Germany, continuous storage water heaters are predominately used in Spain, Italy, Hungary, Czech Republic and Poland. In UK, both types are common. Data on the distribution in other European Countries are currently not available. Load shifting potential of electric storage water heaters highly depends on their storage capacity. As far as consumer's comfort is not compromised, delay in start of operation or interruptions would be possible. The same applies for modulation of power consumption (e.g. changes in temperature settings or power).

The average lifespan of continuous appliances is within the range 13-17 years.

Behavioural appliances
Despite large numbers of installed base in all Member States and a high level of rated power, the flexibility of all behavioural appliances is low. This can be explained by the fact that their operation requires an active involvement of the consumer and thus is time-bound in narrow ranges. In most cases, the consumer wants the service being available directly upon request and load shifts would have serious impacts on consumer's comfort. For this reason, users will presumably not accept shifts in operation. For hobs and ovens, short-term interruptions or postponed heating phases for a few seconds will rather be accepted, if the cooking process is not compromised in any way. However, there is a lack of available studies on this topic.

HVAC
HVAC appliances have a great potential to become communication-enabled or DR enabled, given that they represent the main energy consumption in dwellings in the EU (heating accounts for 53% and cooling for 7%) (Waide et al., 2014). The main constraint regarding the communicating- or external action on HVAC systems is thermal comfort. The main disadvantage would be the possibility to jeopardize occupant's thermal acceptance (normally inside temperature) when demand-response acts on their HVAC appliances (on/off on peak hours, reducing the inverter current, load of the heat pump) during some time. These appliances are present among the whole EU28, with a penetration ratio for heating around 90% (EcoheatCool,2005) and for cooling around 15% (Ecodesign Lot 10, 2008). Heating presents a more homogeneous stock, due to Europe's temperate climate, being the opposite for air conditioners, where the stock is heterogeneous within the Member States. It is negligible in 20 of the Member States (less than 6%), and more important in Mediterranean and Eastern Europe (Italy, Spain, Greece, Romania, Slovakia, Southern France, Portugal). According to (BIOIS, 2011) heating is used approximately 7 months in EU28 (with demand largely varying between countries) and air conditioning 4 months for the countries/regions mentioned before (June to September). Taking into account that the heating market in Europe is saturated, existing heating technologies will decrease in sales, except for those that are more energy efficient and will be replaced (or be installed in new constructions) such as heat pumps i.e. (see also Task 1, Annex 1). As for air conditioners, for a penetration rate of 15% (more saturated markets on Member States mentioned above), future trends (Rivière, 2007) estimate a sales growth, mainly on split reversible A/C systems.

Battery operated rechargeable appliances
Due to the relatively low power consumption, Battery Operated Rechargeable Appliances need to be available in large numbers to be able to provide sufficient flexibility.
In this category we selected smartphones, tablets and laptops as possible candidates. These appliances today are largely available in all the Member States. Numbers of installed base range in hundreds of millions, all together.

Furthermore they already have sufficient control logic and communications features available, so that the implementation will be mainly limited to software. A quick calculation shows that sufficient flexibility (hundreds of GWh per year) can be gained without any change in user behaviour. But it is also clear that for correct calculations, there is still a general lack of available and reliable studies on this subject.

If the flexibility would need to be increased, the devices should be connected to their charging stations (wired or wireless) for longer periods, limiting the mobility that usually is the key feature of these appliances. On top of that, it has to be taken into account that the energy (demand) shifting potential is a balance between flexibility and energy saving, where longer connection leads to more shifting potential, but also to more energy consumption due to power losses (little, but present) when devices are connected. The lifespan of the devices is rather short, 4-5 years.

Residential energy storage system

From their nature, Residential Energy Storage Systems are ideal appliances for providing flexibility in the electric grid. Today we mainly see implementations of these systems in combination with PV installations. In this case maximum self-consumption of the PV generated energy is the goal. These systems can operate fully automatic and have no impact on the users comfort. Apart from this business case, the storage systems can also be used for different other business cases like dynamic pricing, peak shaving from and to the grid and aggregator services.

Although it's not their prime target, they can also provide additional comfort in cases of power downs. If we look at the current installations, we see that these systems are still very small in numbers and only common in Germany (25.000). The individual flexibility however is large. The lifespan of installations is expected to be between 15 and 20 years, but is strongly dependent on its usage (Temperature, Charging and Depth of discharge limits) and the quality of the battery. A quick calculation on the PV case shows a shifting potential of about 5.5 TWh per year.

Lighting

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

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

1.1.3 DATA PROTECTION, DATA SECURITY AND CONSUMER RIGHTS

For DR applications, high-resolution data on energy consumption are required. However, frequent measurement of power consumption may have serious implications on data privacy and the security of consumers as various information on the consumer can be deduced from these data (Siddiqui et al., 2012[78], Molina-Markham et al., 2010[79]). This information include the number of people living in a household or present at home at a certain point of time, type and brand of appliances available in a household, use patterns of devices, use mode, daily routines (e.g. sleeping, eating, showering, watching TV, etc.). In principle it can be said that the higher the frequency of readings, the more precise information can be deduced (Karwe and Strüker, 2014[80]). Related to data privacy, potential questions and concerns raised by consumers are manifold. They include, but are not limited to the following (Siddiqui et al., 2012[78]):

[78] Siddiqui, Zeadally, Alcaraz, Galvao (2012): Smart Grid Privacy: Issues and Solutions. Computer Communications and Networks (ICCCN), 2012.

[79] Molina-Markham, Shenoy, Fu, Cecchet, Irwin (2010): Private Memoirs of a Smart Meter. BuildSys '10 Proceedings of the 2nd ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Building, pp. 61-66.

[80] Karwe and Strüker (2014): A Survey on Privacy in Residential Demand Side Management Applications. In: Cuellar (Ed.): Smart Grid Security. Second International Workshop, SmartGridSec 2014, Munich, Germany, February 26, 2014. Revised Selected Papers. Springer

- Who is collecting and storing the data?
- For how long will the data be stored?
- Frequency of data readings
- Encryption of data
- How will the data be safeguarded?
- Who else has access to the data?
- Will the data be used for other purposes besides electricity delivering and billing?
- Can the data be used for or against a consumer?
- Liability in case of data abuse
- Access to control the appliances

Unless it is ensured that data protection and privacy of individuals are respected, consumers will not accept any DR programmes.
As conditions differ widely in different member states (e.g. penetration rate of smart meters, responsible entities for installation of smart meters, involvement of Data Protection Authorities, data paths, etc.), it is hard to define specific rules and recommendations in view of data processing and data protection. Nevertheless, the Task Force Smart Grid Expert Group 2[81,82]and the Article 29 Data protection working party[83] made general recommendations for data handling and safety as well as consumer protection:

"**Privacy by design and default**" is recommended for the design of technologies and services involved in processing private data. Privacy by Design means that privacy is embedded into design and architecture of the whole system. It should ensure data reduction and data economy as readings should take place only in intervals necessary for the respective system and service. The same applies for the transmission of readings. In general, processing and transmitting of data should be reduced to a minimum. Data should remain on the consumer's side to the highest possible extent. Entities, given the proper authorisation, should only have access to personal data necessary to fulfil their respective role.

The **retention of data** should be related to the purpose. Different retention periods may apply for different purposes (e.g. billing, taxation, law enforcement, optimisation of energy consumption). The Smart Grid Task Force made some recommendations on the scope and length of data retention, which are summarised in Table 13.

[81] Task Force Smart Grids Expert Group 2 (2011): Essential Regulatory Requirements and Recommendations for Data Handling, Data Safety, and Consumer Protection. Recommendation to the European Commission
[82] Task Force Smart Grids Expert Group 2 (2011): Regulatory recommendations for data safety, data handling and data protection report
[83] Article 29 Data Protection Working Party: Opinion 12/2011 on smart metering

Table 13: Recommendation for scope and length of data retention (Smart Grids Task Force, 2011[81])

Purpose	Scope	Length	Kept by
Network maintenance	Personal/anonymised/aggregated	strictly necessary / national law	Utility
Billing and payments	summed up usage	around 12-13 months / national law	Utility and energy market supplier
Billing complaints	detailed personal data	national law	consumer
Taxation – tax records	summed up usage	national law	utility
Taxation – tax breaks	detailed personal data		consumer
Value added services	upon consent	upon consent	any interested
Policy making	anonymised/aggregated	unlimited	public authorities

Data should be retained in an **aggregated and anonymised form** to the highest possible extent. For billing purposes, aggregation of several readings of one individual meter is conceivable, for load management the aggregation of data from several meters. It has to be ensured that the actions of individual households and patterns of single appliances cannot be recognised.

In order to ensure privacy, **safeguards** should be available comprising the whole system (elements of the network at home, the transmission of data, the storage of the data and any processing). These safeguards should be updated on a regular basis.

Any **disclosure of private data to or processing of data** by third parties should require the knowledge and consent of the respective consumer. This should include the right to withdraw any consent given earlier.

If any **Value Added Services** apart from energy supply (e.g. optimisation of energy consumption) are offered by the energy provider or a third party, it has to be an optional service and the customer needs to explicitly opt-in to provide its data for this purpose.

In the case of **mobility** (e.g. customers changing their providers, their locations, etc.), it should be ensured that the data stay linked to the respective customer or will be deleted completely. Regarding a change of the provider, this includes a secure transmission of the data.

Additionally, it has to be mentioned that Directive 95/46/EC on the protection of individuals with regard to the processing of personal data and on the free movement of such data and national laws implementing this Directive also apply to data processing in the framework of smart appliances and smart meters. In some respect, the aforementioned Directive is outdated as it does not take adequate account of new technological developments and Internet Services as for instance Cloud computing. For this reason and in order to harmonise data protection in Europe, a new General Data Protection Regulation is planned for the near future replacing Directive 95/46/EC.

Besides privacy concerns, consumers and experts also raise security concerns in view of smart applications. On the level of individual consumers, hacker attacks may imply a loss of control of single appliances or the introduction of malicious software (e.g. for spying purposes or profiling). On a grid level, attacks and introduction of malware might have enormous consequences. They can initiate an instantaneous increase or drop in demand, both destabilising the grid and resulting in severe problems or even damages of distribution, transmission and generation facilities. (Yan et al., 2012[84])

According to Stakeholders' opinion, the risk of an attack on the infrastructure is considerably higher than the risk of an attack on an individual appliance. Even though, some measures are recommended to decrease the risk of an individual attack. For instance, a manual "connection on/ off" switch should be provided that allows the consumer setting back the appliance to a local control. Additionally, an update capability should be available in the communication interface to tackle known threats and future security needs. Moreover, it has to be ensured that settings can only be changed within proper limits. If these limits are going to be exceeded, a safety shutdown of the respective appliance is recommended.
According to the National Institute of Standards and Technology[85] (NIST), deliberate attacks are not the only threats in view of the security of smart applications. Also potential accidents, e.g. due to equipment failures, user error or natural catastrophes should be taken into account.

1.1.4 Recommendations

Refined product scope
In order to refine the product scope from the perspective of consumer behaviour, all appliances are categorised according to their load shifting potential (Table 14). The categorisation has been done on the basis of the information and assessments mentioned before.

Table 14: Categorisation of appliances according to their load shifting potentials (categorisation in terms of energy or number of products/ applicability of demand shift)

High potential	Medium potential	Low/ no potential
Washing machines	Refrigerators/ freezers	Electric water heater (instantaneous)
Dishwasher	Battery operated rechargeable appliances (smart phones and tablets)	Vacuum cleaners
Tumble dryer		Range hoods
Washer-dryer		Battery operated rechargeable appliances (others)
Electric water heater (storage)		Lighting
HVAC		Hobs
Battery storage systems		Ovens

The „high potential"-category consists of appliances, which have high numbers of installed products and/ or a high level of rated power/ high energy consumption. The consumer acceptance of load shifts or short interruptions is good for these appliances and it seems feasible to handle their comfort constraints.

[84] Yan, Qian, Sharif, Tipper (2012): A Survey on Cyber Security for Smart Grid Communications. IEEE Communications surveys & Tutorials, 14, 4.
[85] NIST Special Publication 1108R2 (2012): NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0. Available online: http://www.nist.gov/smartgrid/upload/NIST_Framework_Release_2-0_corr.pdf

Although **refrigerators and freezers** have high numbers of appliances in stock and it is assumed that smart operation (e.g. frequency control) would be accepted by consumers, these devices are categorised as “medium potential” due to their low level of rated power. The same applies for chargers of **smart phones and tablets**.

The potential of **hobs and ovens** is assessed to be low despite the large installed base in the EU and a high level of rated power. The assessment can be explained by the fact that their operation requires an active involvement of the consumer and thus is time-bound in narrow ranges. For this reason, the acceptance of consumers for shifts in operation is presumable low and only short-term interruptions for a few seconds or postponed heating phases will rather be accepted, if the cooking process is not compromised in any way.

Instantaneous electric water heaters are categorised as a low/ no potential appliance. To reach a high level of consumer acceptance, it is essential to always ensure a sufficient amount of hot water. This is only possible in the case of storage water heaters. In view of instantaneous water heaters, short-term interruptions in power supply would cause losses in comfort, which will not be accepted by consumers.

In view of **vacuum cleaners** and **range hoods**, shifts in operation and short-term interruptions are also improbable. Their power demand remains constant during operation and interruptions in power supply would consequently interrupt their operation. A further reduction of their power would decrease their performance (lower air change rate or a loss of suction power, respectively), and will presumably not be accepted by consumers.

Battery operated rechargeable appliances others than smart phones and tablets are categorised as low/ no potential appliances. This is due to the fact that they either have a smaller installed base or a lower and less predictable charging frequency (e.g. household appliances, power tools, navigation systems).

In the case of **lighting**, load shifts or short term interruptions would decrease the comfort for consumers and will presumable not be accepted.

Onset on barriers and opportunities for Ecodesign

During the last years, the share of appliances offered on the European market, which can be connected to the Internet for safety or convenience reasons, has continuously been growing. It can be expected that this trend will further grow. This might be seen as an opportunity for DR. As far as it is possible to use the same software, there would be (almost) no extra costs for consumers to operate their existing appliances in a smart mode in order to shift loads. This would result in a very short payback time, which was identified as a key success factor.

From the consumers’ point of view, data protection and consumer rights have to be seen as the major barrier. To overcome this barrier, it is essential to harmonise standards at European level and develop technical solutions for appliances, communication and billing systems that ensure the highest security standards when dealing with personal data.

1.2 DEMAND RESPONSE USE CASES – SYSTEM PERSPECTIVE

The use of DR in the energy system can serve multiple objectives. First, it can be used to optimize the day-ahead scheduling of electricity production and consumption. Second, it allows in real-time to match supply and demand in case of deviations in scheduling. These use cases are explained in detail below and the role of smart appliances as provider of flexibility is discussed.

In Task 5, for these use cases a model will be developed allowing the environmental product assessment and definition of the base cases. Section 1.2.2 gives an overview of the European market context and in section 1.2.3 the main data assumptions used in the model are listed.

Note that the modelling of the use cases makes abstraction of any specific energy market structure. For there is varying support for DR in the deregulated EU Member States' energy markets. In some countries no DR mechanisms are available, in others DR is already extensively used in the large industry. The way the energy market is organized will determine the extent and distribution of the return from the DR business cases. The following factors vary significantly between Member States, making an overall assessment of the impact of DR on all market players case-specific (non-exhaustive list of factors):

- The ownership of the smart meter is not identical for all EU Member States (e.g. owner can be the DSO or the retailer).
- The access to ancillary services of the TSO for DR sources varies and depends on the ancillary service products of the respective TSO's.
- Various versions of variable tariffs are available throughout Europe and not all countries support variable tariffs.
- The role, obligations and rights of DR aggregators is not yet clear in many Member States.
- The rights and methods of the DSO to interact with DR for the purpose of safeguarding the distribution grids from this extra source of variability is not yet clear in many Member States.
- In only few Member States, mechanisms exist to alter the perimeter of the BRPs with the effect of residential DR.

1.2.1 DEFINITION OF USE CASES

Two distinct use cases can be defined, based on two important time blocks in the market: day-ahead versus real-time.

1) Day-ahead use case

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

DR could directly participate in the day-ahead market platform. The Balancing Responsible Parties (BRPs) have also the possibility to modify the load in order to match supply and demand. Load reduction or load shifting can avoid costs of additional production during hours with high prices. In this case, the flexibility of DR is directly integrated in the portfolio of the BRP. Independent how DR by the use of smart appliances is offered in day-ahead, it will support the matching of supply and demand at a lower cost. In case of high estimated production of RES during certain hours, load could be shifted or increased during these hours. In case of high estimated load, a decrease or shift in load will have a downward effect on prices.

The day-ahead scheduling of production and consumption is done at national level. However, in recent years, an evolution towards more integrated markets on European level can be observed. Several day-ahead markets within the EU are coupled today, resulting in a unified day-ahead price in case of no congestion of transmission lines.

The harmonisation of day-ahead markets is part of the larger goal of European harmonisation as discussed in 1.2.1. In 2015, a total of 20 EU power markets are coupled through the Multi-Regional Coupling[86].

2) Imbalance use case

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

The TSO is responsible for the stability of the grid and security of supply at the lowest cost in real-time or in near real-time. It will monitor in real-time the deviations of the grid and activate the necessary ancillary services in order to balance the system. Ancillary services can be provided by both, generation and load management, dependent on the type of ancillary service product. Dependent on the country, ancillary services are contracted by the TSO via yearly, monthly or weekly tenders. Today, the three categories of ancillary services are FRC[87], FRRa[88] and FRRm[89]. The relevant ancillary services for DR today are FCR and FRRm. FRC is used by the TSO to ensure that the grid frequency stays within a certain range within the interconnected high-voltage European system. FRRm is used by the TSO to cope with major imbalance and congestion issues.

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

Similar to the day-ahead use case, DR can be part of the imbalance use case in different ways. First, DR can participate directly in the market of ancillary reserves (FCR and FRRm). An example of DR participating to the market of FRRm is the product R3DP in Belgium (see later). The response time for FRRm is on average 15 minutes, which is sufficient for DR to participate. In general, it is more difficult for DR to participate in the market of FCR due to the fast response time that is required (15 seconds). However, applications based on batteries could participate to this market.

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[86] The Multi-Regional Coupling (MRC) is a cooperation between the Power Exchanges APX, Belpex, EPEX SPOT, Nord Pool Spot and OMIE, and the Transmission System Operators 50Hertz, Amprion, Creos, Elia, Energinet.dk, Fingrid, National Grid, REE, REN, RTE, Statnett, Svenska Kraftnät, TenneT TSO B.V. (Netherlands), TenneT TSO GmbH (Germany) and TransnetBW.

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

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

[89] FRRm = manual frequency restauration reserves of currently called tertiary reserves.

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

Today, there exists a large variety of balancing mechanisms[90]. Efforts are made to harmonize these rules within Europe (see also 1.2.1), in order to improve efficiency and increase competition in the market of ancillary services. Dependent on the organisation of the market, which varies between countries, prices of ancillary services, settlement mechanisms in case of imbalance and incentives for BRPs to actively balance their portfolio differ substantially.

Note: besides the two main use cases as discussed above, DR could serve other objectives as well, such as DSO grid congestion cases, reactive power voltage support in the transmission grid,…. However, these use cases are less mature (e.g. DSOs are today not incentivized to contract flexibility as costs for flexibility are not remunerated) and the value of flexibility from smart appliances cannot be estimated based on today's situation.

1.2.2 EU TARGET MODEL AND SCENARIOS

In 2007 the EU Member States agreed upon a clear set of targets for the integration of renewable energy. By 2020, the EU has a goal of a 20% reduction of greenhouse gas emissions, a minimum of 20% of energy savings and an increase of the share of renewable energy to at least 20% of the consumption[91]. Building upon the targets defined for 2020, in October 2014 the EU determined a policy framework for 2030 for climate and energy. The 2030 framework sets a target of 40% reduction in greenhouse gas emissions, a minimum of 27% of EU consumption to be produced from renewable energy sources and a 30% improvement in the EU energy efficiency compared to the projections[92]. The different EU targets with respect to the increase of renewable energy will have large effects on the grid, especially due to the intermittency of most renewable sources (wind and solar).

Besides increasing efforts in meeting the different climate and energy targets, steps are made at European level to stimulate the harmonisation of European energy markets. The European Target Model for Market Integration aims at a more integrated and efficient market with lower prices and increased stability that would benefit Transmission System Operators (TSOs), generators, investors, traders and ultimately end-consumers. The European Target Model addresses all market segments from forward markets to day-ahead, intra-day, balancing markets and cross border capacity calculation. In the short term, congestion on cross border interconnections hinders the integration of markets. Increased capacity and new interconnections should provide a long term structural solution.

In 2015, progress has been made in the first place with the development of network codes and the harmonisation of day-ahead markets[93]. Less progress has currently been made on the level of balancing markets which are still mainly organised on a national level, resulting in a large variety of

[90] https://www.entsoe.eu/Documents/Publications/Market%20Committee%20publications/150127_WGAS_Survey_2014.pdf
[91] Directive 2009/28/EC; Directive 2009/29/EC; Decision 406/2009/EC; Directive 2009/31/EC
[92] http://ec.europa.eu/energy/en/topics/energy-strategy/2030-energy-strategy
[93] https://www.entsoe.eu/Documents/Events/2014/141013_ENTSO-E_Update-on-IEM-related%20project%20work_final.pdf

mechanisms across Europe[94]. An example of initiatives to harmonize the balancing markets, in particular, imbalance settlement, is the international grid cooperation control (IGCC)[95]. The IGCC enables netting of the imbalance volumes between the participating countries, and hence reducing the need for activation of reserves.

The targets for renewable energy, in combination with the ongoing harmonisation of energy markets will determine the future market design. In the following analysis, results are presented for 2015, 2020 and 2030. In addition, the expected market design of an integrated European market, although not yet a reality, is used as a reference case for market design.

1.2.3 DEMAND/LOAD, INSTALLED CAPACITY AND FUEL PRICES

1.2.3.1 Demand or Load

The estimated demand for EU28 is based on the realised hourly load data of 2014 as published by the statistical database of ENTSO-E[96]. The load is corrected for import and export with countries not belonging to the EU28. In order to determine the load in 2020 and 2030, a yearly increase of 1.4% is assumed[97].

1.2.3.2 Installed capacity per Member State

The installed capacity of production units per Member State is based on the installed capacity of 2014 as published by the statistical database of ENTSO-E. For 2020 and 2030, the production mix per Member State is based on the PRIMES scenarios[98]. The PRIMES model simulates the European energy system and markets on a country-by-country basis and across Europe for the entire energy system. The model produces projections over the period 2015 to 2050 in 5-years intervals[99]. Utilized values for the installed wind capacity, solar capacity and peak load are summarized in

Table 15.

[94] https://www.entsoe.eu/Documents/Publications/Market%20Committee%20publications/150127_WGAS_Survey_2014.pdf

[95] http://www.tennet.eu/nl/fileadmin/downloads/About_Tennet/Publications/Other_Publications/plugin-Market_information_IGCC_tcm43-20521.PDF

[96] https://www.entsoe.eu/data/data-portal/Pages/default.aspx

[97] KPMG. Power Sector Development in Europe – Lenders' Perspectives 2011 - A survey of banks on the prospects for power infrastructure financing in Europe

[98] http://ec.europa.eu/transport/media/publications/doc/trends-to-2050-update-2013.pdf.

[99] More information on the PRIMES model is listed on the website of E3Lab of the National Technical University of Athens - http://www.e3mlab.ntua.gr/e3mlab/index.php?option=com_content&view=category&id=35:primes&Itemid=80&layout=default&lang=en

Table 15 Installed RES capacity and peak load per EU-28 Member State per year (Source: ENTSO-E database for 2014 for all Member States except Malta, PRIMES scenario outcomes for 2020 and 2030, and for Malta for 2014, and for peak load in Malta Enemalta[100])

	Installed solar capacity [MW]			Installed wind capacity [MW]			Peak load [MW]		
Year	2014	2020	2030	2014	2020	2030	2014	2020	2030
AT	715	787	1466	2140	3114	6051	11441	12436	14291
BE	2916	2429	4813	2281	4772	7068	13345	14506	16670
BG	275	1116	1534	358	923	1515	6739	7325	8418
CY	79	194	658	144,3	249	329	815	886	1018
CZ	2061	2011	2068	278	307	387	1093	1188	1365
DE	39190	49089	53584	38900	48956	69949	83102	90331	103805
DK	421	360	762	3809	5960	7420	6109	6640	7631
EE	0	0	0	328	495	1056	1425	1549	1780
ES	6536	12655	16945	22740	25213	35707	39640	43089	49515
FI	0	50	60	496	1538	2556	14146	15377	17670
FR	5296	7470	13913	9262	25687	47354	92900	100982	116044
GB	1745	5985	8853	12900	38627	50721	59440	64611	74248
GR	2429	3286	3640	1613	3433	3745	8764	9526	10947
HU	34	27	182	340	640	713	5863	6373	7324
IE	6	93	712	329	903	1236	4491	4882	5610
IT	0	19553	28206	1907	11200	22598	53976	58672	67423
LT	18609	0	0	8683	222	251	1810	1967	2261
LU	68	226	409	282	226	290	994	1080	1242
LV	109	1	1	57	428	681	1380	1500	1724
MT	0	48	211	51	86	191	438	476	547
NI	32	0	674	1	3561	5992	1697	1845	2120
NL	1000	788	1037	2874	9624	12359	18457	20063	23055
PL	14	51	530	3758	6515	8843	22680	24653	28330
PT	221	2212	5613	4486	5689	8324	8322	9046	10395
RO	1101	679	1860	2896	1572	4043	8312	9035	10383
SE	79	182	248	5420	4447	5107	26737	29063	33398
SI	262	130	444	3	225	453	1984	2157	2478
SK	531	689	1009	3	113	455	4126	4485	5154

1.2.3.3 Fuel prices

The fuel price for the different technologies will determine which power plant will run and at which price. The fuel costs in the model for (prices of oil, gas and coal) for 2020 and 2030 are based on an average of the price scenario's as defined in the World Energy Outlook 2013 and the price scenario's

[100] Enemalta:http://www.transport.gov.mt/admin/uploads/media-library/files/DAirMaltaStudyVisit_The%20Energy%20Sector%20in%20Malta.pdf

presented in the Energy Technology Perspectives[101]. Prices for 2014 are based on realised market prices[102]. The prices are not country specific.

The CO2-prices in the model for 2014 are based on the average price of the EUA Dec 2014 contract as quoted during 2014 (published by ICE[103]). The prices for 2020 for CO2 are based on the current published price (16/10/2015) of the EUA December 2020 contract (published by ICE). The price for 2030 is based on an analysis of Thomson Reuters[104].

The prices for biomass are based on typical values for wood pellets as published on FOEX[105]. For biomass, the assumption is taken that in most countries, support schemes exist. An average of 55€/MWh as support value for biomass is used[106]. Table 16 summarizes the fuel prices used in the simulation.

Table 16: Fuel prices for 2014, 2020 and 2030 used in the model

		Year 1 (2014)	Year 2 (2020)	Year 3 (2030)
Nuclear	[EUR/MWh_prim]	6,34	6,34	6,34
Coal	[EUR/MWh_prim]	8,42	11,93	11,97
Natural gas	[EUR/MWh_prim]	25,75	31,66	32,71
Hydro	[EUR/MWh_prim]	0,00	0,00	0,00
Wood pellets	[EUR/MWh_prim]	5,06	4,84	4,34
Oil	[EUR/MWh_prim]	48,48	53,54	57,42
CO2	[EUR/tCO2]	5,96	9,07	48,00

[101] http://www.iea.org/etp/etpmodel/assumptions/
[102] http://knoema.com/wxgcxde/commodity-prices-forecast-2015-2019-charts-and-tables?variable=Natural%20gas%20(US%24%2FmBtu%2C%20Europe)
[103] https://www.theice.com/market-data
[104] http://www.changepartnership.org/wp-content/uploads/2014/10/Point-Carbon-2014-11042014-MSR-Point-Carbon.pdf
[105] http://www.foex.fi/index.php?page=pix-rcp
[106] https://ec.europa.eu/energy/sites/ener/files/documents/ECOFYS%202014%20Subsidies%20and%20costs%20of%20EU%20energy_11_Nov.pdf

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