Smart Domestic Appliances Supporting the System Integration of Renewable Energy

SMART-A

Intelligent Energy Europe

This report summarises the results of the European project "Smart Domestic Appliances in Sustainable Energy Systems (Smart-A)", which assesses the potential synergies from coordinating the energy demand of domestic appliances with the generation of electricity and heat from renewable energies or cogeneration with other load management requirements in electricity networks. The project was supported by the European Commission through the IEE program (contract no. EIE/06/185/SI2.447477).

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Executive Summary

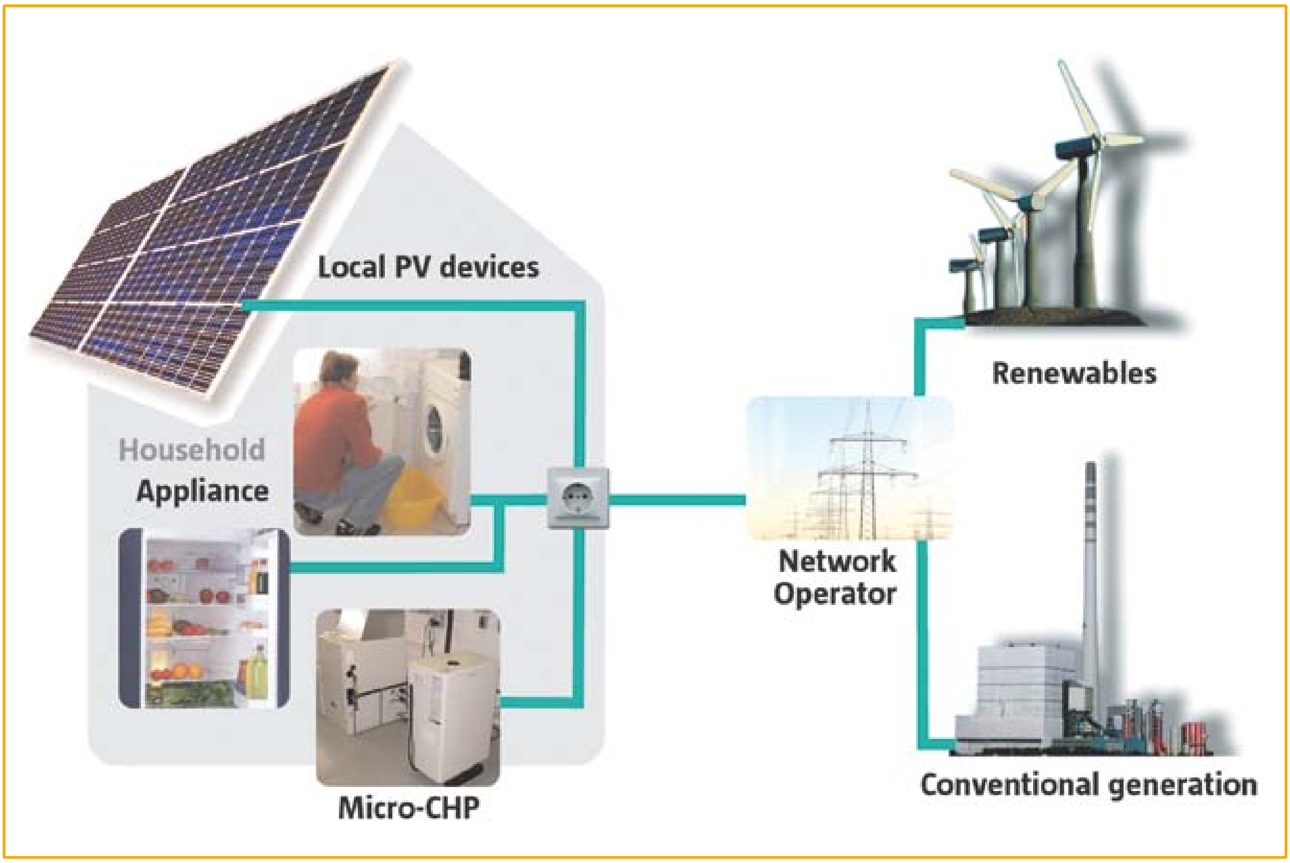
Europe has set the ambitious target of a 20% share of overall energy demand to be supplied from renewable energy by 2020. It is expected that in order to achieve this target, the share of renewable energy in the electricity sector will need to increase to some 35%, which means more than doubling the levels which were achieved by 2005. Most of the increase will come from wind and solar energy, which are both fluctuating resources by nature. In the longer run, industrialised countries will have to reduce their carbon emissions by more than 80% compared to 1990, which may require a complete decarbonisation of the electricity sector by the year 2050. One of the major challenges associated with this drastic restructuring of our energy supply is how electricity networks can cope with the variability of wind and solar energy production.

This challenge is actually two-fold: On the one hand we need the scheduled generation of electricity and demand to match at all times. The progress made in forecasting wind energy production will support the reliability of the schedules for wind generation, but future electricity systems will face higher variability in scheduled power generation. This must be levelled out by increasing the existing capacities for energy storage, e.g. in pumped hydro power plants, and by adapting significant shares of the electricity demand to the available renewable energy production. On the other hand, the increased volatility in electricity generation requires a larger margin of reserve capacity in the energy system, which can react to unexpected deviations from the scheduled production or demand. With less and less conventional power generation in the system, we need to expand other forms of providing responsiveness for the electricity system. The possibility of influencing the energy demand at short notice is one of the options for dealing with this challenge. All in all, we have to develop a new paradigm of flexible energy demand: In the past, the ideal load curve was flat in order to allow for the full load operation of conventional power plants. In the future, the ideal demand needs to be variable in order to adapt to the current production from renewable energy sources.

Smart Appliances as flexible loads

The Smart-A project has examined the suitability of electric domestic appliances for so-called Demand Response activities in the context of high shares of renewable energy. This is intended as a contribution to expanding the scope of demand-side load management beyond the industrial and commercial applications, and some electric storage heating, which are currently being used for levelling out demand peaks and filling load valleys. There has been an intensive discussion about the integration of domestic consumers into concepts of Smart Grids, but up to now it has not really been made clear how households can actually be enabled to manage their electricity demand. The Smart-A project outlines a concept of how domestic appliances can be connected to an intelligent management of electricity systems of the future, which include local cogeneration of electricity and heat as well as high shares of renewable energy production from small-scale photovoltaic systems up to large wind farms (Figure 1). The project also assessed options how appliances can use hot water produced from renewable energy sources or from cogeneration instead of heat produced from electricity.

Figure 1: The Smart Appliance Vision



Source: Author's own illustration

The Smart-A study focuses on ten appliances, which comprise typical white goods such as refrigerators, freezers, dishwashers, oven and stoves, washing machines and tumble dryers as well as air conditioners, circulation pumps for heating systems, electric storage heating and water heaters. Based on an intensive literature survey, a set of data was compiled which describes the usage patterns of each of these appliances and their energy consumption.

For these appliances, two types of load shifting actions have been assessed. Firstly, it is possible to modify the starting time of an appliance cycle. Starting from today's start time delay function, users of appliances could in the future select a time when the cycle should be finished, e.g. when the user returns home from work, and within this time period the appliance optimises the timing of its operation. Depending on the type of appliance, the operation could be shifted by up to 8 hours or more. Secondly, an appliance cycle might be interrupted for a limited period of time under certain conditions. The limitations for such interruptions are typically set by the need to ensure the full service quality of the appliance, e.g. not compromising food in cold appliances or clothes in a washing machine, and according to energy losses which might occur during the interruptions. Typically, appliance cycles should only be interrupted for periods of up to 15 to 30 minutes. For both types of smart operation, we have assumed that the actual control of the appliance stays with an internal controller. This controller optimises the appliance operation and in carrying out this task it can take external load management signals into account, which could be broadcasted by, for example, the electricity network operator.

A rough assessment of the suitability of individual appliances for load management resulted in a quite mixed picture. Electric heating and water heaters provide the largest shifting potentials, but these potentials are already used in many cases by simple night time operation of storage units. Also, low-temperature applications of electricity are not preferable under energy efficiency considerations and as a result these technologies might be used less in the future. Dishwashers provide quite long time spans of load shifting and their smart use seems acceptable to many users. Cold appliances such as refrigerators and freezers allow for a fully automatic smart operation, but have a low power consumption per appliance and are only able to deliver relatively short durations of load reduction. Washing machines and tumble dryers are attractive options for Demand Response, but they require a closer interaction with the user compared to other appliances. Ovens and stoves are not really suitable for load management as they are used on demand, and air conditioners and circulation pumps are only partly suitable.

The cooperation of consumers is essential for the realisation of the Smart Appliances concept. To this end the Smart-A project has undertaken extensive consumer research, including literature analysis, a consumer survey, focus groups and phone interviews. From the point of view of consumers, Smart Appliances can require different levels of involvement: Firstly, some appliances can be operated in a fully automatic smart mode, which the consumer hardly notices. Secondly, appliances might require the user to select once between smart and unsmart operation during a setup procedure ("set and forget"). Thirdly, the consumer might be required to make considerations about smart appliance operation case by case. This might require just pressing a "smart" button when starting a cycle, but it could also involve the processing of complex information provided by a display on the appliance.

In the Smart-A research, consumers showed a surprisingly high general acceptance of Smart Appliances. However, as the samples were not fully representative, the quantitative results should be interpreted with caution. Generally, consumers are not willing to change their habits and daily routines in order to enable smart appliance operation and they want to be able to retain full control over their appliances if desired. There are concerns about leaving appliances unattended or operating them during night, but these concerns differ significantly between individual appliance types. Consumers expect Smart Appliances to include additional comfort and safety features and for them to be easy to operate. Under these conditions, consumers tend to accept additional purchasing costs of up to 25 EUR per appliance even if they are not compensated for this. Nevertheless, an attractive and simple economic incentive, e.g. through the electricity bill, would certainly increase the uptake of Smart Appliances. Consumers seem to expect that privacy of personal data and data security can be ensured. This remains an important topic for the integration of consumers into Smart Grid concepts.

Economic benefits of Smart Appliances

Regarding the actual use of Smart Appliances in the management of electricity systems, the Smart-A project focuses on the balancing of variable wind power generation. This is expected to be the application of Demand Response with the highest economic benefit under the framework of the high shares of wind and solar energy which can be expected in the near and more distant future. Other relevant applications of Smart Appliances include the management of individual balancing groups in the electricity market or congestion management in electricity networks on the distribution or transmission level.

In a first step of modelling the interaction of Smart Appliances with different types of electricity systems, we found that the highest economic value of such Demand Response options can be realised in regions which feature high shares of variable wind power production and low flexibility in the power generation system. This means a large share of inflexible nuclear or fossil power plants, as opposed to more flexible generation systems which are dominated by large shares of controllable hydro power or gas-fired power plants suitable for peak operation. Given an assumed 30% share of wind power in the total installed generation capacity, we estimated a gross value of 1 kW of controllable load in a range between some 20 EUR per year in regions with a highly flexible generation system and some 90 EUR per year in inflexible systems. Regions with moderate generation flexibility show a value of about 45 EUR/kW/a. The specific value of Demand Response for purposes of balancing wind generation decrease significantly if the share of wind power is lower, and increases further in the case of even higher shares.

These economic benefits of Smart Appliances are based on the fact that the availability of additional Demand Response options reduces the need for operating conventional power plants in part-loaded mode in order to provide the required reserve capacity in the electricity network. This has two effects: Firstly, the part-loaded operation of these plants is less efficient than full power operation. Thus, the fossil fuel consumption and the CO_2 emissions decrease if less plants operate part-loaded. Secondly, the lower number of conventional power plants which are required for the provision of reserve capacity allows more wind energy to be produced in the total generation system. This means that in cases of high wind and low energy demand, the potential wind production does not have to be curtailed to the same extent as it would be without Smart Appliances. Again, the replacement of fossil-fuelled power generation by wind under these conditions reduces fuel cost and CO_2 emissions.

In a second step of modelling we addressed the different values of the smart operation of selected appliances in a region with moderate generation flexibility and a 25% share of wind power in installed generation capacity. Depending on the maximum duration of the load shift and the volume of energy to be shifted per appliance, we found that dishwashers might be able to reap a total economic benefit of some 90 EUR over a lifetime of 12 years. A washing machine generates only about half of this benefit due to a lower shifting flexibility. If the washing machine is combined with a tumble dryer into a single appliance, the benefit from smart operation could be up to 200 EUR over 10 years.

In a separate modelling exercise we assessed the integration of Smart Appliances in local energy systems, which feature high shares of local photovoltaic production and might use local cogeneration plants for heat and electricity supply. In this setting we analysed whether Smart Appliances can support the optimal use of locally produced energy and at the same time contribute to the management of a transmission network with high shares of wind generation. We found that under these objectives the overall benefits of Smart Appliances are only moderate. However, it is interesting to note that the use of local cogeneration plants does not conflict with a Smart Appliances strategy. Both technologies can work together quite well.

Comparison of costs and benefits

In a next step, we compared the potential gross economic benefits of Smart Appliances with their additional investment and operational costs. Here, we took into account the annualised higher production costs of Smart Appliances, which are mostly driven by additional communication capabilities of the appliances, and the slight increase in energy consumption due to increased standby operation of the appliances. As the analysis is focused on the year 2025, we assumed that no extra costs arise for the provision of in-house communication, e.g. based on WLAN. Under these assumptions we found that for many appliances the total extra costs of 1 kW of controllable load could be in the range of 9 to 15 EUR per year in a moderate costs scenario and up to 30 EUR per year in a high costs scenario. A quick comparison with the gross values reported above for different types of generation systems indicates that Smart Appliances could have a net economic benefit in most parts of Europe, with the exception of regions which have a highly flexible generation system.

In order to give a more detailed picture of the cost-benefit ratio of Smart Appliances in Europe, we transferred the methodology which was used in the modelling exercise to the 27 EU Member States and to Norway and Switzerland. Based on projections for the future structure of the national generation mix and the expected share of wind power by the year 2025, we were able to estimate the value of 1 kW of controllable load in each of the countries. This resulted in a quite diverse picture:
For 13 of the 29 countries, the value was estimated to be well above 15 EUR/kW/a in a moderate energy price scenario. We also established that these countries represent the majority of the overall potential of Smart Appliance operation in Europe. Of a total Demand Response potential by Smart Appliances of some 60 GW which we estimated for the year 2025, 40 GW seem to be viable in economic terms. Typical countries with a low value of controllable load have a generation system with high flexibility, such as in Austria or Sweden, or can expect only a moderate penetration of wind power, such as in Finland or Romania. For Norway and Switzerland both conditions apply and thus the specific value of Demand Response remains very low.

Through stronger integration of the transmission systems in Europe, the national differences in the generation systems will gradually become less relevant. However, a situation where all of Europe is only a single balancing region and all physical bottlenecks in the transmission system have been removed seems quite unrealistic for the next 15 years. In this extreme case, Smart Appliances would entail much lower benefits in many countries and their overall European average value would only be marginally higher than the expected cost. This underlines the efficiency gains which a further integration of European transmission systems can bring about. As long as full integration is not achieved, Smart Appliances will be useful for supporting the balancing needs of national or regional transmission systems.

Incentive mechanisms for Smart Appliances

For the success of a new concept such as Smart Appliances it is not sufficient that the cost-benefit ratio is positive from an overall economic perspective. Ultimately decisions will be taken from an individual perspective, and thus it is important to understand how the costs and benefits of Smart Appliances are allocated to the relevant actors. We have assessed this in a final step of the analysis, but only a qualitative assessment was possible. Looking at the current regulatory and market frameworks it can be expected that most of the economic benefit will occur in the electricity sector, e.g. as cost reductions for system balancing or electricity network operation. This benefit will usually be passed on at least partly to all electricity consumers; other parts of the benefit might remain with the utilities as extra profits. However, the extra costs for the production and operation of Smart Appliances will most likely be borne only by the smart households. The benefits passed on to all consumers will certainly not be high enough to make this distribution of costs and benefits attractive for the users of appliances, which are the main actors needed to implement Smart Appliances.

Thus we need incentive mechanisms which collect part of the benefits within the electricity sector and direct them to the smart households. Because there are different ways of how Smart Appliances can actually be implemented and operated, we might need different incentive schemes. We have outlined a selection of five implementation models of Smart Appliances which are using fixed premiums or variable electricity tariffs. It should be noted that not all of these models require advanced Smart Meters, but many of them depend on some form of communication gateway within the household, which establishes a unidirectional or bidirectional connection with the individual appliances.

Finally, we developed a set of recommendations for the implementation of Smart Appliances. These are geared to different actors such as the appliance manufacturers, the electricity industry, standardisation bodies and policy makers. On the technological side, the standardisation of cross-sector communication between energy meters or other gateways and the appliances is one of the most urgent challenges. On the socio-economic side, development of adequate business models for the operation of Smart Appliances and related incentive schemes for households is very important. Proposed concrete actions include the integration of a credit for proven benefits of Smart Appliances in the energy efficiency assessments under the EU Energy Label and the development of energy-efficient washer-dryers as well as advanced appliance technologies which replace electrical energy by hot water, which could be supplied by renewable energy or local cogeneration.

A proposal for a roadmap for the further development of Smart Appliances in Europe begins with a phase of feasibility studies and pilot projects, which are needed to verify and detail the rough estimates made in the Smart-A project. This could be followed by a market introduction phase for those Smart Appliance applications which are promising in terms of economic benefit and consumer acceptance. This market introduction would require a degressive public support program in order to enable appliance manufacturers to enter into self-sustaining mass production. Based on the results of the market introduction, the penetration of Smart Appliances could then be further increased and the benefits of Smart Appliances in terms of supporting the integration of renewable energies in European electricity systems could be reaped.

1 Introduction

Based on a set of far-reaching policy decisions, Europe has started a major restructuring of its electricity system. The objective of these decisions is to boost renewable energy sources, increase energy efficiency, significantly reduce CO_2 emissions and make Europe less dependent on energy imports. First and foremost the new Renewable Energy Directive (2009/28/EC) legally implements an earlier political agreement to increase the share of renewable energy in total energy consumption from 8,5% in 2005 to 20% by 2020. This ambitious increase will cover all three energy sectors: electricity, heating and cooling, and transport. Most likely the 2020 target will mean that the share of renewable energy in Europe's electricity production will reach or even exceed 35% within the next ten years. This would mean that the share of electricity from renewable energy sources (RES) will more than double compared to 2005 levels when renewable energies contributed some 15% to European electricity generation. The largest part of this increase will come from wind power, both from onshore and offshore generation sites. Even higher shares of wind and solar energy will be needed in order to achieve the more ambitious target for the CO_2 reduction in today's industrialised countries of between 80% and 95% by 2050.

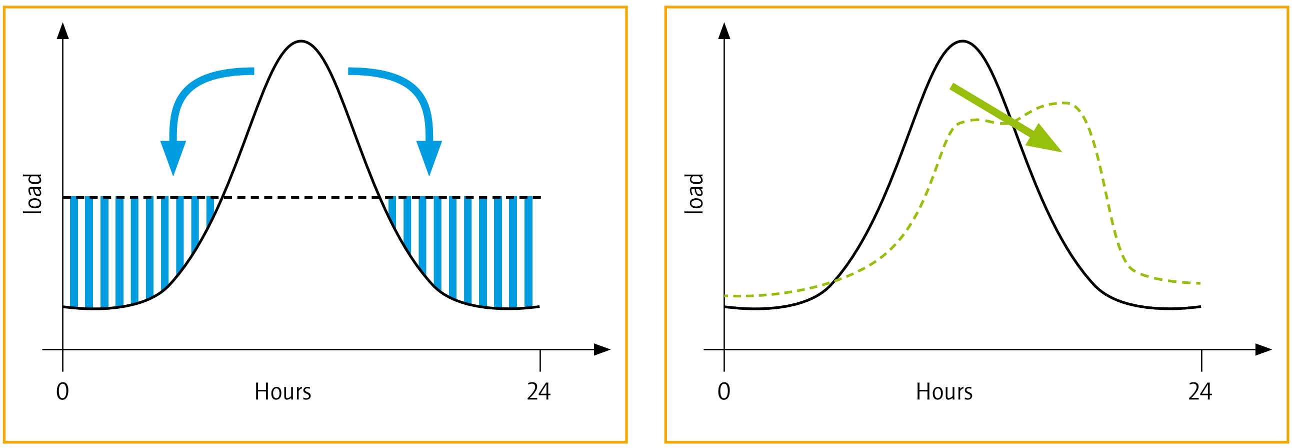
As wind and solar power are by nature fluctuating energy resources, European electricity systems must become able to deal with the new generation mix and its variability. Improved wind forecasts are helping to reduce the uncertainty in wind generation in short to medium time ranges. But nevertheless the electricity system must be developed further in order to react to the variations in wind generation and deal with periods of very high and very low wind generation. Already today the situation arises in which wind generation must be curtailed in order to ensure a stable operation of the electricity networks. On the one hand this is related to the balance between generation and demand in individual regions in Europe and grid bottlenecks which limit the possibilities of transferring extra wind generation to other regions. On the other hand there is the problem of ensuring grid stability in times of high wind generation and low demand. In order to be capable of dealing with sudden variations in wind generation, the system operator needs to ensure a certain margin of reserve capacity at all times. Typically this responsiveness is ensured by energy storage devices such as pumped hydro power plants and by conventional power plants which are operated part loaded in order to provide positive or negative reserve capacity at short notice. However, with rising shares of wind energy in total energy production, the limited potential of these sources of responsiveness will be exploited and new options will be required.

One of the additional measures for dealing with generation variability is Demand Response. Under this concept, the demand for electricity is not deemed static or uncontrollable any more; rather it is enabled to respond to price signals or to other indicators reflecting the current load on the electricity system.[1] Together with distributed generation, energy storage technologies and more flexible operation of centralised power plants, Demand Response can help to cope with the challenges of future energy systems.

So far, the work on Demand Response options has mostly focused on large consumers in the industrial and commercial sector. In the domestic sector, the most common measure of controlling demand is to switch thermal loads such as electric storage heating systems or electric storage water heaters, which might be supported by time-of-use tariffs with fixed tariff zones. Typically, such devices are being switched on during pre-defined night times and discharge the thermal energy stored during that day. This pattern of operation results from the long-lasting paradigm that the ideal load curve of electricity demand is flat during all hours of a day, which allows conventional power plants to operate continuously at full load and level out the stress in electricity networks.

[1] *For a recent overview, see Albadi and El-Saadany (2008).*

Figure 2: The new paradigm of flexible electricity demand



Source: Author's own illustration

The upcoming transformation of the electricity system, which will bring about a strong growth of generation from wind and solar energy, will lead to a new paradigm of flexible electricity demand: In the future we are looking for a general variability of electric demand, which enables the energy system to adapt better to the variable shares of renewable energy generation. We would like to be able to shift demand towards times of high wind and solar power generation. In contrast to the previous paradigm, the ideal load curve of the future will feature demand peaks in those hours where plenty of renewable energy is available, and load valleys in times of low renewable generation.

All in all, the energy system of the future will be more complex and must contain a higher level of intelligence and flexibility than has been the case in the past. In the longer run we will need to exploit all means of responsiveness of thermal electricity generation as well as energy storage and Demand Response which are available at acceptable cost.

This report focuses on the possibilities of a conceptual and technological integration of domestic electric appliances into the concept of Demand Response in electricity systems.

State-of-the-art domestic appliances are not only becoming more and more energy efficient, they can also offer a range of options for load-shifting. This can include delaying the start of washing or dishwashing cycles, interruptions of the operation of appliances, or the use of refrigerators and freezers for temporarily storing energy in order to avoid operation of the compressor during peak times. Although the energy consumption and load of a single appliance is negligible compared to the challenge of managing regional distribution networks and national electricity systems, the impact of a coordinated smart operation of millions of domestic appliances can be significant. First projects in this field have been undertaken for example in the Dynamic Demand Control project in the UK where the variations of the system frequency are used as an indicator for the stress on the system, which triggers Demand Response actions of appliances (Short and Leach 2006).

The following chapter describes the framework conditions for the operation of appliances and the possibilities for modifying their consumption profile. Based on a set of generic criteria, the major types of appliances are evaluated regarding their suitability for smart operation. Chapter 3 addresses the consumer preferences and concerns regarding Smart Appliances, and potential measures to ensure participation in Demand Response programs. Chapter 4 explains the results of different modelling exercises regarding the gross economic benefit which Smart Appliances can bring about under different framework conditions. In chapter 5, an analysis is undertaken of how Smart Appliances can be integrated in the management of local energy systems which feature high shares of local energy production. An overall assessment of the costs and benefits of Smart Appliances in Europe and the related potentials can be found in chapter 6. Chapter 7 deals with the distribution of costs and benefits from an individual actor perspective, and discusses potential incentive mechanisms and implementation models for Smart Appliances. Finally, chapter 8 sets out recommendations for the implementation of Smart Appliances, which are followed by a rough draft for a roadmap for their development.

2 *Demand Response Options Provided by Domestic Appliances*

As a first step of the analysis we need to understand how and at what time of day household appliances are typically operated in Europe. Based on a broad review of existing literature and data, the Smart-A project team has compiled this information for the following ten appliances:

Table 1: Domestic appliances selected for the Smart-A project

AC	Air Conditioner
CP	Heating Circulation Pump
DW	Dishwasher
EH	Electric Storage Heating
FR	Freezer
OS	Oven & Stove
RF	Refrigerator
TD	Tumble Dryer
WH	Electric Water Heater
WM	Washing Machine

As can be seen from this list, the analysis focused on the so-called "white goods" plus a selection of further household appliances. Most other electricity consuming devices in private households are typically used by consumers "on demand" and thus do not allow for much load shifting, such as computers, audio and video sets and lighting.

Based on the data available and some of our own assumptions, the project team derived sets of data for each of the ten appliances listed in Table 1 which include the preferences of consumers in major European countries for using the appliances at certain times of the day and the average duration and energy consumption of an appliance cycle. For those appliances which operate in automatic mode, such as refrigerators, freezers, circulation pumps and electric storage heating, the typical patterns of operation were assessed.

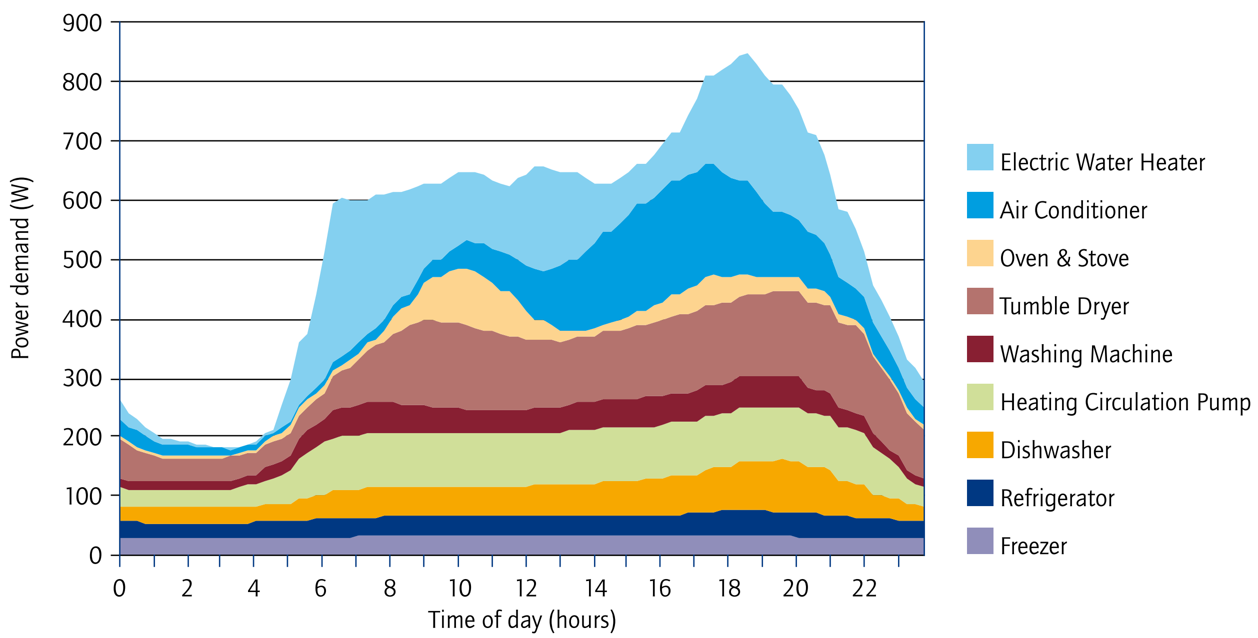
The result of this analysis is a set of data which describes the probability of operation of each of the ten appliances over the 24 hours of a typical day and the related energy demand. Figure 3 shows the energy consumption of a generic European household which, on a typical day, is equipped with nine of the ten appliances listed above. As the load of electric heating systems is significantly higher than that of other appliances, these systems have been left out in this figure.[2]

The Figure 3 shows the continuous operation of freezers and refrigerators, the use of circulation pumps and air conditioners following the demand for heat or cooling and the use of other appliances based on the routines and preferences of the users. This results in an overall consumption peak by these nine appliances of about 850 watts in the early evening which is then followed by a steep decrease to some 200 watts during the night. Clearly this kind of information is very useful in order to assess at what time of a day each appliance is likely to be operated and thus how much load could be shifted. However, projections for smart appliance operations in the future need to reflect changes in the penetration rates and the daily usage patterns for each type of appliance as well as improvements in energy efficiency. For the scenarios in this project, appropriate assumptions have been made.

Figure 3 represents a statistical average over all days of the year for a generic household which is using all nine appliances. It should be noted that the total electricity demand of this household is also influenced by other energy consuming devices which are not addressed by this study.

[2] *Note also that for reasons of improving energy efficiency, the use of electrical energy for low-temperature applications is highly questionable. Germany has decided to replace most of the existing electric heating systems by 2020.*

Figure 3: Average load curve of a generic European household which is using nine of the ap-pliances included in this study



Source: Stamminger 2009a

How can we shift the load of appliances?

For the purpose of this study, two options for load shifting have been taken into account:

- **Smart Timing of appliance cycles:** This means that the start of the operation of an appliance is delayed or anticipated based on the load management requirements of the energy system. The easiest variant of smart timing is the already quite widespread feature of appliances to pre-set the start time manually when switching it on. However, a truly "smart" operation would mean instead that the consumer sets the appliance in a "ready" mode and selects the desired time at which the cycle of the appliance should be finished. In the given timeframe the appliance can optimise its operation: It could start the cycle just in time to finish by the time set by the consumer or it could start earlier than this, based on price signals or other indicators given from the energy system. Smart timing could also mean that a refrigerator or freezer stores cold in its compartment in a period preceding an expected load peak in the energy network. This would allow these appliances to avoid the operation of their compressors during this peak period.

  The limitations for this smart operation are mostly set by consumer preferences (see the following section), but also by technical constraints. For example, even if consumers accepted the operation of washing machines at night, it might still not be possible due to the noise produced in the spinning phase. Also, the wet clothes should not be left too long in the washing machine after the end of a cycle. Consumer action is required to take them out and hang them on the line or to dry them in a tumble dryer. These restrictions are much less relevant in the case of dishwashers, which can easily be left alone for several hours after the end of their cycle. Refrigerators and freezers are operated in a cycling mode. As long as their doors are kept closed, the cycle is determined by the thermal losses between the compartment and the ambient temperature and the capacity of the compressor. An improved thermal insulation of the cold appliances and a colder lower threshold temperature for the compartment could extend the time span between the operations of the compressor and thus the maximum period for load shifting. Ovens and stoves are typically used on demand and thus their shifting potential is limited to cases where consumers actually change their daily schedule.

- **Interruptions of appliance cycles:** This involves appliances which are already in operation. Under certain conditions it may be possible to interrupt the cycle of the appliances in the case that a load reduction in the electricity network would be desired. Such an interruption of the operation could be triggered by an external signal to the appliances. However, we assume that control over the operation remains with the internal controller of the appliance and is not taken over by an external unit. The internal controller might be able to stop the operation of the appliance for a certain period, which is typically restricted for technical reasons.

  For example if a washing machine or a dishwasher is in a hot washing or rinsing phase, the thermal losses of stopping the operation at this stage of the cycle can be quite high. Any interruption longer than a few minutes would cost an unacceptable amount of energy to heat up the water in the compartment again after the interruption. Similarly, interruptions of the cycles of cold appliances (refrigerators and freezers) are limited by the thermal behaviour of their compartments and the upper threshold temperature at which the compressor must run again. In contrast, the heat content of tumble dryers is much lower and thus a longer interruption can be acceptable under energy efficiency terms. Circulation pumps of heating systems and air conditioners may also be interrupted for a certain period, depending on the thermal behaviour of the building and the comfort criteria of the inhabitants.

As a general principle for the load shifting options discussed above, the service quality of the appliance must be fully maintained. This means that modifications in the operation of cold appliances may not compromise the food in their compartments. Washing machines and tumble dryers should not put the positive results of the washing and drying process at risk. Similar quality criteria apply for the other appliances.

Table 2: Typical options for Demand Response provided by Smart Appliances

Smart Timing of Appliance Cycles	Interruptions of Appliance Cycles
Expected typical time shifts of the cycle:	Expected typical duration of interruption:
■ Washing machine / Dryer: 3 – 6 hrs	■ Washing machine: ~ 15 mins
	■ Dryer: ~ 30 mins
■ Dishwasher: 3 – 8 hrs	■ Dishwasher: ~ 15 mins
■ Refrigerator / freezer: 15 – 30 mins	■ Refrigerator / freezer: ~ 15 mins
■ Other appliances: 15 – 30 mins ... 1 hr	■ Other appliances: ~ 15 mins

Source: Stamminger 2009a

The results of this analysis are summarised in Table 2. This table already takes into account major results of the analysis of the consumer acceptance of smart appliance operation (see the next chapter of this report). Typically, the smart timing of appliance cycles offers longer time constants than interruption of the cycles do. The longest periods for load shifting can be expected from a smart timing of the operation of dishwashers. However, washing machines and tumble dryers also allow for shifts up to 6 hours or even longer. For most appliances the maximum time for interruptions of cycles is about 15 minutes.

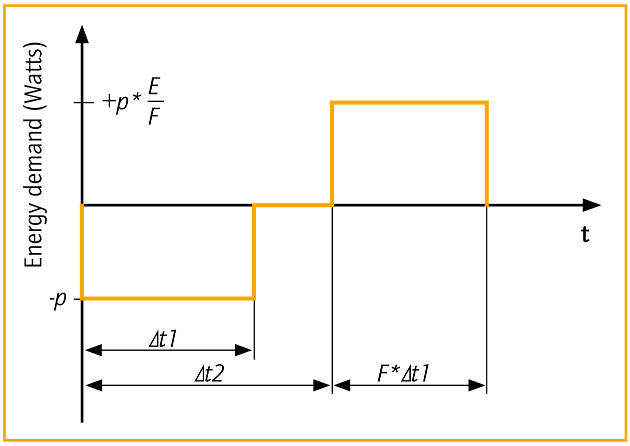
Usually, the majority of fully automatic appliances in a region – such as refrigerators and freezers – operate in a diversified mode, i.e. their operation is stochastic. If the operation of appliances is interrupted by a central energy manager, then it is important that this diversity is restored at least to some extent when the appliances are switched on again. Otherwise, new load peaks will occur in the period after the interruption.

As can be seen from the examples described above, the load shape of a Demand Response measure by a Smart Appliance usually consists of a load reduction period and an energy recovery period. Clearly, a delay in the operation of an appliance or an interruption of a cycle firstly results in a load reduction for a certain period compared to the base case. At the time when the delayed cycle is started or the interruption is finished the energy demand will increase compared to the base case. It is also possible that the start of the cycle is "preponed" instead of being delayed. In this case a load increase is followed by a load reduction.

Figure 4 shows a generic description of a load shifting activity by a domestic appliance. The change in energy demand compared to the base case is characterised by the amplitude of load reduction (p), the duration of the load reduction (Δt1) and the duration of the load recovery, which might be longer or shorter than the reduction (described by factor F). Depending on this and on the eventual energy losses between load reduction and load recovery (described by factor E), the increase of the energy demand in the recovery period may be as high as the load reduction or may be lower or higher. In the simple case that there are no energy losses (E=1), the additional amount of energy consumed in the recovery period will be of the same volume as the reduction of energy consumption in the load reduction period. The differentiation between Δt1 and Δt2 indicates that the recovery period does not necessarily follow directly after the reduction period.

If we look at the picture for a single appliance, the variation in energy demand is negligible compared to the total load to be managed in European energy networks. However if we are able to coordinate Demand Response actions of millions of appliances in Europe, the impact on the energy systems can be significant. Further details can be found in the Smart-A report on domestic appliances (Stamminger 2009a).

Figure 4: Generic description of a load shifting activity by a domestic appliance



Source: Author's own illustration

What appliances are best suited for use in load shifting?

Table 3: Key features of HH appliances (expectation for the year 2025)

Appliance		WM	TD	DW	OS	RF	FR	AC	WH	EH	CP
Energy consumption and average load											
Annual energy consumption	[kWh/a]	120	190	190	180	320	330	680	1.500	12.400	370
Average load over the year	[W]	13	22	22	20	37	38	78	170	1.410	42
Typical times of operations		day	day	day	day	day & night	day & night	day	night	night	day
Assumed appliance penetration in % of all households											
Region A		95%	20%	50%	50%	100%	50%	60%	30%	4%	70%
Region B		90%	55%	65%	98%	100%	60%	5%	30%	10%	80%
Region C		95%	40%	50%	60%	100%	30%	20%	50%	4%	80%
Region D		95%	50%	70%	80%	100%	40%	20%	20%	4%	80%
Region E		95%	60%	50%	60%	100%	40%	10%	8%	4%	60%

Source: Estimates based on Stamminger 2009a

In order to assess the contribution of the different appliances in our analysis to the load shifting potential, we need to address some key features of these appliances. Table 3 shows the expectations for the year 2025 regarding the average annual energy consumption per appliance, the average electric load per appliance over the year, a rough indication of the typical times of operation and the penetration rates. For the subsequent analysis of the Smart Appliances potential in Europe, we differentiate between five generic regions in Europe:

Region A representing typical situations in southern European countries
Region B representing typical situations in Scandinavia
Region C representing typical situations in the new Member States (EU12)
Region D representing typical situations in Germany or Austria
Region E representing typical situations in the UK

Countries or regions not explicitly mentioned here can be described by combinations of the features of two or more of the selected generic regions.

It should be noted that the figures for the average electric load per appliance over the year have been estimated roughly; there is no differentiation between day and night times or weekends, but rather the average energy consumption of an appliance is distributed over all hours of the year.

Table 4: Qualitative assessment of the suitability of appliances for load management

	WM	TD	DW	OS	RF	FR	AC	WH	EH	CP
Specific load during operation	high	high	high	high	low	low	mod.	high	v. high	low
Availability	low	low	low	low	high	high	low	mod.	mod.	mod.
Shifting flexibility	mod.	mod.	high	low	low	low	low	mod.	high	mod.
Convenience for consumers	low	low	mod.	low	high	high	low	mod.	high	mod.

Source: Seebach et al 2009

Taking into account results from further steps of work in the Smart-A project, which are presented in the subsequent chapters of this report, the table above gives a qualitative summary of the suitability of appliances for load management based on four criteria. We will see in chapter 4 that the maximum duration of the possible load shift and the total energy volume to be shifted per appliances are two of the main drivers for the value of Smart Appliances in balancing of future electricity systems in Europe. Thus a high specific load during the operation of an appliance and a long maximum period of the load shift are indicators of a high value of an appliance type in Demand Response schemes. However, the operation of an appliance can clearly only be shifted if it is operating or if the consumer has set it to a "ready to start" mode. The likelihood of this is expressed by the "availability" indicator. Finally, Demand Response programs will only deliver good results if the load shifting is accepted by consumers. The following chapter will provide more information on how the indicator of convenience of load shifting for consumers has been determined.

As a result of this assessment, it is no surprise that the most interesting options for load management, electric storage heating and water heaters are those appliances which are already exploited for load management, typically based on a static night tariff operation. Using the Smart Appliances concept, these loads could be managed in a smarter way in the future, following the actual demand for load management. Also, if we want to expand the potential of demand-side load management, other appliances provide additional load shifting capacities. However, their suitability remains ambiguous:

- Dishwashers provide a significant average load and a relatively long maximum time constant for load shifting. The impact of load shifting to consumers seems to be acceptable. However, the availability of this appliance for load shifting is relatively low. This could be compensated in practice by large numbers of controllable appliances and by a mixture of dishwashers with other appliances.

- Cold appliances provide a high availability and their load shift will hardly be noticeable for consumers. But their load per appliance is quite low, which means that we need large numbers of appliances in order to create a noticeable effect. Also, the time constant of load shifting by cold appliances is typically limited to approximately 15 minutes. Despite these disadvantages, refrigerators and freezers have an interesting potential in terms of load shifting, which could be controlled fully automatically.

- Washing machines and tumble dryers are also well-suited types of appliances for load shifting, but only under the condition that it is possible to reduce the impact of the load shifting activity of the consumer. Fully automatic Demand Response action seems to be difficult for these appliances. Thus preference could be given to improved user interaction, e.g. through a display on the appliance.

It should be noted that the suitability of washing machines and tumble dryers for load management could be improved significantly if it were possible to develop combined washer-dryers with a good overall energy efficiency. In this case, the shifting flexibility would increase and the potential negative impact on consumer convenience would be reduced significantly.

3 Consumer Acceptance of Smart Domestic Appliances

The concept of Smart Appliances aims to enable domestic households to support the operation of the electricity system by participating in load management. Clearly, all technical potentials for using domestic appliances as smart consumer loads will be irrelevant if the owners and operators of the appliances are not supporting this concept. Therefore a key success factor for the further development of the Smart Appliances concept is to understand how consumers react to the idea of using their appliances as a tool for load management and find out how the participation rate of Demand Response programs for Smart Appliances can be increased.

Depending on how this load management is put into practice, the consumers will experience different levels of involvement in the Demand Response activity. In this regard, three general levels of consumer interaction with Smart Appliances can be distinguished:

1. **Fully automatic Smart Appliance operation:**
   Here, the appliance is designed in such a way that the consumer cannot modify or switch off the smart operation mode. This could apply to the controls of compressors in refrigerators and freezers, which could strive to avoid operation during short peak load periods based on a signal broadcasted by the electricity supplier or the distribution system operator.

2. **"Set and forget" Smart Appliance operation:**
   In this case, the consumer is asked to select once the smart operation of the appliance, e.g. during a setup procedure when installing the appliance. After this, the consumer will usually not think about the smart operation any more. However, it would be possible for him or her to modify the setting back to "unsmart" operation, if desired. For example, the appliance could be equipped with a timer, and if the consumer sets the timer to a certain time by which the cycle should be completed, the appliance is able by default to operate at any time between the point in time when the timer is set and the latest time at which it must start operation in order to finish the cycle at the time specified by the consumer.

3. **Case-by-case consideration of Smart Appliance operation:**
   In this case, the consumer is asked to take a decision on the smart operation every time he or she starts a cycle. For example, the consumer could choose to press a separate "smart" button when starting the cycle of an appliance in order to enable operation at any time within a defined time interval (e.g. between when the consumer leaves for work and when he or she returns). In more complex arrangements, the appliance might receive a signal indicating the current situation in the energy system, which might be reflected in a real-time electricity price. This signal could be communicated to the consumer through the display of the appliance. Based on this signal he or she could then take appropriate decisions, e.g. choosing an energy saving cycle with a lower temperature, starting the appliance later during the day or maybe even using it on another day.

The degree of involvement of domestic consumers in the Demand Response activity increases from the first to the third level. In the case of a fully automatic Smart Appliance operation, it might only be necessary that the consumer decides to buy a Smart Appliance as opposed to other models without smart features. However, it would also be possible that for some appliance types certain modes of smart operation become an industry standard or even a regulatory requirement in the longer term. In this case the consumer would have no choice but to use a Smart Appliance.[3] The "set and forget" type of Smart Appliance only requires a one-off decision by the consumer. The third level of consumer interaction is the most complex and might only be realistic under certain conditions and for selected appliances.

In order to better understand the consumer preferences in relation to Smart Appliances, the Smart-A project has undertaken extensive consumer research. This comprised comprehensive literature research, a consumer survey based on returned questionnaires from some 2.900 households in four different European countries plus qualitative research using phone interviews and focus groups. The results of this work are documented in a Smart-A project report on consumer acceptance (Mert et al 2008).

[3] At the moment, this option seems to be a possibility for cold appliances only, such as refrigerators and freezers, which operate in automatic mode anyway.

In a nutshell, the consumers involved in this research showed surprisingly high general acceptance of the concept of Smart Appliances. The rate of declared general acceptance of Smart Appliances was above 80% of all respondents for washing machines, tumble dryers, dishwashers, cold appliances, electric heating systems, water heaters and circulation pumps, and was above 50% for air conditioners.[4] Nevertheless several restrictions in practice will limit the actual uptake of Smart Appliances. It became clear that consumers expect a perceptible economic benefit if they are contributing to load management in energy systems. If they have to bear investment costs for a Smart Appliance which are more than 25 EUR above the cost of a regular appliance in the same market segment, they usually expect a very short payback period for these extra costs of no more than three years. Extra investment costs of up to 25 EUR for Smart Appliances seem to be acceptable for many consumers even if there is no financial reward from the energy retailer. Regarding refinancing of such higher investment costs, consumers would accept either cheaper electricity tariffs for using smart appliances or a cycle-based incentive scheme, which compensates them for each smart operation of an appliance.

The research undertaken also showed that, as a principle, consumers are not willing to change their daily routine in order to adapt to a smart operation of appliances. This obviously limits the potential for Smart Appliance operation, e.g. the maximum duration over which the cycle of an appliance can be shifted. While it is clear that hardly anybody is willing to take clothes out of a washing machine during the night, it must also be taken into account that only a few consumers might agree to change, for example, the time of loading and starting the operation of their dishwasher to a different time of the day than they are used to. However, the wider use of timer functions might be accepted by many consumers. Clearly, if consumers buy a Smart Appliance, they want to be able to retain full control over the appliance, e.g. by overriding the smart operation functionality under certain circumstances.

Moreover, consumers tend to be sceptical about the technical reliability of the smart operation of appliances. This point was most evident in the discussions about smart washing machines, where many respondents objected to the idea of pre-setting a timer of the appliance and allowing it to operate while they are not at home. Such restrictions on washing machines also have an impact on the smart use of dryers because they are mostly used after a washing cycle has finished. Interestingly enough, the respondents were not as negative about operating a dishwasher unattended, although this appliance is usually located in the kitchen and close to the central rooms of the house or apartment whereas washing machines are often located in the basement of the building.

However, the results of the discussions with consumers indicate that if it is possible to demonstrate clearly to consumers that Smart Appliances are a proven and mature technology which might even show additional safety and comfort features (e.g. signalling of faults, providing remote information of the status of the appliance), consumers tend to accept even slightly higher costs for the Smart Appliance compared to conventional ones.

There are also some additional restrictions which need to be taken into account. For example, consumers do not want to leave wet laundry in a washing machine for a long time, and due to the noise of washing machines it is not possible in many cases to operate them between the late evening and the morning. Compared to this, the readiness of consumers to use dishwashers during the night is much greater and this appliance therefore allows for a longer time constant of the load shift.

Although consumers seem to be very reluctant to accept any interference to the regular operation of refrigerators and freezers in order not to endanger the quality of the food contained, these two cold appliances represent quite a good option in terms of automatic smart operation (see above) because their operation is fully automatic anyway. In this case, the consumer would hardly notice that the pattern of operation of the compressor is different to the "unsmart" mode.

[4] *For the interpretation of these results some specifics of the sample for the quantitative research should be considered: The sample showed a high rate of male respondents, people with academic education, technological know-how and high environmental attitude. Thus the high acceptance levels might not be representative for other social strata.*

Finally, the consumers participating in the Smart-A research were not too concerned about data protection and data privacy issues. In all five countries covered by the analysis (Austria, Germany, Italy, Slovenia, the United Kingdom), more than 80% of the consumers were ready to accept the collection and processing of data about the usage of their appliance by the energy supplier or another agent responsible for the Smart Appliance operation. Evidently, this must be interpreted in such a way that consumers expect per se that sufficient and effective measures for the protection of personal data are taken. They would also welcome the possibility of using the information collected about the energy consumption of their appliances (e.g. through a web-based portal) in order to realise energy-saving potentials.

A qualitative summary of the results of the consumer research in the Smart-A project is shown in Table 5. In order to realise the concept of Smart Appliances successfully, all the measures mentioned in the right-hand column of the table should be implemented. The important issues of how user routine can be taken into account in Smart-A programmes as well as what and how many economic incentives are required will be addressed in chapter 7 below.

Table 5: Potential consumer concerns about Smart Appliances and related measures

<table>
<tr><th>Consumer Concerns</th><th>Measures for increasing acceptance</th></tr>
<tr><td>No interest in changing daily routines</td><td>Take user routines into account when designing
Smart-A programmes</td></tr>
<tr><td>Higher investment cost</td><td>Create adequate economic incentives
Attractive design</td></tr>
<tr><td>Consumers want to be able to retain
full control over their appliances</td><td>Enhanced comfort and usability,
option for consumer to override smart functions</td></tr>
<tr><td>Health and safety issues
(fire, flooding, food might be compromised)</td><td rowspan="2">Enhanced safety functions:
■ Overloading signal
■ Temperature surveillance
■ Water stop
■ Detection of technical faults

High quality service & support</td></tr>
<tr><td>Doubts about maturity of the technology</td></tr>
<tr><td>Concerns about data privacy and protection</td><td>High standards for data security and protection</td></tr>
<tr><td>Scepticism about the ecological benefits</td><td>Provision of background information about the benefits
of the Smart Appliances concept</td></tr>
</table>

Source: Mert et al 2008

4 Electrical System Wide Impact of Smart Domestic Appliances

There are several possibilities of how Smart Appliances can be used for load management in electricity systems. These options can be categorised as follows:

1. **Scheduling of Smart Appliance operation:**
   This means that Smart Appliances are used in order to match the expected load and the scheduled generation in a balancing group, e.g. on a day-ahead basis. Smart Appliances are used as a resource in the load scheduling process, and compete with supply-side options and other demand-side options (e.g. load management at large industrial and commercial consumers).

2. **Electricity network balancing:**
   In this case, the Smart Appliances are kept as a resource for short-term system balancing, which is required in order to manage deviations between the expected load and the scheduled generation in an electricity network. Here, the system operator (or more generally the actor responsible for system balancing) acquires resources for positive and negative system balancing power. Accordingly, Smart Appliances are competing with other balancing power resources, such as the regulation of part-loaded conventional power plants, pumped hydro power, other forms of storage technologies for electricity as well as the curtailment of interruptible demand. Furthermore, it is already current practice in some regions to curtail wind generation in the case of high wind production and low demand.

3. **Electricity network congestion management:**
   Here, Smart Appliances are used in order to manage the technical limitations of electricity networks (usually at the distribution system level) which are facing congestion. For example, if there is an area which is supplied by weak lines, Smart Appliances can be used to reduce peak demand in this area. Smart Appliances are competing in this case with all other decentralised resources which an "active distribution system operator" can use, including distributed generation and other Demand Response options (Bauknecht and Brunekreeft 2008).

4. **Other ancillary services for system operation:**
   These can include voltage regulation and reactive power correction, which are not treated in further detail here.

The flexibility of a Smart Appliance can only be used for one strategy at a time. However, as part of an advanced concept of operating demand-side resources, it would be possible to use the same Smart Appliance for different purposes at different times, depending on the framework conditions and needs of the electricity system.

In this section we discuss the potential benefits which the introduction of Smart Appliances can bring to the electricity system. As a framework condition, we have taken on board the EU's target of 20% of the overall energy demand to be produced from renewable energy sources by 2020. Many experts expect that in order to meet this target, the share of renewable electricity production in Europe will have to reach or even exceed 35%. However, for the analysis in this study we have chosen a slightly longer time frame: In order to allow for the required innovations of appliances and communication technology and their diffusion into the market, we look at the year 2025. By this year, the renewable electricity share in Europe could be 40% or even higher, which would roughly mean a doubling of the current share of RES electricity generation. In the longer run, the electricity system will have to be based mostly or even completely on renewable energy sources.

It is expected that in the coming decades the largest share of the increase of RES electricity production will come from offshore and onshore wind and another share from solar energy. Both technologies are fluctuating generation resources which depend on the availability of wind and solar irradiation, and their share in generation will be even higher than the European average in those regions which offer favourable conditions for their use. This poses a significant challenge to the management and stability of electricity systems.

It is known that the fluctuations in the total generation of a larger number of wind parks which are all connected to a transmission system are significantly smaller than is the case with a single wind converter. Also the predictability of wind power generation has improved remarkably. Nevertheless, the ambitious renewable energy targets will imply a significant additional burden on electricity systems, both in terms of congestion management and balancing, see for example the extensive "grid study" undertaken for Germany (dena 2005). Therefore the analysis in the Smart-A study focuses on the usage of Smart Appliances for electricity network balancing and congestion management. The use of Smart Appliances as scheduled resources and their use for other ancillary services has not been considered further because in the context of the high shares of RES electricity generation, the higher value for Demand Response can be expected from network balancing and congestion management.

It should be noted that the term "value" is used in this chapter to denote the reduction of costs for the operation of the electricity system from an overall economic perspective. Chapters 6 and 7 will compare this value with the additional costs for the implementation and operation of Smart Appliances and will address the question of how a net benefit resulting from the smart load management by appliances should be allocated to the actors involved.

The major results of our analysis of the value of Smart Appliances in electricity networks are summarised in the remainder of this chapter. Further details can be found in the corresponding Smart-A report (Silva et al 2009).

Modelling results for the generic use of Demand Response in network balancing

The first part of the analysis focused on the overall benefits which Smart Appliances may be able to bring about in electricity network balancing. For this purpose dynamic model calculations have been performed with a linear optimisation model. The model assesses the benefits which Demand Response can add to different types of electricity system in the case that significant shares of wind power create certain imbalances.

Introducing Smart Appliances as a resource for network balancing leads to monetary and ecologic benefits because of two effects:

- The existence of additional Demand Response options reduces the need for the operation of part-loaded conventional power plants based on fossil fuel. Currently these plants ensure the stability of the grid by providing the required margin of fast (secondary and tertiary) reserve. The part-loaded operation of these plants is relatively inefficient and leads to higher CO_2 emissions per kWh produced compared to the case where only part of these plants would operate at full load. If the requirement to operate conventional power part-loaded can be reduced, it reduces fuel costs and CO_2 emissions.

- In the case that Smart Appliances help to decrease the number of fossil-fuelled power plants which have to operate part-loaded for reasons of system stability, it facilitates a higher production of wind energy in times when the demand is low and a lot of wind is available. Although there is a general priority dispatch of wind generation in the electricity system, wind power generation must currently be curtailed under these conditions because otherwise the stability of the electricity system cannot be ensured. Smart Appliances can thus help to replace the minimum share of fossil-fuelled power plants needed in an electricity system and allow more wind to be used. This effect also reduces fuel costs and CO_2 emissions.

The objective of this first step of modelling was to determine the benefits of adding controllable load to a generic electricity system, e.g. by introducing Smart Appliances. We have modelled the two effects of introducing Demand Response as a resource for network balancing as described above. We have used a generic pattern of a 1 kW load reduction for three hours which is immediately followed by a load recovery lasting also for three hours. This effect could for example be obtained by delaying the operation of two washing machines by three hours. However, at this stage in the analysis there is no a differentiation between different types of appliances and their typical patterns of load shifting yet.

The monetary benefits of increased usage of wind power and reduced fossil fuel consumption are expressed as the reduction in the costs of fossil fuel used plus the related reduction in cost for emissions allowances in the EU ETS system per kW of controllable load.[5] The reduction of fossil fuel costs is also shown as a percentage of total cost for fossil fuel in the system compared to the base case where no Demand Response is available. Finally we identify the relative increase in wind production compared to the base case.

The model is based on several generic mixes of power plants with different degrees of generation flexibility. The generation flexibility indicator describes the ability of a power generation system in a country or region to deal with imbalances between power generation and demand. This indicator is driven by the share of "must run" (base load) plants and the shares of power plants with different levels of minimum stable generation which can provide positive or negative balancing power. Additional factors like the ramping times of power plants have not been taken into account in this analysis.

[5] The results displayed here relate to a lower CO_2 price scenario of 22 EUR/t. Note that the results shown in the Smart-A report on energy networks exclude the avoided costs for CO_2 emissions.

Table 6: Key features of the five generic regions for the first step of the model analysis

	Region A	RegionB	Region C	Region D	Region E
Couldbe related to	South Europe	Scandinvia	New Member States	Germany/ Austria	United Kingdom
Generation Flexibility	Low	High	Medium	Medium	Medium
Share of variable generation, e.g. wind	Medium (15 ... 25%)	Low (0 ... 15%)	Low (0 ... 15%)	High (25 ... 45%)	Low/Medium (0 ... 25%)
Demand profile	Summer peak	Winter peak	Winter peak	Winter peak	Winter peak
Assumed „smart" load per 1.000 households	100 kW	150 kW	100 kW	150 kW	150 kW

Source: Silva et al 2009

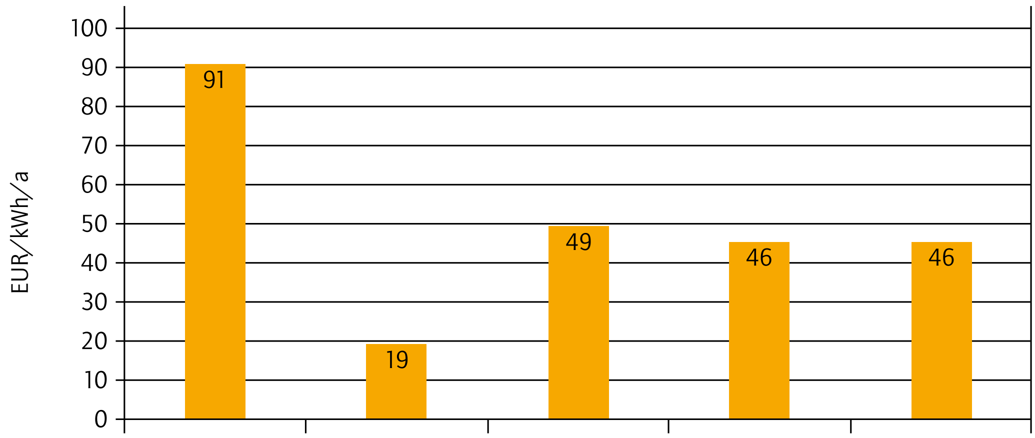
As already mentioned in the section on Demand Response options for domestic appliances above, we address the variations in the framework conditions for Smart Appliance operation across Europe based on five generic regional cases. For the purposes of the network balancing model, we have characterised each of these regions by its generation flexibility, by the share of variable wind or solar generation in the total production mix and the shape of the demand profiles. The results of the model analysis are shown in Figure 5 for the case of 30% wind penetration in the generation capacity in each of the five regions. The Smart-A report on energy networks (Silva et al 2009) shows the results for variations of this penetration rate. Corresponding to the share of wind in the system, an optimal penetration rate of Smart Appliances has been estimated for each of the regions. This was selected in such a way that the specific monetary benefit of controllable load was maximised under the given framework conditions. As a boundary, the expected uptake of Smart Appliances by consumers in each region has also been taken into account in these calculations.

It should be noted that the modelling of these five generic regions can only be a rough analysis. We use it later for an extrapolation of the results for the whole of Europe. For more detailed results on a national or regional level, much more country-specific data would have to be taken into account. Such a detailed analysis was beyond the scope of this study.

The results of this first step of modelling show that the value of Demand Response by Smart Appliances strongly depends on the flexibility of the generation system in the respective region. The highest value can be obtained in southern European countries (Region A), which feature relatively inflexible, fossil-based generation systems. Compared to this, the specific value of Smart Appliances in system balancing is lower in the Scandinavian region by nearly a factor of 5. Here a high share of hydropower plants allows a flexible operation of the existing power plants and therefore allows for the integration of the assumed 20% share of wind power without requiring the curtailment of wind production.

As the parameter variations undertaken in the detailed Smart-A report on system modelling show, the value of Smart Appliances strongly depends on the share of fluctuating wind generation in a system. In all the regions with medium or low generation flexibility (Regions A, C, D & E), the economic benefit of Demand Response more than doubles in the case that the penetration of wind energy increases from 20% to 30%. For the Scandinavian region (Region B), the specific value of Demand Response increases only by about 50% if the wind penetration increases to 30%. Due to the high flexibility of the Scandinavian generation system, wind penetrations of up to 30% can be accommodated without significant curtailment of wind generation. In this region the specific value of Demand Response increases significantly only in the case of wind penetrations above 40%.

Figure 5: Economic value of 1 kW of controllable load in five selected generic regions in Europe



	Region A	RegionB	Region C	Region D	Region E
Could be related to	South Europe	Scandinvia	New Member States	Germany/ Austria	United Kingdom
Reduction of total annual cost for fossil fuel	3 ... 6%	< 0,5%	0,1 ... 1,0%	3 ... 5%	0,5 ... 3%
Increased uptake of wind in the system (1)	30 ... 50%	0%	0 ... 70%	35 ... 70%	0 ... 70%

(1) as a percentage of the wind production curtailed

Based on a 30% penetration of wind in the generation capacity of each region.
Source: Silva et al 2009

Modelling results for the use of individual types of Smart Appliances in network balancing

As described above, technical constraints and certain consumer preferences determine the actual flexibility in the operation appliances and significant differences exist between the load shifting patterns offered, for example, by a washing machine and a refrigerator. Therefore we have used the same approach of modelling as described above in order to assess the value of the smart operation of individual types of appliances in network balancing. This forms the second step in our analysis of the benefits of Smart Appliances.

Preliminary model runs in this second step showed that the value of smart operation of an appliance depends mostly on two factors: the maximum duration of the load reduction and the amount of energy consumed in a cycle of the appliance, which is available to be shifted. Based on these criteria the most promising appliances are washing machines, dryers and dishwashers, all of which offer a time constant of the Demand Response action of 1 hour or more and also have a significant load to be shifted. Therefore the simulations undertaken in the step of modelling focused on these three appliances. The dryer is included in the analysis in the form of a combination of washing machine and dryer as a dryer is usually operated after a cycle of a washing machine has finished.

As the framework for the smart operation of these appliances we have assumed an electricity system with a maximum forecasted demand of 19,8 GW,[6] a medium flexibility generation system and an installed wind capacity of 5 GW. 8 million households are connected to this electricity system. 70% of these households operated washing machines and an additional 20% used washing machines in combination with tumble dryers. 30% of all households were using dishwashers. For reasons of simplicity we have assumed that all these appliances are allowed to participate in smart operation. However, the simulations showed that only part of this high number of appliances were actually required for system balancing.

Based on these assumptions it was possible to determine the benefits which Smart Appliances can bring about for the electricity system as described above. The Demand Response options offered by households enabled a reduction of the curtailment of wind generation in times of low demand by approximately 50% and reduced the total cost of fossil fuel for the operation of the system by nearly 4,5%.

This cost reduction can be distributed to the individual appliances based on their actual energy shifted. As can be see from Table 7, the highest value per appliance can be obtained from a combination of washing machine and tumble dryer, which are treated here as a single appliance.[7] The dishwasher also shows a significant value, which is mostly due to its ability to shift load up to 6 hours. The single washing machine has only half the value of the dishwasher for the balancing of the electricity system.

These figures show, albeit in an indicative way, that under certain conditions Smart Appliances can realise a relevant gross value when used in system balancing. However, as this value must pay for all extra costs of the smart functionalities and incentivise their actual use by the consumer, the figures also indicate a potentially quite narrow business case for the smart operation of at least some types of appliances.

[6] This is roughly equivalent to the demand in The Netherlands or Poland.

[7] Actually, this could mean a single appliance or two separate appliances which are operated in sequence by the consumer. Today, so-called washer-dryers are typically not as energy-efficient as separate appliances and therefore washer-dryers are hardly available on the market. Thus this option refers in practice to two separate appliances, the smart operation of which requires the consumer to load the washed clothes manually into the dryer.

Table 7: Indicative value of individual types of Smart Appliances used for system balancing

	Washing Machine	Washer + Dryer	Dishwasher
Assumptions			
Penetration rate of Smart Appliances	70%	20%	30%
Duration of consumption pattern	2 hrs	4 hrs	2 hrs
Shifting capability	up to 3 hrs	3 hrs	6 hrs
Modelling results			
Value per appliance and year	3,70 EUR/a	16,40 EUR/a	7,40 EUR/a
Value per appliance over a 12 yr. lifetime	44 EUR	200 EUR	89 EUR

Source: Silva et al 2009

Modelling results for the use of Smart Appliances in network congestion management

A third step in the analysis of the benefits of Smart Appliances in national energy systems addressed the potential benefits of Smart Appliances in the case of significant distribution network congestion. Here, Smart Appliances are used to manage peak loads on congested branches of a distribution system.

For this purpose, a model representing an IEEE 30 Bus Network with 41 branches and a peak load of 186 MW was established as a test system. The framework conditions were set in such a way that due to system congestion, certain consumers had to be disconnected during peak times in the winter season. Details of the selected model setting are described in the Smart-A report on electricity networks (Silva et al 2009).

Under the specific assumptions made for this example, the use of Smart Appliances made it possible for the volume of load shed to be reduced to zero. The resulting value of Smart Appliances for the purpose of managing network congestion are driven strongly by the costs arising for the distribution system operator to disconnect consumers from its network. In the modelling exercise, these costs were assumed to be 3.750 EUR/MW. This assumption leads to values for the different types of appliances used in the analysis which are by a factor between 2 and 3 higher than those determined in the second step of modelling where Smart Appliances were used for balancing wind power generation.

It must be noted that such high values of the smart operation of appliances as indicated in Table 8 can only occur in very specific framework conditions of network congestion where the high cost of disconnecting consumers can be reduced by using Demand Response. Although the assumptions made for these calculations were not unrealistic, it is not possible to generalise the results to other cases of network congestion. In any case, the results show that under certain conditions of severe network congestions, the value of Smart Appliances as a resource for Demand Response can be significantly higher than is the case with participation in balancing of a national electricity system. Under such conditions, Smart Appliances can be a highly beneficial demand-side resource.

Table 8: Value of individual types of Smart Appliances used for network congestion management

	Washing Machine	Washer + Dryer	Dishwasher
Assumptions			
Avoided cost of disconnecting consumers	3.750 EUR/MW	3.750 EUR/MW	3.750 EUR/MW
Duration of consumption pattern	2 hrs	4 hrs	2 hrs
Shifting capability	up to 3 hrs	3 hrs	6 hrs
Modelling results			
Value per appliance and year	7,50 EUR/a	48 EUR/a	15 EUR/a

Source: Silva et al 2009

5 Impact of Smart Domestic Appliances on Local Energy Systems

In a separate modelling activity we have analysed the role which Smart Appliances can play in the management of renewable energy generation on a local level. The objective of the analysis was to find out how Smart Appliances can cooperate with the management of local energy production, either from renewable energy sources or the local cogeneration of heat and electricity. For this purpose we have defined local energy systems as an agglomeration of households and small enterprises within a geographic area where meteorological circumstances are constant and the distribution of heat makes sense in terms of modern technology. A local energy system can therefore be a city quarter or a small town.

However, the local energy systems in our model do not only manage distributed energy production. They are also connected to an electricity transmission network, which has the features of one of the five generic regions described in Table 6 and needs to handle different shares of wind generation. By connecting the Smart Appliances in the local energy systems to the larger electricity networks, we enable their use not only for the management of the local energy system, but also in contributing to the balancing of wind generation connected to the transmission system. The link between the two balancing tasks was established through a price signal for all electricity imported into or exported from the local energy system: this price was set at 40 EUR/MWh at all times, with the exception of times when wind production in the transmission system had to be curtailed. During these periods, the price for electricity crossing the border of the local energy system was set to zero. This incentivises the Smart Appliances in the local energy system to shift their consumption to these periods of high wind and low overall demand. The time series indicating wind curtailment were taken from the modelling activities on electricity networks in the five generic regions described in the previous chapter.[8]

The optimisation objective of the simulations was to maximise the use of locally produced energy and at the same time use as much excess wind energy from the transmission system, which would otherwise have been curtailed, as possible. This was implemented in monetary terms by accounting for the overall value of electricity imports to the local energy system and subtracting the value of electricity exports. Locally produced energy was assumed to be available at no cost. Because the assumed price for electricity depended on whether wind curtailment is currently occurring in the transmission system or not, the actors in the simulation of the local energy system received the right incentives: In the case of excess wind generation, an import of electricity into the local system was possible at no cost, and thus the Smart Appliances had an incentive to shift their consumption to these times.

Within the local energy systems, we have modelled the heat demand of 2.000 households for space heating and hot water as well as the electricity demand of a set of appliances (refrigerator, freezer, dishwasher, tumble dryer, washing machine), plus a base load of electricity demand for other purposes. All refrigerators and all washing machines were assumed to be capable of smart operation. Each household in the model was equipped with a PV plant of 4 m² and a share of the households use solar thermal collectors. The total surface of collectors in the local energy system was 2.000 m². The heat demand above the heat supplied from the collectors was covered by gas boilers. In some model runs, a penetration of 10% micro-CHP units (Stirling engines) was assumed, which are integrated into the gas boilers used for heating.

Technically, the model was developed on the basis of an agent-driven framework. The starting conditions and load curves for each agent are defined statistically based on a probability distribution by Monte-Carlo simulation. All calculations were carried out on an hourly basis for full years. For each of the five generic regions in Europe a sample location was selected for which detailed meteorological data was available. Further details of the local energy systems model can be found in the Smart-A report on local energy systems (Möllering 2009).

The model runs were performed in four scenarios:

- Base case without Smart Appliances and with no local CHP units
- With Smart Appliances, but with no local CHP units
- With local CHP units, but without Smart Appliances
- With Smart Appliances and local CHP units

Obviously, the introduction of local CHP plants leads to a quite significant reduction of the electricity imports into the local energy system compared to the basic case. Since CHP as such is not the focus of interest in the Smart-A study, we have eliminated this effect from the results shown below. Thus the economic benefit of Smart Appliances in local energy systems is shown once as a comparison between the smart and the basic scenario ("no CHP" case) and once as a comparison between the SmartCHP and the CHP scenario ("with CHP" case). This allows us to compare the benefits of introducing Smart Appliances in these two cases.

A summary of the results of the modelling of local energy systems with Smart Appliances is shown in Figure 6. Here, the penetration of wind has been selected for each of the five different regional cases according to the results of the PRIMES model for the year 2025 (Capros et al 2008a and b). The figure shows the reduction in the costs for importing energy into the local energy system by introducing Smart Appliances into the households. As can be seen, the overall benefit of Smart Appliances in local energy systems is only moderate under the conditions assumed (1 EUR per household and year on average). However, it is noteworthy that this benefit is not significantly reduced in the case where local CHP plants are operated. This means that, in principle, Smart Appliances and local cogeneration can work well together and their individual benefits can be added together when used in combination.

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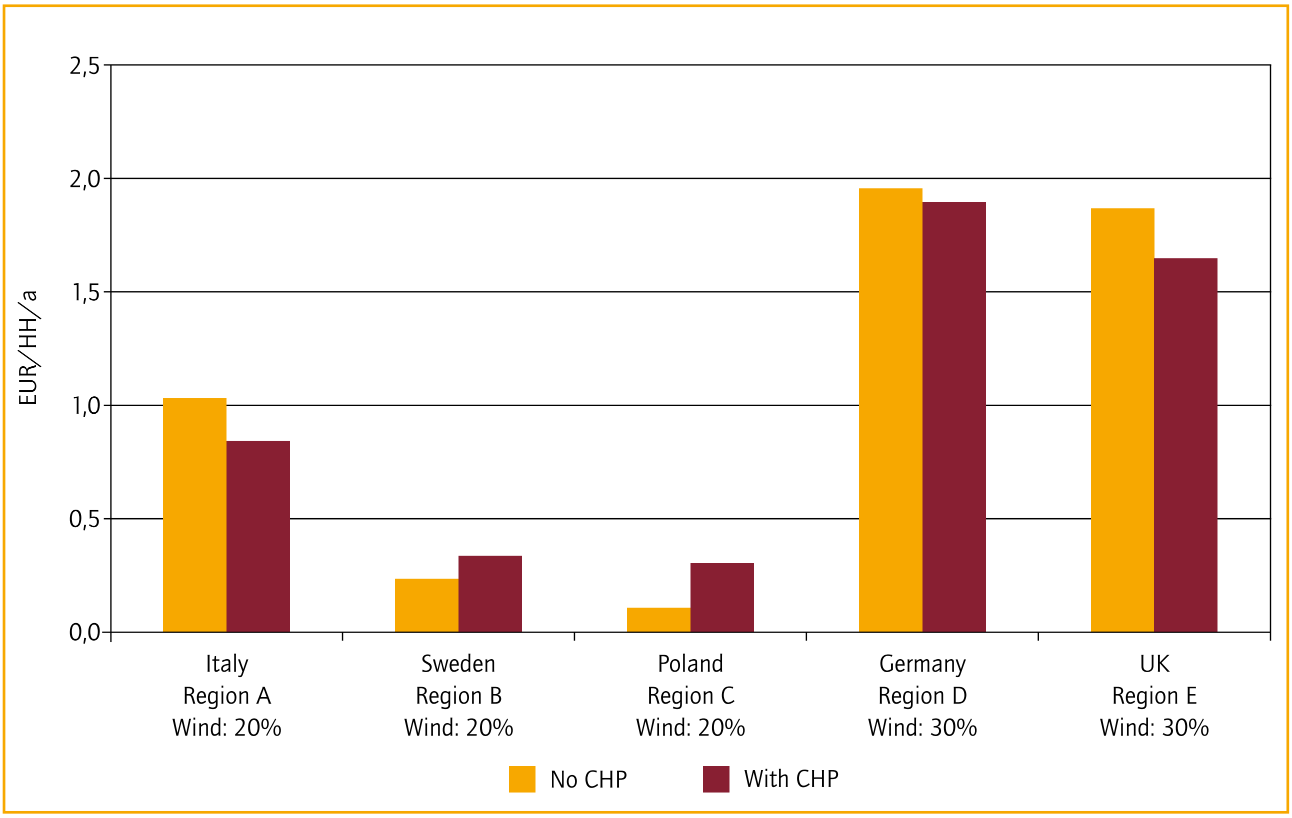
[8] This creates a somewhat static connection between the two models. Within this project, it was not possible to establish a full dynamic connection.

Figure 6: Economic benefit of introducing Smart Appliances in local energy systems



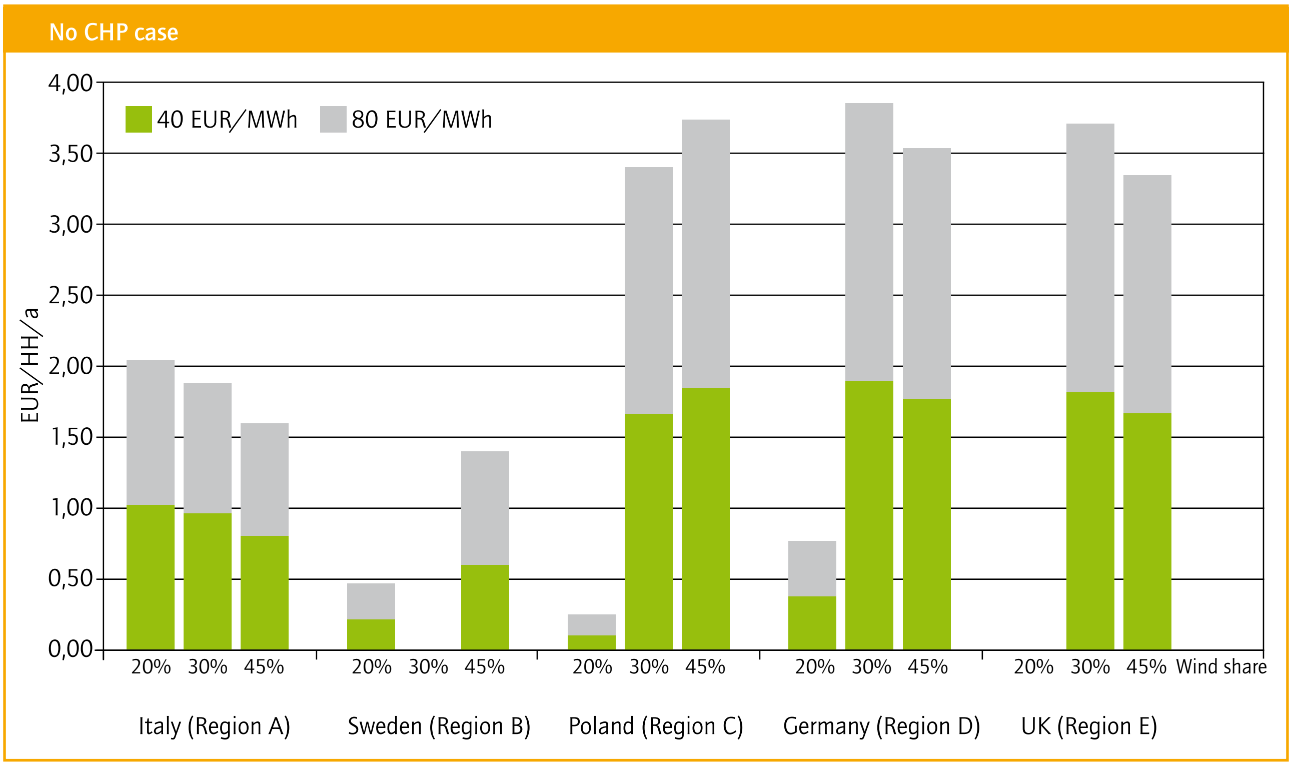
Source: Author's own illustration based on Moellering 2009

Analysing the sensitivity of the results in some more detail yields interesting observations. Whereas Figure 6 shows the results per country related to a fixed share of installed wind power expected for 2025, Figure 7 and Figure 8 vary the share of variable renewable energy installations between 20% and 45%. Also, the assumed cost for electricity being imported or exported across the border of the local energy system (at times when there is no wind curtailed in the transmission system) is modified between 40 and 80 EUR/MWh.

The two figures show that the variation of the economic benefit of Smart Appliances in the local energy system, expressed in the reduction of costs for importing electricity at times when there is no excess wind power in the transmission system, follows different patterns depending on the framework conditions. The activity of the household appliances in the model follow quite complex algorithms: In principle, the model rewards Smart Appliances if they can shift energy consumption from times where the transmission system can cope with the wind production to those times when wind production needs to be curtailed. The more hours of the year in which wind is curtailed, the more effect Smart Appliances can have under this objective. Thus, the higher the wind share, the larger the benefit of the Smart Appliances. This can be seen clearly in the case of Poland. However, in some cases, the local generation of electricity (from photovoltaics or in the case of "with CHP" also from local CHP plants) exceeds the electricity demand in the local system, and thus the local energy system becomes an exporter of electricity. In this case, Smart Appliances can no longer have much influence under the simplified conditions chosen for this model. Under these conditions, higher shares of wind power reduce the value of exported electricity because the number of hours in the year increase during which the exported electricity has no value. This can be seen clearly in the case of Italy.

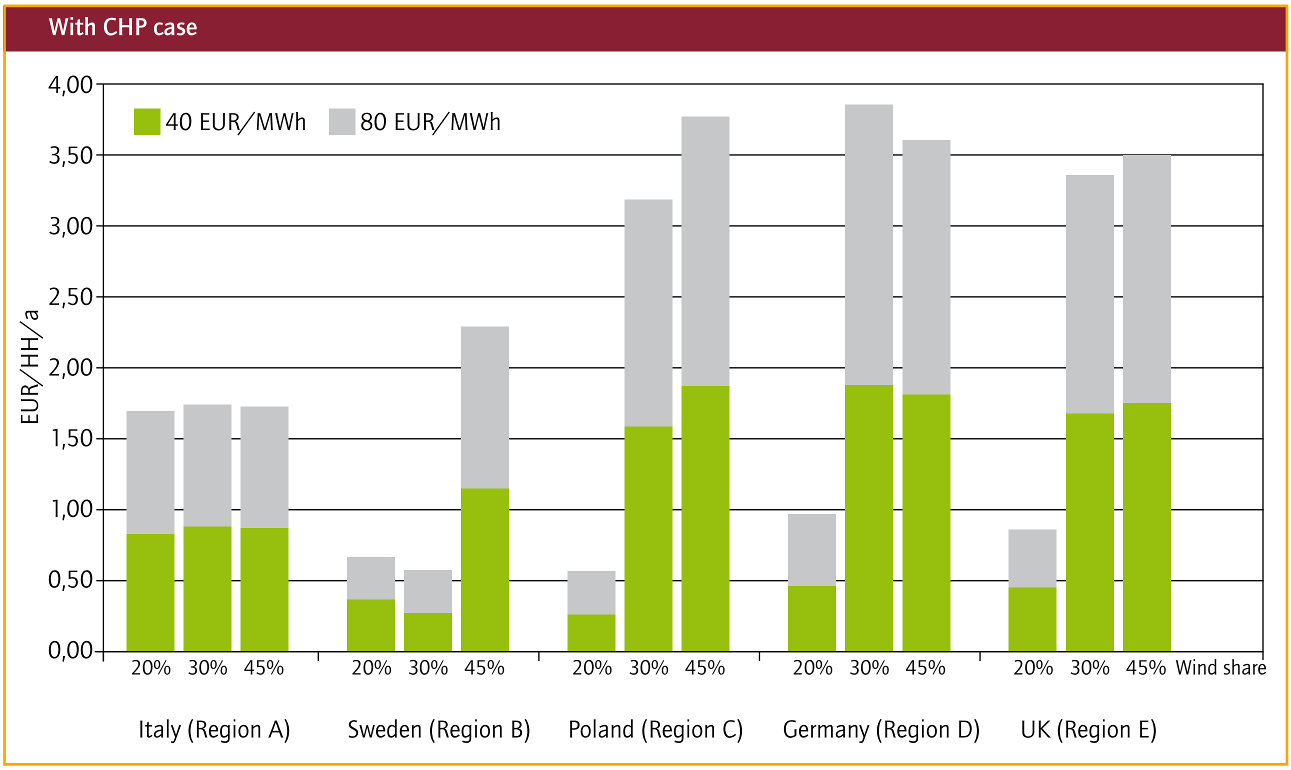
As already stated above, the introduction of local CHP generation does not in principle reduce the value gained by Smart Appliances. For high wind shares, there is not much difference between the values shown in Figure 7 and in Figure 8. In the case of higher electricity prices (80 EUR/MWh instead of 40 EUR/MWh), which is not unlikely for the year 2025, the benefits of Smart Appliances in reducing cost of electricity imported into the local energy system increase accordingly.

Figure 7: Sensitivity analysis of the economic benefit of Smart Appliances in local energy systems (without local CHP)



Source: Author's own illustration based on Möllering 2009

Figure 8: Sensitivity analysis of the economic benefit of Smart Appliances in local energy systems (with local CHP)



Source: Author's own illustration based on Möllering 2009

6 Potential and Overall Costs & Benefits of Smart Appliances

Based on the results presented in the previous chapters, we will now assess the overall potential of Smart Appliances in terms of the purposes of load management in Europe. Firstly, we need to consolidate the information which we have obtained for the costs and for the benefits of Smart Appliances. This enables us to compare costs and benefits on a country-by-country basis. Based on this we will make a rough estimate of the economic potential of Smart Appliances. Finally we will look at the potential CO_2 savings.

It should be noted that all costs and benefits figures presented in this chapter relate to the year 2025 and the assumption of a mass production of Smart Appliances, which has yielded low production costs. In the market introduction phase, higher specific costs must be expected. Because of the uncertainty of future costs for energy and CO_2 and also for the investment costs for Smart Appliances, we used two cost scenarios: "moderate" and "high". Details of the methodology as well as costs and benefits estimated for the year 2010 are described in the Smart-A report on Costs and Benefits of Smart Appliances in Europe (Seebach et al 2009) .

Also, it should be noted all costs and benefits addressed in this chapter represent a societal perspective and not an individual consumer's perspective. This means that we only look at the economic impact of Smart Appliances from an overall economic point of view, which excludes monetary transfers between individual actors, profits and taxes.

Overall costs of Smart Appliances as a Demand Response resource

In order to make Smart Appliances operational as a Demand Response resource, we considered three major cost elements:

- **Higher costs of the appliance:** Today, most new appliances already feature electronic controllers which in principle would be capable of managing a smart operation of the appliance. However, each Smart Appliance has to be equipped with a communication module, which will typically be either a powerline communication (PLC) or a wireless module (such as WLAN or ZigBee). Assuming a mass production of Smart Appliances by 2025 after a reasonable phase of market introduction, we estimate uniform additional production costs of between 1,70 EUR (moderate cost scenario) and 3,30 EUR (high cost scenario) for all appliances for enabling their smart operation (based on Stamminger 2009a).

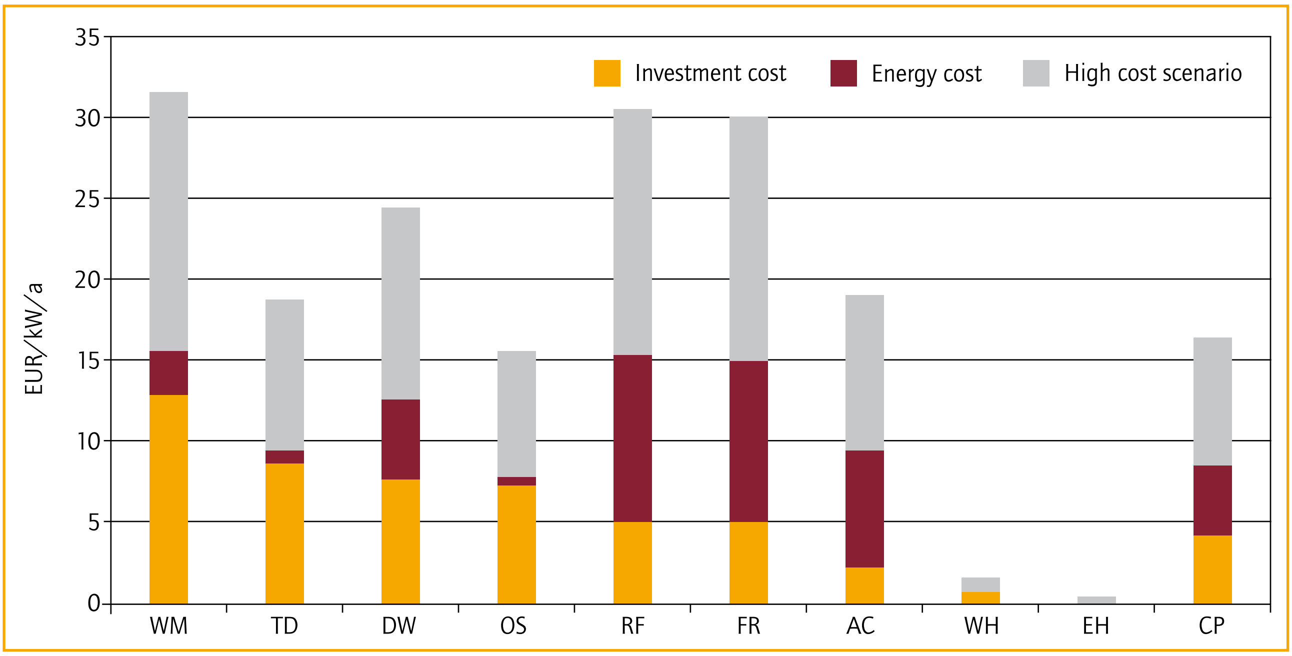
- **Costs for in-house communication:** The smart operation of appliances requires one-way or two-way communication between the appliance and a central gateway in the household, which can be integrated into a Smart Meter or a separate device. The gateway connects the household via the internet or PLC to the central control of an external load manager, which can be the energy retailer, the local system operator or an independent actor. The link between the appliances and the gateway (powerline or wireless communication) does not require the installation of additional wires. By the year 2025, most households will be equipped with a Smart Meter and also with WLAN devices. Thus we assume no extra cost for in-house communication. For further details see the Smart-A report on communication containers (Möllering 2007) and the section on communication and control in the report on electricity networks (Silva et al 2009).

- **Additional electricity costs due to standby consumption:** The ability of Smart Appliances to respond to signals from the electricity network requires them to be in standby mode, e.g. because the user has set the appliance in a "ready to start" mode. We have estimated the number of hours of standby operation for each type of appliance and the respective standby energy demand. This results in an increase of the electricity consumption of the appliance between 0,1% and 2%. Related to the production cost of electricity, the additional cost for standby consumption range between 0,02 and 0,55 EUR per appliance and year in the moderate energy cost scenario and up to 1,10 EUR per appliance and year in the high cost scenario.

Other costs for the central management of Smart Appliances were not taken into account in this rough assessment because they are not specific to the option of Smart Appliances. Rather, any kind of load management, virtual power plant, etc. requires some effort in terms of central and regional management.

In order to make the capability of different Smart Appliances comparable in terms of their managing of electric load, the costs identified above were related to the unit of 1 kW of controllable load which is available for Demand Side Management (DSM) throughout the year. For this purpose, the investment costs were annualised over the lifetime of the appliance. We also needed to assess the patterns of operation of the individual appliances, which includes the number of hours during which the appliance is typically used and the average load during this operation. The related information was derived from the Smart-A report on appliances (Stamminger 2009a).

Figure 9: Annualised additional costs per kW controllable load according to appliance type



Source: Author's own illustration based on Seebach et al 2009

The results of this calculation are shown in Figure 9. In the moderate cost scenario, the additional cost are 1 EUR/kW/a or even less for the water heaters and electric heating. The other appliances range between 7,70 and 16 EUR/kW/a. Due to the relatively low average load per year, washing machines show the highest annualised investment cost whereas for refrigerators and freezers the total costs are dominated by the additional costs of stand-by operation. Due to the assumptions described above, the total costs per controllable load in the high cost scenario are higher than those in the moderate scenario by a factor of 2.

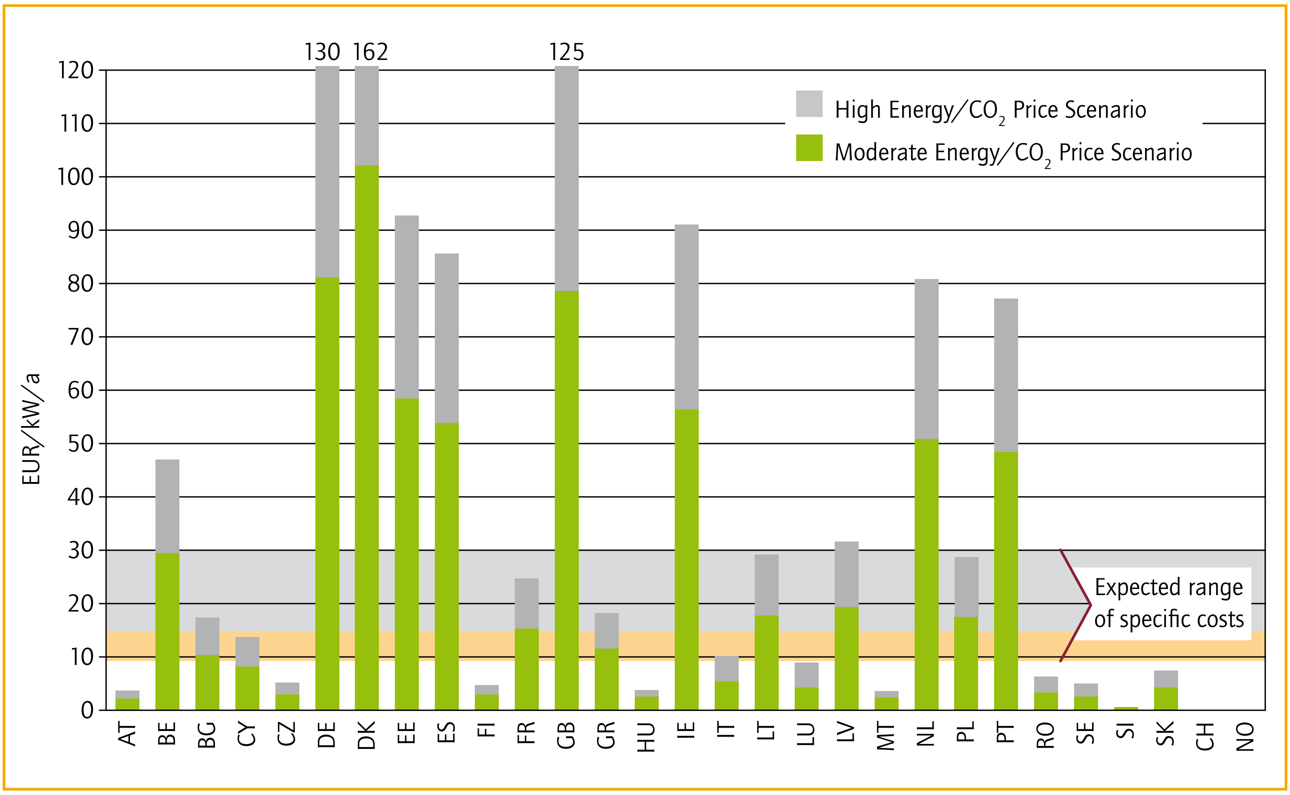
Economic benefits of Smart Appliances operation in individual countries in Europe

In chapter 4 we quantified the value of Smart Appliances for purposes of balancing the variable wind energy production in five generic regions of Europe. We found that this value strongly depends on the flexibility of the generation system in the respective country and also on the share of variable renewable energy production. Based on a number of assumptions we saw that the highest value of Smart Appliances can be obtained in countries with a low flexibility generation system (e.g. a large share of nuclear or coal fired power plants), whereas the lowest values applied to countries where a high share of controllable hydro power makes for a highly flexible generation system.

Starting from this rather generic description, we applied these results to the level of the individual countries in Europe. For this purpose we assessed the electricity generation system of each country, based on the scenarios for the expected shares of different types of power plants for the year 2025, which were developed using the PRIMES model (Capros et al 2008a and b). Comparing the information from this source and the methodology used by the Smart-A report on electricity networks (Silva et al 2009), we found that of the 29 European countries, six are rated as highly flexible generation systems, seven are rated as "medium flexible" and 16 are considered "low flexible". The share of wind power in the total installed generation capacity is assumed to be some 20% on average for all EU29 countries, with the highest shares of between 30% and 40% being in Denmark, Ireland, Portugal and Spain.

On the basis of these assumptions it was possible to apply the economic values of Smart Appliances in different generic regions (as reported in chapter 4) to the 29 European countries. This resulted in an estimate of the gross benefit per kW of controllable load which the introduction of Smart Appliances could bring about in each country by the year 2025 as shown in Figure 10. It should be noted that this estimate is quite rough because we were not able to assess the generation flexibility of the countries in detail. Further information about the methodology used is given in the Smart-A report on Costs and Benefits of Smart Appliances in Europe (Seebach et al 2009).

Figure 10: Estimated annual gross economic benefits of Smart Appliances per kW controllable load (in year 2025)



Source: Author's own illustration based on Seebach et al 2009

As can be seen from the figure, the specific value of Smart Appliances as a Demand Response option differs quite significantly from country to country. The estimates are shown for the moderate as well as for the high energy price scenarios, which determine the avoided fuel costs in fossil power plants used for providing the required reserve margin.

The benefit per kW controllable load is the highest in Denmark, Germany and the UK, which under the selected criteria are all rated as "low flexibility" generation systems and where the share of wind in installed power generation capacity is expected to be above 25% by the year 2025. Another four countries show specific values of Smart Appliances above 50 EUR/kW/a in the moderate energy price scenario. The lowest values are estimated for countries where the flexibility of the generation system is expected to remain high (such as in Austria, Sweden or Malta) or where the share of wind in total generation capacity is expected to be low (e.g. in the Czech Republic, Finland, Hungary and Romania). In Norway and Switzerland both conditions apply and thus the specific value of Demand Response for purposes of balancing wind generation is below 1 EUR/kW/a.

However, the balancing of wind power should not be carried out only on a national basis in the future. It is very likely that by 2025 a system has been established whereby European countries support each other to some extent in managing the variable shares in renewable energy generation. Under this framework condition, Smart Appliances in all European countries could be used for this purpose, even if their specific value is low in the analysis on the national level as shown in Figure 10. Also, the high specific value of Smart Appliances in some other countries will be levelled out. As a rough assessment for this scenario, we applied the methodology explained above not only to the 29 countries separately, but also to the whole of Europe. In this simplified case, which ignores the real-world restrictions of the European transmission grid, we found that the average gross economic benefit of Smart Appliances used for balancing of wind generation across EU29 in the year 2025 would be between 14 and 22 EUR/kW/a, depending on the energy price scenario.

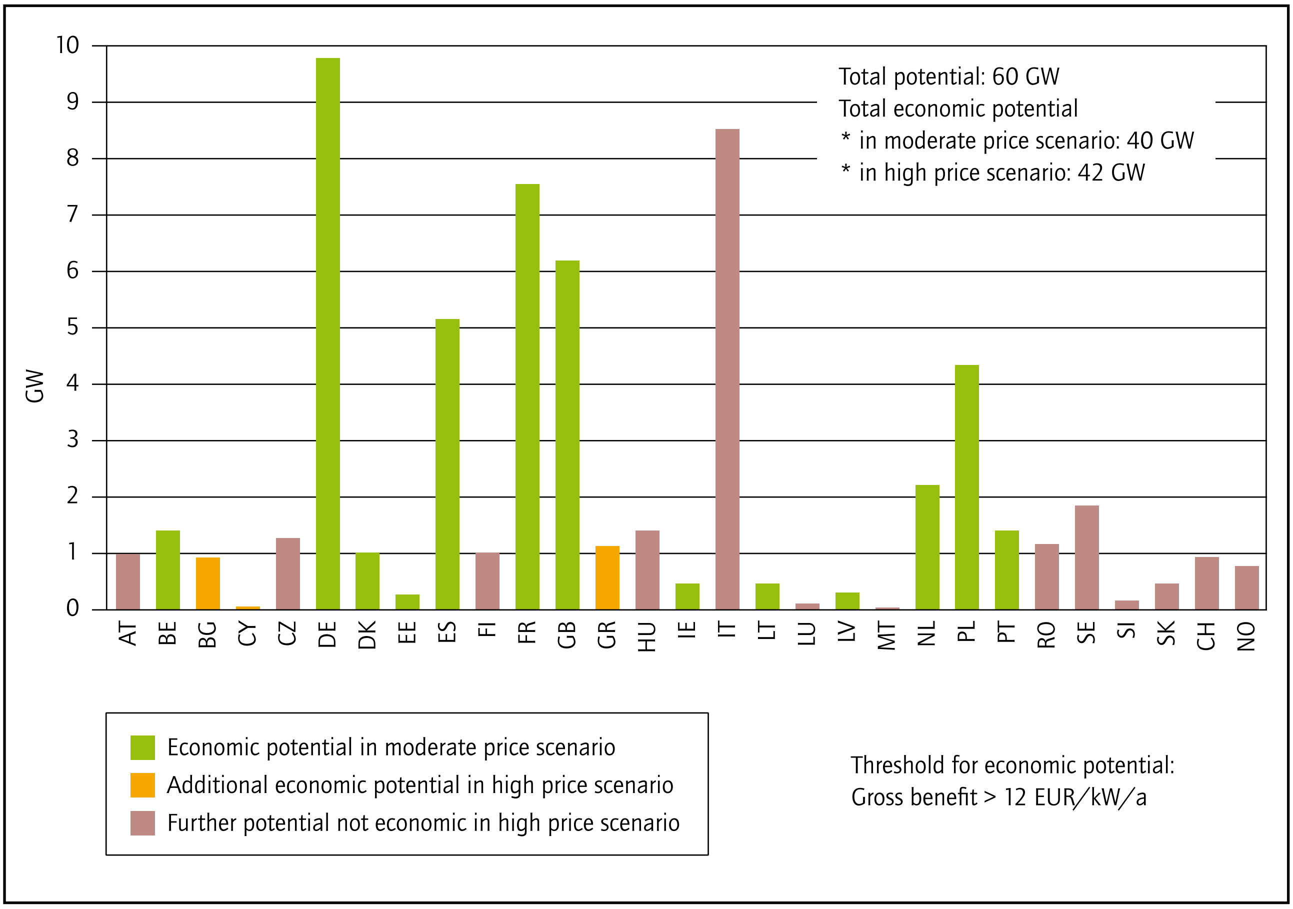
Figure 10 also shows the expected range of costs for implementing Smart Appliances as a Demand Response resource, which were shown in more detail in Figure 9. Leaving aside electric heating and water heaters, which are already running on night time tariffs in many countries, and also oven and stoves, the operation of which can hardly be shifted in time, we found that the specific costs for the implementation of Smart Appliances in mass production in the year 2025 could be between 9 and 15 EUR/kW/a in the moderate energy price scenario and up to 30 EUR/kW/a in the high price scenario. Figure 10 enables these specific costs for implementing Smart Appliances to be compared with their specific benefit in the individual countries. As can be seen from the figure, 13 countries show an economic value higher than 15 EUR/kW/a in the lower energy price scenario and 10 countries show a value higher than 30 EUR/kW/a in the higher energy price scenario. Depending on the development of prices for energy and CO_2 as well as the additional investment costs for Smart Appliances, the respective countries can expect a net benefit from using Smart Appliances for balancing wind generation. We can also see from Figure 10 that this net benefit can be quite significant in some countries.

As already stated, with a stronger integration of the transmission systems in Europe and their balancing mechanisms, the national differences of neighbouring countries shown in Figure 10 will become less relevant. In the extreme and rather theoretical case of an ideal transmission system across the whole of Europe without any bottlenecks and with a joint balancing mechanism, the economic value of Smart Appliances for balancing wind generation would be only marginally higher than their expected cost. This underlines the efficiency gains which can be reaped by a gradual integration of the national transmission systems, both in terms of removing the physical bottlenecks as well as linking the balancing regimes. As long as this full integration is not achieved, there will be a higher need for providers of balancing power in many countries, and Smart Appliances are one of the resources which can be beneficial under certain framework conditions.

Potential of Smart Appliances operation in individual countries in Europe

By linking the expectations regarding the future penetration rates of domestic appliances in the individual countries in Europe and the expected future energy demand and usage patterns of the appliances, we can now determine the gross potential for Smart Appliances which could be used for load management in each country. For 2010 we expect a total average load of all relevant appliances in Europe of 79 GW, which will be reduced to some 60 GW by the year 2025 due to the expected market diffusion of more energy efficient devices. The distribution of this load between the 29 countries is shown in Figure 11. The values shown are much smaller than the installed total capacity of the appliances in the respective countries, and also much smaller than the total average load of the appliances during their individual operation cycles. This is because we have used a distribution of the load of the appliances to all hours of the year in order to reflect the fact that at a given time only those appliances are available for load shifting which are actually operating or which are set in a "ready to start" mode at that point in time.

Figure 11: Estimated maximum potential of domestic appliances for smart operation in EU29 countries (year 2025)



Source: Author's own illustration based on Seebach et al 2009

This figure also differentiates the average load of the household appliances in each country according to the general economic viability of Smart Appliances. Using the results for the moderate and high energy price scenarios as shown in Figure 10, the load of appliances is rated as an economic potential for Smart Appliances operation if the benefits of Demand Response for balancing wind power generation in the respective country was estimated to be higher than 12 EUR/kW/a in either of the energy price scenarios. This threshold value has been set on the basis of the range of expected cost for making Smart Appliances operational as a Demand Response resource as shown in Figure 9.

Following this methodology, we find a gross potential of some 40 GW annual average appliance load to be economically viable in the moderate energy price scenario. In the case of the high energy price scenario, only another 2 GW of gross Demand Response load become viable. With the exception of Italy, which was classified as a medium flexible generation system and has a moderate expected share of wind energy by 2025, all countries which have a potential for Smart Appliances as a Demand Response option above 2 GW fulfil the conditions for their potential to be viable already in the moderate energy price scenario. The largest Smart Appliance potentials, which are also viable in their respective national generation systems in the year 2025, can be found in Germany, France, the UK, Spain and Poland. These five countries together represent a total annual average Smart Appliances potential of 33 GW, which is nearly 80% of the total potential which was estimated to be economically viable.

Potential CO_2 savings from the use of Smart Appliances

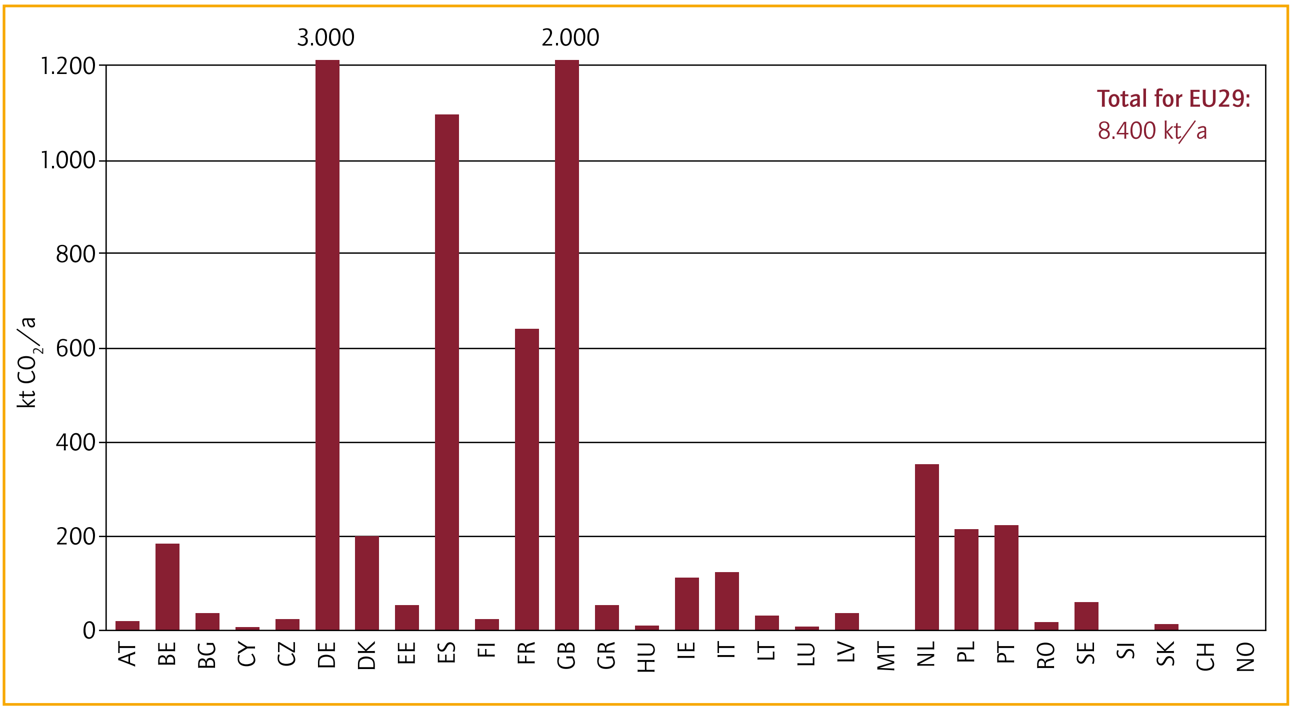
The economic value which has been assigned to Smart Appliances as a Demand Response resource is created by a reduction in fossil fuel consumed by power plants. In Figure 5 we showed that the introduction of Smart Appliances can bring about a reduction in fossil fuel consumption of all power plants in a country of up to 6%, depending on the framework conditions in the respective electricity system. This reduction is achieved firstly by a reduction of the number of fossil-fuelled plants operating in an inefficient part-loaded mode and secondly by a reduction of wind curtailment due to the increased ability of the electricity system to absorb variations in wind power generation.

Obviously, a reduction in fossil fuel consumption not only means reduced fuel costs, but also reduced CO_2 emissions. In order to simplify the analysis, we have assumed that the marginal power plants whose operation is avoided by the introduction of Smart Appliances are fuelled with natural gas in all countries. In terms of CO_2 emissions, this is a conservative approach since in quite a number of countries, balancing power is also provided by power plants using other fossil fuels which have higher specific emissions.

In order to assess the CO_2 emissions reduction implied by Smart Appliances, we have used the classification of the 29 European countries regarding their generation flexibility in the year 2025 as described above and compared these with modelling results in generic power systems as described in the Smart-A report on electricity networks (Silva et al 2009). On this basis we were able to determine the estimated overall fuel cost reduction which could be achieved in each country by the introduction of Smart Appliances, and from this we derived the estimated CO_2 reduction. Due to the fact that the number of appliances available for Demand Response in the respective countries has been chosen quite ambitiously by Silva et al (2009), this methodology leads to an estimate of the maximum CO_2 reduction which can be expected from the introduction of Smart Appliances. Details of the methodology are described in the Smart-A report on Costs and Benefits of Smart Appliances in Europe (Seebach et al 2009).

The results of this estimate are presented in Figure 12. The highest CO_2 reductions can be achieved for the conditions assumed for Germany, the UK and Spain. These are countries with a large electricity market, whose generation system is rated "low flexibility" or "moderate flexibility" and which are expected to show a share of wind power in total installed generation capacity of more than 25%. Countries with high flexible generation systems, low expected wind shares or relatively small electricity markets show a low number of expected CO_2 savings through Smart Appliances. For the total of the 29 countries, the maximum annual CO_2 savings through Smart Appliances in the year 2025 could be 8.400 kt/a, which is equivalent to approx. 1% of the total expected CO_2 emissions of the power sector in these countries.

Figure 12: Estimated maximum annual CO_2 savings through Smart Appliances (year 2025)



Source: Seebach et al 2009

7 Incentives and Implementation Models for Smart Appliances

So far, our analysis has looked at the case of Smart Appliances from an overall economic perspective. We have established that economic benefits occur in the electricity industry if Smart Appliances can be used for the balancing of variable wind generation, and that additional costs occur in the production and operation of smart appliances. We have also seen that in many European countries, but not in all, the potential benefits of this use appliances are higher than the expected costs in the case of a mass production of Smart Appliances by the year 2025.

But in order to get Smart Appliances actually implemented, we need to understand the individual economic perspective of the actors involved in the implementation of these devices. In this chapter we address the relevant actor groups and analyse the distribution of costs and benefits among them in qualitative terms.[9] Based on this we discuss a set of incentive mechanisms which can be used for making Smart Appliances attractive for the relevant actors. Finally we address a selection of implementation models, which give a picture of what the actual business case of Smart Appliances could look like. Further details can be found in the Smart-A report on Costs and Benefits of Smart Appliances in Europe (Seebach et al 2009).

[9] *A quantitative analysis on a micro-economic level was beyond the scope of the Smart-A project.*

Default allocation of costs and benefits of Smart Appliances to the actors involved

The focus of the analysis in the Smart-A project was the use of Smart Appliances for balancing wind generation. As already mentioned in chapter 4, Smart Appliances can also support the management of balancing groups in the electricity market and of congestions in the electricity networks. Their potential further use for the provision of other ancillary services for electricity system operation was not addressed by this project.

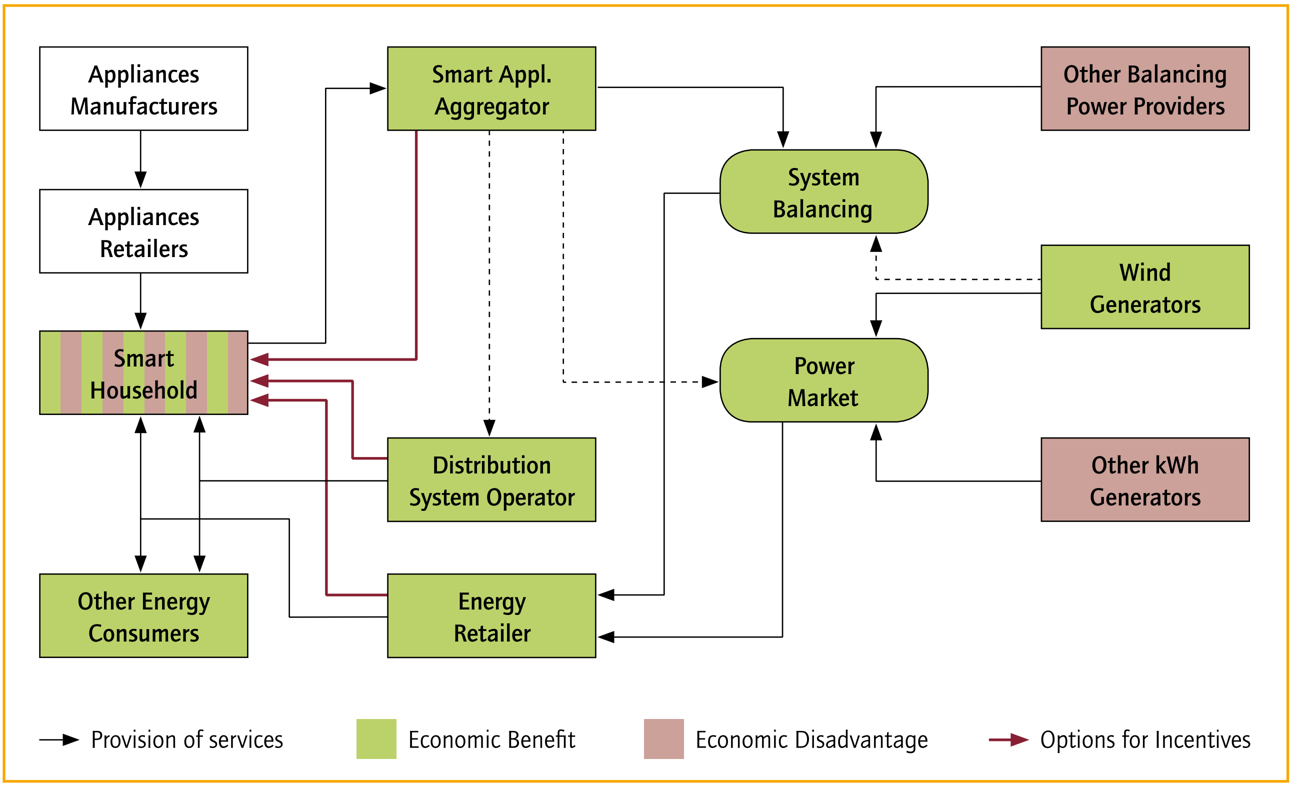
Table 9 shows the actors which can be relevant in order to implement Smart Appliances or which are affected by their operation. Figure 13 depicts in an qualitative way how the costs and benefits are distributed between these actors based on the current regulatory and market frameworks. The colours used denote a very rough assessment of whether the respective actor will have a net profit or a net loss by the introduction of Smart Appliances in the absence of specific incentive schemes.

Table 9: Relevant actors for Smart Appliances operation

Energy industry	Power plant operators (kWh generators) Operators of wind generators Providers of Balancing Power (other than Smart Appliances) The energy retailer of the "smart" households The distribution system operator of the "smart" households Other energy retailers and distribution system operators
Appliances Sector	(Smart) Appliances Manufacturers (Smart) Appliances Retailers
Intermediaries	Aggregators and service providers for Smart Appliances
Consumers	"Smart" households Other electricity consumers

Source: Seebach et al 2009

Figure 13: The default distribution of costs and benefits



Source: Seebach et al 2009

Obviously, we need manufacturers of Smart Appliances and retailers who sell them to consumers. The additional costs for producing Smart Appliances will be passed on to the consumers in the default setting. The consumers using Smart Appliances are denoted "Smart households" in this chapter. Besides higher costs for purchasing the appliances, they will have to bear the costs for additional standby energy consumption, and they might also have to pay continuous attention to the smart operation of the appliance.

In order to convert individual Smart Appliances into a product which can be marketed as, for example, reserve capacity or balancing power, some kind of aggregator will be required, which coordinates the smart operation of large numbers of devices. The function of this aggregator could be taken on by different actors, such as an electricity system operator on the distribution or transmission level, individual electricity retailers or independent service providers. The aggregator will most likely be a commercial actor who will only perform the task if he or she expects to make a certain profit on it.

Depending on the purpose for which the Smart Appliances are being used, different actors in the electricity system are affected. In the case of the use of Smart Appliances for balancing wind power variability, the operators of wind power plants will be able to increase their power generation and thus their income. On the other hand, other participants in the balancing market will lose part of their business if Smart Appliances are able to offer reserve capacity and balancing power at better conditions. This could apply to certain operators of conventional power plants. Balancing power is typically purchased by the operators of transmission systems or an independent body responsible for balancing. If Smart Appliances are competitive, their entrance into the market will reduce the average market price for system balancing power. Also, given the rules for priority access and dispatch of renewable energy in Europe, an increased ability of the electricity system to draw on wind power will drive some conventional power generation out of the market for those hours of the year during which Smart Appliances actually help to reduce wind curtailment. This means a loss of marginal income for some conventional power plants which operate in the regular power market (which are denoted "other kWh generators" in Figure 13 in order to distinguish them from the conventional providers of balancing power). Typically this also implies a lower price in the power market.

In the case that Smart Appliances are used for the management of balancing groups in the electricity market, they will reduce the operating costs for electricity retailers. Finally, if Smart Appliances support the management of congestions in electricity networks, this will bring about a cost reduction for the system operator. In Figure 13 we assume this use of Smart Appliances only on the level of the distribution system.

Under the current market and regulatory framework, reductions of the costs for system balancing and of the price in the power market, reduced cost for electricity retailers and lower cost for electricity network operators will partly be passed on to all electricity consumers. This means that only part of these benefits of Smart Appliances operation will be allocated to the smart households, which in the default setting have to bear most or all of the costs of Smart Appliances. Rather, part of the cost reductions will remain with the different actors in the electricity sector as extra profits, and the rest will be passed on to all electricity consumers on a pro-rata basis. Thus, under the current regulatory and market conditions the smart households will only see a very small financial reward for their contribution to improving the performance of the electricity system. Table 10 summarises these effects.

It is obvious that a reduction of CO_2 emissions in the electricity sector as shown in Figure 12 has some indirect effects on many actors through the European Emissions Trading System. However, these effects are not regarded in further detail here.

Table 10: Examples of the default allocation of costs and benefits of Smart Appliances to relevant actors

Benefit/ Costs	Beneficiary/ Disadvantaged	Effect/ Default allocation
A) Effects of making Smart Appliances operational		
Investment and operational cost for Smart Appliances	Smart consumer	Need for compensation, e.g. through the retailer or Smart Appliances aggregator
Attention required for the Smart Appliances operation	Smart consumer	Need for compensation, e.g. through the retailer or Smart Appliances aggregator
B) Effects of Smart Appliances used for the provision of balancing power		
Reduction of cost for balancing power	Balancing market client	Benefit (partly) passed on to all electricity consumers through their retailers and DSOs
Higher income due to reduced wind spill	Wind power producers	(None)
Reduced electricity price due to reduced wind spill	Electricity retailers	Benefit (partly) passed on to all electricity consumers
Stranded cost of conventional balancing capacity	Other providers of balancing power	Smart appliances take over part of the producer rents of conventional balancing plants
C) Effects of Smart Appliances participating in the spot market for energy		
General reduction of peak demand leads to lower average electricity price	Electricity retailers	Benefit (partly) passed on to all electricity consumers through their retailers
Reduction of peak power demand fom a particular consumer group	Balance group manager responsible for these consumers	Benefit (partly) passed on to all electric-ty consumers of this retailer
	Operator of the respective distribution network	Reduced peak load (and potentially reduced demand for network investments) typically reduces use of system charges for all electricity consumers connected to the distribution system
Peak power production: reduced income / stranded cost	Peak power producers	Smart appliances take over part of the producer rents of conventional peak power producers

Note: Benefits of the introduction of Smart Appliances are set in green text while economic disadvantages are set in red.
Source: Seebach et al 2009

Incentives for Smart Appliances

Clearly, the default allocation of the costs and benefits of Smart Appliances under the current framework does not support the motivation of smart households to invest in the new technology and to use it in a smart way. This means that we need to use adequate incentive mechanisms in order to transfer at least part of the total benefits which Smart Appliances can bring about. Figure 13 already indicates some of the potential transfers of benefits to the smart households. They are meant to compensate such households for the higher cost of Smart Appliances purchase and operation. However, given the fact that some implementation models of Smart Appliances require day-to-day attention by the consumers, it is clear that on top of this compensation an additional incentive will be needed in order to motivate them to participate continuously in Smart Appliances operation.

Generally, Demand Response measures of consumers can be incentivised by the actors in the electricity industry through different types of measures:

- **Fixed premium-based incentives** are set by, for example, electricity retailers for consumers which allow them to exercise direct load control of certain electric appliances or more generally agree to curtailable supply contracts. Such agreements are usually made only with certain commercial customers. For domestic appliances, direct load control could be acceptable for water heaters or electric space heating under certain conditions.

- **Market-based incentives** require a tendering procedure in which the level of incentives for direct load control or curtailable supply is determined by a market mechanism. Due to the increased complexity of this procedure, this type of incentive seems less applicable to Smart Appliances.

- **Fixed time-of-use tariffs** are already being used to a large extent for electric (storage) heating and also partly for water (storage) heaters. Their use could be extended to other appliances, but as the tariff time zones are fixed, this incentive is quite static and does not support a truly smart integration of the demand side.

- **Real-time pricing** is the more flexible variant of the incentive models based on overall electricity tariffs. Here the tariff levels can be adapted at short notice according to the current conditions in the electricity system, e.g. based on price movements at the spot market for electricity. Thus this option enables incentives to be given to consumers exactly at times when Demand Response action is required. Real-time pricing requires real-time communication at least from the electricity retailer to a smart meter. In order to report back actual changes in consumption, bidirectional communication may be helpful.

As a variant of the fixed premium-based incentives, electricity retailers, network operators or Smart Appliances aggregators could pay a lump sum incentive for the purchase and installation of a Smart Appliance if the smart operation of this appliances is fully automatic. Another variant would be a fixed cycle-based incentive to consumers which could be paid if the consumer has set its appliance in a "ready to start" mode and has allowed for a certain period of time during which an external agent can trigger the actual start of the cycle. Similarly, the fixed premium could be paid if an external signal may interrupt a cycle of an appliance which is already in operation.

In the following, we list five selected options for implementation models for Smart Appliances. Further details on these models can be found in the Smart-A report on Costs and Benefits of Smart Appliances in Europe (Seebach et al 2009).

A) Lump sum payment for fully automatic Smart Appliance operation

This model can be used for appliances which allow for a fully automatic smart operation. For example, refrigerators and freezers can adjust the operation of their compressors based on load management signals from the electricity utility. The consumers would not notice this smart operation as it only brings about small changes in the automatic control of the temperature in the cooling compartment. However, due to the time constant of energy losses in today's appliances, the operation cannot typically be shifted for longer than 15 minutes. With some limitations, the model could also be applied to other appliances which operate in fully automatic cycles, such as circulation pumps or certain air conditioners.

The required incentive would be a one-off premium which is paid for each purchase and connection of an appliance which is by default set to this fully automatic smart operation. In its easiest form, the premium is paid to the consumer, but in principle it could also be paid to the manufacturer or the retailer of Smart Appliances. In order to trigger the smart operation, unidirectional communication between an external agent and the appliance would be sufficient, via powerline or wireless communication. A smart meter is not required. The external load manager could work with a stochastic approach based on historic experience in order to anticipate how a group of appliances will react to a load management signal.

B) Incentive for the availability of Smart Appliance operation

Here, the consumer is rewarded for enabling his or her appliance to operate in a smart mode for a certain period of time. For example, the consumer loads dishes into the dishwasher, selects a certain point in time when the cycle should be finished and switches the appliance in a "ready to start" mode. Depending on the duration of the flexibility period until the appliance needs to start its cycle in order to meet the set finish time, a certain payment can be made to the consumer, irrespective of whether the smart operation of the appliance is actually being used or not. The incentive could also take into account whether the flexibility period covers pre-defined peak time or load valley periods.

In order to implement this model, two-way communication between the appliance and an external load manager must be established. Beyond this communication functionality, a smart meter is not required. In a variant of this model, a separate premium could be paid if the appliance is actually used for smart operation.

C) Cycle-based incentive for the actual use of Smart Appliances

In this model, an incentive is generally paid to all Smart Appliances where operation is avoided during a period indicated by a signal broadcasted via powerline or wireless communication. The actual reaction of appliances is reported back to an external load manager based on bidirectional communication. The model requires monitoring of the actual performance of the appliance, either in simple terms or in more detail. This could be done using special types of smart meters or different communication gateways. The incentive might be differentiated based on the duration and the volume of the load shift.

This model is quite open regarding the appliance technologies and the duration of the load shifted. For example, the broadcasted signal could trigger a temporary interruption in the cycle of a tumble dryer, but it could also launch a message on the display of a washing machine which signals to the consumer that a premium is offered if he or she selects a delay of the cycle start time. However, a general difficulty of this model could be proper determination of the baseline for the appliance operation (what would happen if there was no load management signal?).

D) Smart Appliances supported by time-of-use tariffs

Here we assume a household using a fixed time-of-use tariff. This tariff rewards the shift of energy usage from the pre-defined high tariff periods to low tariff periods (e.g. at night). Advanced time-of-use tariffs already use more than two tariff levels, which give more differentiated incentives. Smart Appliances can support the consumers in shifting consumption away from high tariff periods.

In a basic variant of this model, the appliances have no connectivity; they are only used by consumers in order to manage their consumption manually, e.g. through the use of start timer functions. In an advanced variant, the appliances recognise the current tariff zone and alert the consumer if a cycle is to be started in a high tariff period. The consumer might also be able to pre-set that the appliance starts its operation automatically after the low tariff zone has started. Whereas the basic variant is not really a smart operation of appliances, the advanced variant requires the appliance to manage information about the tariff zones, which may include tariff changes from time to time. This model could be supported by simple multiple register meters and possibly unidirectional communication of tariff periods, but it does not require smart meters.

E) Real-time pricing for households with Smart Appliances

In this model we assume a household which is using a real-time tariff which follows the changes in the electricity market at short notice. For this purpose a variable price signal has to be communicated to the consumer. This is typically done through a home display. Smart Appliances could support this by also providing current tariff information through their displays. The energy consumption of the household needs to be recorded by a smart meter in relatively short time intervals together with the respective price.

This model allows the most stringent connection of DSM activity to the actual situation in the electricity market. There is a number of options for ways in which Smart Appliances can support the consumer in reacting to the real-time tariff beyond just displaying information on the current tariff level. For example, an appliance can be set in a "ready to start" mode by the consumer and can start its operation as soon as the electricity tariff drops below a certain level. In the case that the tariff model allows short price peaks, the appliance controllers could also interrupt the operation of a device if it is possible in terms of the current status of the cycle.

It should be noted that the effects of time-of-use and real-time tariffs encompass the total electricity consumption of a household, not only the Smart Appliances. Thus they give incentives for shifting of any type of electricity consumption, even if it is not related to one of the appliances which are in the focus of the Smart-A project. This can be regarded as an additional benefit if the household is able to modify its consumption according to the price signal. However, there are households that will find it difficult to change their daily routines which determine the electricity consumption, e.g. families with children. Under certain conditions, a switch to a flexible electricity tariff might actually increase the energy bill of these households, even if they are using Smart Appliances. This underlines that consumers should be well informed about the implications of different tariff models before they make a choice.

There are certainly other models for the implementation of Smart Appliances. The selection above already shows the diversity of the possibilities and their implications regarding metering and communication technologies. It should be noted that only some of the implementation models mentioned above actually require a smart meter and some of them can even work with unidirectional communication only, e.g. a price signal. However, with more advanced metering and communication infrastructure the range of options for the operation of Smart Appliances increases.

8 Strategies for the Implementation of Smart Appliances

We have shown in the previous chapters that Smart Appliances can support the load management in electricity systems and that their use as a Demand Response resource has a positive cost-benefit ratio in many European countries. However, there are a number of significant barriers which need to be overcome in order to realise the cost-efficient potential of Smart Appliances. The Smart-A report on strategies and recommendations (Stamminger 2009b) outlines the relevant constraints and measures to overcome them as well as recommendations for actions to be taken during different phases of a Smart Appliances strategy.

Barriers against Smart Appliances and related measures to overcome them

In the following, the most relevant barriers against Smart Appliances and potential measures against them are listed.

- The **concept of Smart Appliances is relatively new** and has not yet been tested sufficiently. Governments and industry should join forces to further investigate the idea of Smart Appliances through research and pilot projects in order to identify solutions which are technically feasible, acceptable for consumers and beneficial both in economic and environmental terms.

- Whereas the standardisation of communication technology and protocols has made a lot of progress in the appliances industry and more recently has been making progress within the electricity sector, there are **not yet sufficient standards for the cross-sector communication** (e.g. between smart meters and appliances). Such standards should be developed quickly at least on the European and if possible even on the global level.

- Smart Appliances depend on **innovative communication channels**. Solutions and standards are needed for appropriate types of communication gateways in the household (connected to a smart meter or not), the communication between the utilities and the gateway as well as in-house communication between the gateway and individual appliances. If it is preferable that the Smart Meters are the gateways in the household, this should be standardised before large numbers of smart meters are rolled out.

- The **costs and benefits of Smart Appliances are distributed unevenly** under the current regulatory and market framework. Electricity retailers should continue to develop and test adequate and innovative incentive mechanisms which compensate the users of Smart Appliances for their extra costs and their continuous participation in the smart operation of appliances. Regulators should develop a framework under which costs for Smart Appliances can be accepted if they help system operators to manage distribution or transmission systems in an economic way.

- In order to increase **consumer acceptance** of Smart Appliances, the manufacturers should make the technology easy to handle, safe in unattended operation and very low in noise. Smart Appliances should allow consumers to override the smart functionalities. Policy makers should investigate whether and under which conditions Smart Appliances functionalities can be taken into account as a credit in the rating of appliances under the EU Energy Label.

- The smart operation of appliances requires them to be in standby for certain periods of time. The **standby energy consumption** of appliances, meters and communication infrastructure increases the cost for Smart Appliances and reduces the environmental benefit. Thus the manufacturers of these technologies should strive to further reduce the energy consumption in standby mode.

- When implementing Smart Meters and Smart Appliances, the electricity industry should ensure an approach which is **compatible with liberalised electricity markets**. Proprietary systems should be avoided where possible.

- The operation of Smart Appliances might raise **concerns related to the privacy and security of personal data** of consumers. The technological concepts for Smart Appliances and related communication and billing systems should ensure the privacy and security of sensitive data. The protection standards should be harmonised at a European level.

- The Smart Appliances **concept is complex and benefits are difficult for consumers to understand**. The appliance and the electricity industry should work together with public bodies in order to inform consumers correctly and in a transparent way about costs and benefits of Smart Appliances.

- In order to actually implement the concept of Smart Appliances, the **new roles of aggregators and service providers for Smart Appliances** must be developed and tested. This role is inevitable in order for large numbers of appliances to be coordinated in such a way that they can act similarly as a single large actor which can participate in the energy market.

- In order to reach the low levels of additional cost for Smart Appliances used in the analysis of the economic viability of Smart Appliances in the Smart-A project, manufacturers must be able to realise **cost reductions through mass production**. In order to arrive at this stage, market introduction programmes will be required which include commitments from the electricity industry as well as public support to the first generations of Smart Appliances. Following the learning curve of cost reductions, the public support should be degressive over time. Once certain Smart Appliances technologies have proven to be reliable and beneficial, policy makers should consider making their use a mandatory requirement for all new appliances of the relevant type.

- There remains a **demand for additional research on Demand Response options and a better use of renewable energy by domestic appliances**, both on the technical as well as the socio-economical level. European and national research activities should be coordinated in order to produce the required knowledge and promote the cooperation of actors from different actor groups.

As can be seen from the list above, coordinated action by different actor groups is necessary in order to further develop the concept of Smart Appliances and implement those applications which prove beneficial. This involves at least the appliance industry, electricity retailers and system operators, standardisation bodies, energy regulatory, consumer organisations, policy makers and governmental bodies.

Selected actions for the promotion of Smart Appliances

Based on the list of measures in order to tear down the barriers against the use of Smart Appliances as a Demand Response resource, the Smart-A project has highlighted some concrete actions which could be launched within different time horizons.

- **Promotion of shifting dishwasher operation into the night**
  The analysis in the Smart-A project has shown that dishwashers contribute to peak loads from domestic households in the evenings. At the same time, our consumer research has shown a high acceptance amongst consumers to shift the operation of dishwashers to night hours. As a first and very simple measure, appliance manufacturers and electricity utilities should promote this shift of dishwasher operation. Although this is not a truly smart activity, it can help to reduce peak loads with only limited effort and at the same time educates consumers to adjust part of their energy demand according to the framework conditions in the electricity system. This measure does not require much preparation and thus could be started as an ad-hoc action.

- **Introduction of flexible electricity tariffs**
  There are many ongoing activities geared to assessing the impact of real-time electricity tariffs and smart meters on the consumption pattern of consumers. These activities fit quite well with the Smart Appliances concept. Although Smart Appliances can also be implemented based on other incentive mechanisms, flexible electricity tariffs are very promising. With increasing knowledge becoming available from pilot projects, energy retailers should introduce new tariff models quickly into the market. However, this should occur on a voluntary basis for the consumer as some households might not be able to shift relevant parts of their consumption. Other business models for Smart Appliances beyond flexible tariffs should also be developed, which provide incentives for automatic smart operation of certain appliances or a consumer-controlled smart operation of individual appliances.

- **Further development and roll-out of Smart Meters**
  As can be seen for the current discussions in the electricity sector, it is not yet clear which requirements must be met by smart meters for domestic consumers. The options range from simple electronic meters with several tariff registers via Automated Meter Reading to full Automated Meter Management (AMM) which might include bidirectional communication and a gateway for remote switching and communication to in-house appliances. Not all implementation models for Smart Appliances require AMM meters, but their diffusion into the market would certainly help Smart Appliances concepts to become reality. Thus, requirements for Smart Meters should be standardised and a broad agreement should be sought on the types of meters to be rolled out in large numbers.

- **Integration of Smart Appliances benefits into the EU Energy Label**
  Depending on further research on the net benefits which different types of Smart Appliances can bring about in the context of the electricity supply system, a certain energy efficiency credit could be given to Smart Appliances in the rating under the EU Energy Label.

- **Improvement of cross-sector standardisation and communication**
  As a prerequisite of the full-scale application of Smart Appliances it is necessary that information can be exchanged between appliances, a central gateway in a household and some form of external load manager. This communication can be based on existing technology such as powerline and wireless communication (WLAN or Zigbee), but the protocols for communication between the energy and the appliance sectors still needs to be developed further. The IP protocol seems to be a promising basis for this further development. Based on this infrastructure, standardised business models for the smart operation of appliances should be developed, which allow households with Smart Appliances to switch between energy suppliers or move between the service areas of different distribution network operators without losing the capability of being smart consumers.

- **High standards for the privacy and security of data**
  During further development of communication technologies and standards, high priority should be given to solutions which ensure the protection of data related to consumers and their appliances. A European directive could help to support the harmonisation in this field.

- **Development of washer-dryers**
  Washer-dryers allow the combination of the washing and the drying cycles of two appliances which are currently usually separated. This combined appliance would allow a similar flexibility regarding load shifting as this is currently the case for dishwashers. Due to the long cycle and the significant energy demand per cycle, washer-dryers are a very attractive type of Smart Appliance in this context. However, the washer-dryers that are currently available have a low energy efficiency. The appliance industry should examine the potentials for further improvements of the combined washing and drying process.

- **Promotion of the use of hot water in domestic appliances**
  Beyond the scope of electric load management, energy efficiency and increased uptake of renewable energy could also be boosted if more domestic appliances were to use hot water instead of heating up cold water using electricity. Washing machines and dishwashers can be constructed in such a way that they work with an additional hot water intake. The related energy efficiency gains could be promoted by appliance retailers and could also be reflected in the EU Energy Label.

In the longer run, further technological developments could help to increase the energy efficiency of the appliances in the context of the systems providing electricity (and hot water if applicable). The Smart-A report on domestic appliances (Stamminger 2009a) has identified several options in this regard, which should be assessed further and developed if they prove to be promising.

9 Outlook

The Smart-A project has for the first time assessed details of the potential use of Smart Appliances in Demand Response programmes. While the qualitative results are quite robust, many of the quantitative results regarding the economic value of Smart Appliances and the cost of their production and operation had to be based on assumptions made by the project team. Thus the numeric results presented in this report should be interpreted as rough estimates which need to be verified by more research. However, if the assumptions prove to be realistic, Smart Appliances can be a significant part of the smart energy system of the future.

In a larger context, the issues of Smart Grids and Smart Metering are advancing fast, and several pilot projects are under way on the European as well as on national levels. Smart Appliances could be a very promising part of these concepts. In an optimistic scenario for the more distant future, most or even all of the electricity consumed in Europe is produced from renewable energy sources, and most of the electric appliances operated in European households participate in a smart management of the production and the demand for electric energy.

Whether and to what extent appliances can really play a big role in meeting the challenges of a renewable energy supply system in Europe is still uncertain. Thus, our proposal for a roadmap for the further development of Smart Appliances in Europe consists of several phases.

- **Phase 1: Feasibility studies and pilot projects**
  In this phase, further studies should be performed in order to verify the feasibility of the Smart Appliances concept. This should encompass the fields of the technologies required, the acceptance by consumers and the assessment of cost and benefits for different usages of Smart Appliances. The potential roles and business models of Smart Appliances aggregators should also be tested These studies should run in parallel and benefit from pilot projects for Smart Grid concepts, which actually test the Smart Appliances concept and different implementation models in the field.

  As a further activity in this phase, European standardisation bodies should step up their efforts in terms of harmonising the communication protocols and technologies in the field of Smart Metering and between gateways in the household and domestic appliances. At the end of phase 1 it should be possible to identify which types of Smart Appliances operation are beneficial under which framework conditions.

- **Phase 2: Market introduction**
  Based on the results of the first phase, the market introduction of Smart Appliances should focus on those types of appliance operation which have proven to be most promising. Based on the results of the Smart-A project, we expect this to include dishwashers, tumble dryers and washing machines for use in regions of Europe with low flexibility power generation systems and expected high shares of wind energy. Smart Appliances could also be used in specific cases of network congestion. The market introduction would need to be coordinated between appliance manufacturers, electricity utilities and newly emerging Smart Appliances aggregators. Public support programs should be developed by the respective governments in order to cover higher cost of appliances in the first years with small production numbers. Depending on the decrease of manufacturing costs due to mass production, the public support can be reduced gradually. Alongside the market introduction, evaluation programs should verify the results achieved, which enables further development of the Smart Appliances concept where required.

- **Phase 3: Market expansion**
  After a successful phase of market introduction, other types of smart appliance operation could be introduced into the market, which can benefit from the experience gained in phase 2. This could encompass all appliances which offer an overall net benefit. The regional scope of the Smart Appliances activity could be expanded to regions in Europe with medium flexibility power generation systems and with medium to high shares of wind energy. Depending on the progress in reducing the production cost for individual types of Smart Appliances, the public support can be reduced further and finally be phased out completely.

  Also based on the results of the market expansion phase, decisions could be taken to make certain smart functionalities, which have proven to be reliable and beneficial, a requirement for all appliances of these types sold in Europe after a certain date. for other technologies, the evaluations should continue to further optimise the use of Smart Appliances where possible.

- **Phase 4: Further expansion and market saturation**
  Depending on the success of the previous phases, Smart Appliances can further increase their market shares based on the incentives given by electricity utilities. If necessary, further smart functionalities can become mandatory after it has been proven that they fulfil the criteria of reliability and economic viability. New appliance technologies might expand the possibilities of load management by appliances beyond the scope addressed in the Smart-A project.

This roadmap might sound quite ambitious for the whole group of appliances covered in the Smart-A project. However, based on the results of our assessments it can be expected that several applications of Demand Response through domestic appliances will prove to be successful. This will help to realise the vision of a smart electricity system in which flexible demand helps to manage high shares of variable wind and solar power generation and thus gradually decarbonise the electricity system of Europe.

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