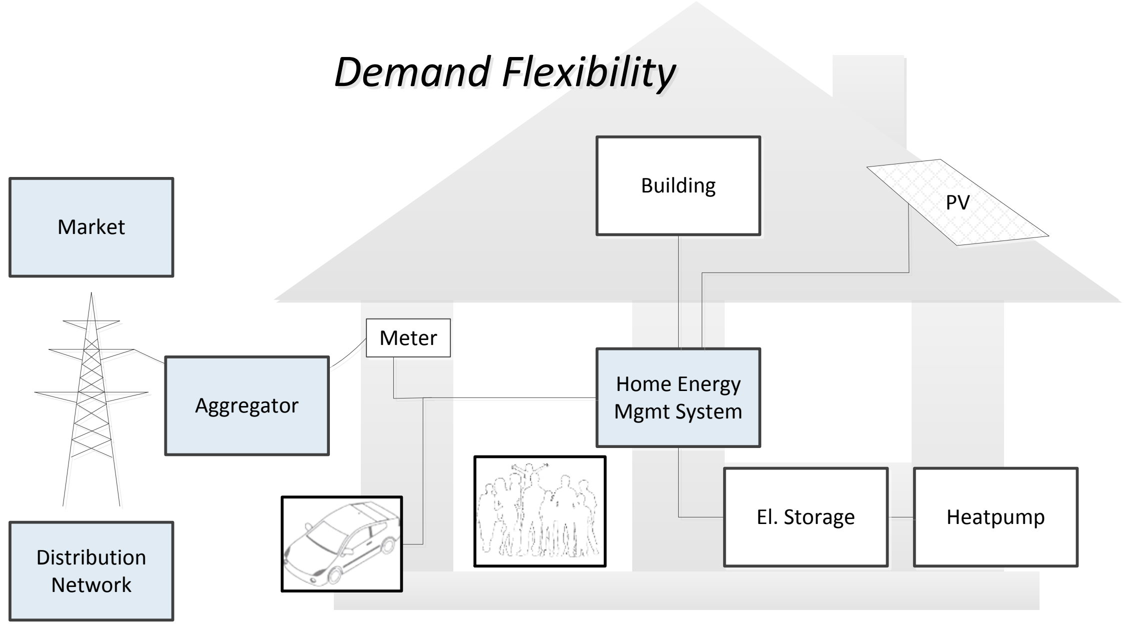

IEA DSM Task 17

Roles and Potentials of Flexible Consumers and Prosumers

Demand Flexibility in Households and Buildings

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Foreword

Context

Task 17 of the IEA DSM program is to provide an analysis of the use of demand response, distributed generation and storage for energy systems operation [1]. The project consists of four subtasks. Subtask 10 describes the context and covers the current role and the interactions of flexible consumers and producers in the energy system. Subtask 11 covers the changes and impacts on grid and market operation once optimally using demand flexibility and includes valuation of demand side flexibility. Subtask 12 collects experiences and describes best practices in several countries. Subtask 13 ends with the conclusions. This document is the result of Subtask 10. Figure 0-1 illustrates the approach and the project structure.

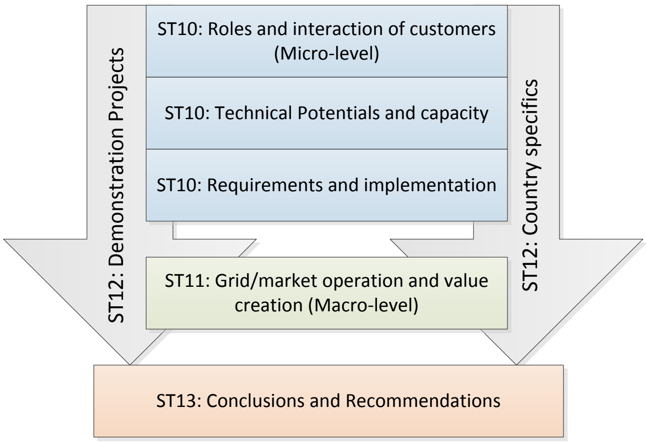

Figure 0-1 General approach of Task 17

Aim of the document

This document aims to identify the role and potential of equipment in residential and commercial buildings in providing flexibility services in future energy systems. The requirements for flexibility and interaction of distributed energy resources (e.g., distributed generation, storage, responsive load) are analyzed. The current progress, outlook and trends in participation of end-users and the active integration of Distributed Energy Resources (DER) at the residential network level are discussed. The potential of different types of individual and aggregated demand flexibility is identified and quantified, as well as potential mechanisms to use it in power systems operations to achieve economic and social policy objectives.

Structure and methodology

The information in this report relies on the knowledge of country experts obtained from interviews and direct contributions as well as from papers, discussions and presentations at workshops. The document starts with a description of the operational context in terms of commercial and grid operation. After a brief introduction to power systems and mechanisms for power system operation from a market and a transmission and distribution system perspective, the roles and potentials of residential demand flexibility, distributed generation and energy storage for providing services are discussed. Moreover, identified technologies are assessed regarding their potential applicability and maturity in the context of different technical and commercial frameworks.

Executive Summary

Use of active end-user flexibility in electricity demand, supply or storage at the residential level is still in its infancy. User acceptance issues, market design and regulation, grid and market operational constraints, technical issues with communication protocols and response automation and, as a result of that, the lack of appropriate sound business models form tantalizing challenges for DSM. With the new world-wide de-carbonization agreements, new additional objectives and constraints are added to the supply/demand optimization schemes for the electricity system to include environmental and resiliency targets.

This document is the first in a series to introduce how value creation in power systems of end user flexibility can be enhanced. It functions as a preface by describing the interfaces, roles, and potentials of providing flexibility services. The role of residential end-user equipment in buildings in providing flexibility services in the future energy system is identified. Technical potentials (kW and kWh) of distributed energy resources (distributed generation, storage, and responsive load) are also included in this analysis. Moreover, identified technologies are assessed regarding their potential applicability and maturity in the context of different technical and commercial frameworks.

The document is the prelude to the subtask 11 deliverable that describes how these potentials can be further translated into commercial and grid operation cost/benefit analyses.

Contents

Abbreviations

ADR	Aggregated demand response
AGG	Aggregator
ADR	Aggregated Demand Response
BRP	Balance Responsible Party (EU)
BA	Balancing Authority (US)
BEES	Battery Electrical Energy Storage
B2B	Business to Business
BEMS	Building Energy Management System
DF	Demand Flexibility
DNO	Distribution Network Operator
DR	Demand Response
DSF	Demand Side Flexibility
DSM	Demand Side Management
DSO	Distribution System Operator
DF	Demand flexibility
DER	Distributed Energy Resource
DG	Distributed Generation
EE	Energy Efficiency
FSP	Flexibility Service Provider
HEMS	Home Energy Management System
ISO	Independent System Operator
MO	Market Operator
PTU	Program Time Unit
SCADA	Supervisory Control and Data Acquisition
SGCG	Smart Grids Coordination Group
TNO	Transmission Network Operator
TSO	Transmission System Operator
VPP	Virtual Power Plant
VPN	Virtual Private Network

Definitions

Aggregated Demand Response
Can be understood as aggregating a large number of small resources and utilizing statistical behavior to increase availability and reliability, which would not be possible when using a single resource individually.

Aggregator
Definition from the Smart Grids Task Force – Expert Group 3:
"A legal entity that aggregates the load or generation of various demand and/or generation/production units. Aggregation can be a function that can be met by existing market actors, or can be carried out by a separate actor. EED: aggregator means a demand service provider that combines multiple short-duration consumer loads for sale or auction in organised energy markets." [2]

Flexibility Service Provider (FSP)
An FSP makes use of aggregated devices delivering flexibility in supply or demand. For instance it could be an aggregator who offers services with the portfolio of flexible resources to different stakeholders/actors in electricity system operation.

Flexibility Operator
Is the entity which uses the provisioned flexibility (e.g. facilitated by an FSP) on a market (e.g. BRP or DSO).

Balance Responsible Party (BRP), Balancing Authority (BA)
A legal entity that manages a portfolio of demand and supply of electricity and has commitment to the system operator in an ENTSO-E control zone to balance supply and demand in the managed portfolio on a Program Time Unit (PTU) basis according to energy programs. Legally, all metered nodes in the power system have program responsibility; this responsibility currently ultimately is delegated to the BRP.

Customer Energy Management System (CEMS) / Home Energy Management System (HEMS)
A customer or home energy management system coordinates with energy-using equipment (such as HVAC, water heaters, lights, pumps, local generation, and storage to control their operation to conveniently meet the needs of the household occupants. It may also include energy efficiency functions that help reduce the overall energy needs of the home. This automation system is an important enabler for demand response. Additionally it enables the possibility to receive a DR signal or tariff/price signal to provide a number of automated services that optimize operation to reach cost and energy efficiency with the constraints of the transmission and distribution system.

Demand side management (DSM)
"The planning, implementation, and monitoring of activities designed to encourage consumers to modify patterns of energy usage, including the timing and level of electricity demand. Demand side management includes demand response and demand reduction." [2] In this context it is assumed to include Energy Efficiency as well as Demand Response as DSM operational objectives. The presence of a consumer-side generation or storage system (such as PV and battery) does not necessarily imply the active management of these resources at the demand side. Only active participation of these resources by responding to a signal or other strategy to

alter the shape of the load profile is considered as a ‘managed’ demand or an ‘active’ demand side management,

Demand Response (DR)

DR can be defined as a change in the consumption pattern of electricity consumers (e.g. load shifting, load decrease) in response to a signal (e.g. changes of electricity price) or due to other incentives or objectives (e.g. increase of the overall system performance, reliability of supply) [3],[4]. It includes the active response of generation and storage systems at the consumer-side (‘behind-the-meter’), by changing their ‘original’ generation pattern. Demand response, a term seen from the utility perspective, thus also includes generation in terms of negative demand.

Distributed Energy Resource (DER)

Subsumes devices on both sides of the electric meter in the distribution network (as opposed to central generation units) that are able to provide or consume energy (e.g. PV system, storage). Additionally it is capable of reacting to certain control signals or provides services (e.g. on/off, power reduction, voltage control) requested from energy management systems or other system controls. With respect to this definition a DER can be considered as a Demand Response Resource if it is under control to response to higher control objectives and varies from its static generation or demand pattern.

Demand (Side) Flexibility (DF, DSF)

Adapted from the definition from the Flexibility Roadmap (Copper Alliance, Ecofys 2015).

“Flexibility is the ability of demand-side power system components to produce or absorb power at different rates, over various timescales, and under various power system conditions in response to a signal or triggered by a local event at the residential premises. Demand-side flexibility options include varying consumption. Opportunities for varying demand exist in many energy intensive industrial processes, irrigation and municipal water pumping, wastewater treatment, air and water heating and cooling (HVAC) systems, and electric vehicle charging. Energy efficiency investments (such as better insulation in buildings) can contribute to flexibility by freeing up traditional resources (such as HVAC units in this case) to offer greater temporal variability”

Definition from Eurelectric, Jan 2014:

“On an individual level, flexibility is the modification of generation injection and/or consumption patterns in reaction to an external signal (price signal or activation) in order to provide a service within the energy system. The parameters used to characterize flexibility in electricity include: the amount of power modulation, the duration, the rate of change, the response time, the location etc. ”

Definition from Rocky Mountain Institute, August, 2015 [5]

“Demand flexibility uses communication and control technology to shift electricity use across hours of the day while delivering end-use services (e.g., air conditioning, domestic hot water, electric vehicle charging) at the same or better quality but lower cost. It does this by applying automatic control to reshape a customer’s demand profile continuously in ways that either are invisible to or minimally affect the customer, and by leveraging more-granular rate structures that monetize demand flexibility’s capability to reduce costs for both customers and the grid.

Importantly, demand flexibility need not complicate or compromise customer experience. Technologies and business models exist today to shift load seamlessly while maintaining or even improving the quality, simplicity, choice, and value of energy services to customers."

Distributed Generation (DG)
Smaller size generation (as opposed to bulk generation and dispersed) connected to the distribution network on medium and low voltage levels. Typical nominal powers are ranging from 1-50MW to 5-100kW in the respective network level. DG can be controlled locally or be part of central dispatched control operations.

Dispersed Generation
Smallest generation connected to the distribution network on low voltage levels and, opposed to bulk generation, not connected to a control center. Typical nominal powers are ranging from 1-5kW in the LV network level. Dispersed generation is best forecasted in an aggregated way; no mechanisms for direct control generally are implemented into current SCADA-systems so direct DSO control is not possible. Small, distributed generation systems like residential PV-units are also coined dispersed generation to emphasize the fact, that they are free-running.

Distribution Network Operator (DNO)
DNO maintains the distribution networks infrastructure in an asset based, investment manner. The DNO role is completely regulated and no commercial operation is possible.

Distribution System Operator (DSO)
DSO is responsible for the reliable operation of the distribution system.

Energy Efficiency (EE)
Thermodynamically, energy efficiency means the efficiency of a physical or chemical conversion process. Energy efficiency measures are ranked under demand side management (DSM), so utility driven. The definition from the Smart Grids Task Force – Expert Group 3 is:
"An actual reduction in the overall energy used, not just a shift from peak periods. Energy efficiency measures are a way of managing and restraining the growth in energy consumption. Something is more energy efficient if it delivers more services for the same energy input, or the same services for less energy input." [2]

Variable Output Renewable Generation
Generator which uses a primary energy source which is variable in its nature, e.g., photovoltaic systems, wind power generators, small hydro plants. The variability and predictability of these generators depends on their type and environmental conditions.

Prosumer
A utility customer that produces electricity. Roof top PV installations and energy storage battery systems are examples of homeowner investments that allow people to do both - consume and produce energy - for use locally or export during certain parts of the day or the year.

1 Introduction

1.1 Background

In the electricity sector, flexibility of supply and demand and the use of this flexibility are well-known at the industrial, commercial and wholesale level of operation. News messages from 20 years ago [6] indicated, that the use of end-user flexibility enabled by ICT was expected and planned, but eventually failed to find mass application. Real-world introduction and management of these automated systems appears to be difficult, mainly from a market perspective, although some technical challenges mainly related to the cost of technologies were present. For instance, the costs appeared to be substantial while the benefits had to be shared between too many parties. In the last decade, the cost of communication bandwidth via fiber or wireless and processing power for automated systems has fallen sharply. Through developments like small and powerful user interface applications and the Internet of Things (IoT) reduce the footprint of automated systems, while cloud deployment of applications and services further decrease automation system management and maintenance efforts. Additionally, end-user flexibility is increasingly needed due to a more fluctuation power generator fleet and to new types of electricity demands as a result of electrification (heat pumps, electric vehicles) and renewable generation. So, a new window of opportunity appears to be opening for demand side flexibility services. However, allowing demand side flexibility in the current market design brings along many questions on potentials, roles and responsibilities. Who should benefit from such services and to what extend? How are monetary benefits and costs distributed to actors? What is the contribution to society of using the flexibility? Since the system design has changed, these questions are underlined by issues introduced by an unbundled regime.

Figure 1-1 illustrates the societal point of view on demand side flexibility. The societal point of view includes three main domains to be considered, i.e. the commercial/market domain, the network domain and the domain of cost recovery, which is usually done via tariffing the end consumers. Electric flexibility potential can be generally discriminated into 2 types. They include instantaneous power capacity flexibility measured in kW(t) and volumes of electric flexibility measured in kWh(t). Flexibility can offer benefits in both domain, the commercial domain and network domain. Benefits in the commercial domain will predominantly be related to the flexibility of energy production or consumption, i.e. power generated or consumed over time. These flexibility services are of volumetric nature and can lead to a smaller amount of costly generation plants to meet system peak demand. Benefits in the network domain relate to flexibility of power produced or consumed at a point of time. These flexibility services are hence of capacity nature. Typically, the utilization of flexibility in networks might lead to reduced network expansion costs.

From the societal point of view, it seems beneficial to have an energy system that offers to harvest benefits from both, volumetric and capacity based flexibility options. Such a system needs to take into account the ability of producers and consumers equally to adapt to certain system constraints. In particular, a system which is designated to achieve a societal optimum needs to take end consumers into account and to enforce them with the necessary knowledge and decision opportunities. Benefits of flexibility are savings in capital or operational expenditures

(CAPEX/OPEX[1]). They are handed over to end consumers via tariffs related to network usage and commercial generation cost via tariffs in energy bills.

The regulatory context is not to be forgotten since it has a strong societal context. First and foremost regulation sets the framework for the management and accounting of the electricity networks, because it is inherently a natural monopoly. It also sets the framework for market design and operation. Subsidies are mainly based on regulations. Often, to achieve a more environmental friendly system, subsidies are introduced and rolled down to end consumers. Examples are CO_2-taxes, green certificates on generation, regulating electricity taxes that have their impact on the capital and operational expenditures of all stakeholders. Technical rules and guidelines as well as market forces further define the commercial operation of power systems, mainly based on the amount or volume (energy = kWh). Technical performance requirements of the system, e.g., quality of delivered energy with respect to voltage quality, availability of the system or the resilience against disturbances, also root in the societal context. Such requirements have an impact on the way how electric energy is transported and distributed to end consumers.

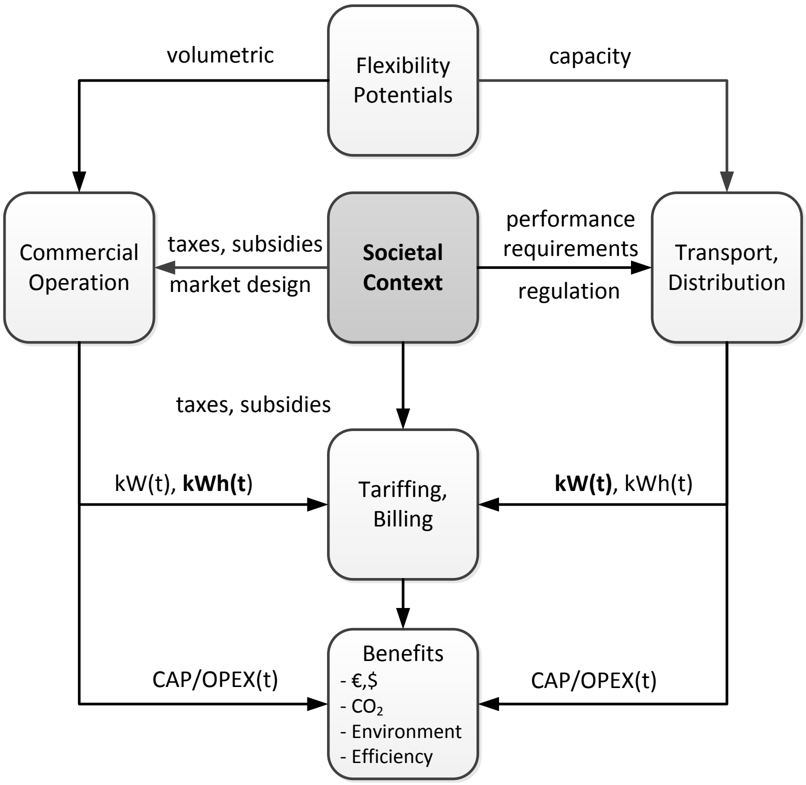

Figure 1-1 Societal context of DR flexibility

Besides investigating monetary benefits for different actors and the assignment of responsibilities, one needs to look at demand side flexibility in a broader context. The benefits of flexibility services may be also expressed through contributions to environmental targets like carbon dioxide reduction or increased energy efficiency. For investigating the contribution of flexibility services in the power system to these targets, the complete system should be considered, as environmental benefits can be realized in different sectors of the power system. For example, a reduced production through CO2 intensive generators has obviously positive effects but also a reduced network expansion is beneficial for the environment. When looking at

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[1] Capital expenditures (CAPEX) and operating expenses (OPEX) represent two basic categories of business expenses.

the energy efficiency contribution of flexibility measures, in a widened context, heat and gas distribution infrastructures should also be considered. In this report, the focus will be on electricity only, as including questions on energy system convergence leads to a degree of complexity which cannot be managed here.

The question is if the mix of incentives expressed in tariffs, taxes and subsidies creates the necessary incentives to manage the current system adequately or transform it into a desired state which offers a higher overall system efficiency. For example, assuming increased utilization of flexibility offers a higher efficiency in managing congestions, systems with regulated maximum capacity based distribution tariffs set no incentives for demand response. Congestions are resolved with other, probably more conventional solutions; time-dependent distribution tariffs could offer needed incentives.

The current ‘evolution’ of the electricity system will have to include re-engineering market and tariff designs, regulations, taxes and subsidies to better harmonize and utilize the enhanced smart grid capabilities, including the more adaptable nature of the system arising from greater flexibility of resource utilization.

Apart from traditional players in the energy field, energy communities and energy suppliers are emerging with new roles as energy service company stakeholders that serve the increasing number of dispersed residential generation and consumption systems. The regulatory and market design frameworks in different countries as well as the physical topology of the transmission and distribution networks differ considerably on a country-by-country basis. Therefore, barriers and opportunities for demand flexibility (DF), demand response (DR), distributed generation (DG) and electrical energy storage (EES) also differ on a per-country basis.

1.2 Motivation to Engage Flexible Resources

1.2.1 Flexibility in the energy system

Flexibility in demand and supply already plays an important role in balancing and matching supply and demand in the electricity system at the wholesale and B2B level. In conventional power systems generation follows demand by adjusting generation levels up or down to match changes. Additional and especially unexpected peak generation capacity is very costly; in portfolios energy companies earn 80 % of their profits with 20 % of their most flexible generators. In some countries demand management programs have been in place to remunerate consumers for changing their demand on request (demand response) and subsequently to reduce the system peak demand. In general these events are extreme high load situations and are targeted at large load resources like industrial plants. Other examples of changing consumption include short-duration (e.g., 30 minute) cycling of air conditioning units and irrigators reducing pumping loads during heavy demand periods.

Flexibility on the demand side – beside other benefits, like avoiding investment in the generation side or in the network reinforcement – is seen as an essential contribution for cost-effective and secure integration of renewable resources. They are of fluctuating nature and hence are difficult to forecast, which endangers the balance of production and consumption in real time. Additionally, flexibility can be utilized to better integrate renewable energy source into the electricity network, since infeed peaks, which could cause network congestions could be balanced. Programs and services have to advance to harvest the vast possibilities technology can offer: by exploitation of increase and decrease of demand, on regular basis and not only at critical times when the generation fleet cannot supply peak demand or by inclusion of storage technologies for balancing production and consumption at different time scales. This includes the involvement of potential energy storage components, like municipal water and irrigation pumping with physical reservoir space that allows some flexibility in the timing of the pumping. Heating and cooling applications involve energy storage in the form of thermal mass. Flexibility can be enhanced if systems are equipped with additional storage capabilities (heat storage buffer, insulated water tanks), for more independent operation. With the electrification of transport and heating, even more capabilities and need of flexibility is introduced, like controlled charging of electric vehicles. Heat pumps are another promising technology which introduce higher efficiency and flexibility, especially when combined with thermal storage [7].

End-user aggregated flexibility will further play a critical role in the transition to a generally more distributed energy system based on 100% renewables. As the generation mix evolves to include mostly small generators which are situated close to the demand, infrastructure cost can be decreased through increasing the local balancing of production and consumption as well as of efficiency in general. With such measures reliability and resiliency of power systems could be improved as large scale black outs could be counteracted by large amounts of local “cells” which are supplying themselves over a limited amount of time. This flexibility context [7] is depicted in Figure 1-2.

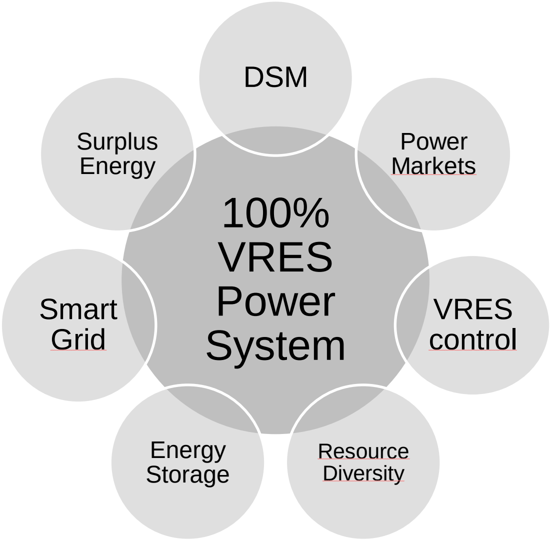

Figure 1-2: Elements of flexibility in a 100% renewable powered energy system [7]

Demand and supply flexibility in the transition to an energy system based on 100% renewables will have the following key characteristics:

- Utilization of **demand** flexibility, including energy storage and end-customers.
- Closer to real-time operation of wholesale and ancillary services **power markets.** Expanding geographic reach as well as including local constraints.
- Active control and integration of **variable renewable generators** to provide grid support services and to reduce variability and uncertainty.
- New mechanisms and other price incentives to reflect **diversity** related benefits and needs of services.
- Coverage of longer and seasonal periods by large **bulk energy storage**, e.g., in case of low renewable energy supply.
- Evolvement of advanced communication and controls over all network levels to coordinate flexible resources across supply and demand, and across transmission and distribution grids—the "**smart grid**."
- **Surplus energy** will accelerate electrification and novel electric energy use.

1.2.2 Costs structure as a driver

Due to liberalization, subsidized infeed of renewables and lowering of fuel prices, commodity tariffs have decreased during the last 15 years, while network tariffs and taxes have increased due to grid investments. Table 1-1 lists data from various countries.

Table 1-1 Average Electricity tariff components [%] on a by country basis

Country	Energy	Network	Tax
Austria [8]	32	27	41
Netherlands [9]	22	23	55
US (state) [10],[11]	39-57	33-41%	11[2]
Sweden	30	30	40
Switzerland	30	37	33
Poland [12]	32	42	26
India[3]	40-80	5-10	5-20

Apart from the average components, the tariff types are listed in Table 1-2.

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[2] US tax rates differ by State. For example, Texas exempts residential customers from sales taxes leavng only a 2% gross receipts tax on areas with 10,000 or more customer. New York' tax rate is 26%. The average is taken from Energy Information Administration. "Table 8.3. Revenue and Expense Statistics for Major U.S. Investor-Owned Electric Utilities,"

[3] In India, the electricity tariff differs from state to state. In some cases, it is different for utilities (distribution companies) within a state. In case of public utilities (distribution companies) there is no specific mention of network charges and hence levying separate network/wheeling charges is not a general practise as most of the network is owned by the government (through the distribution companies). Hence, energy charge constitute major component in the electricity bill followed by taxes (fuel adjustment charge, exercise duty, surcharge, municipal tax etc). In some utilities (ex. Mumbai, Maharashtra) wheeling charges are included in the tariff and their share is about 40% in the electricity bill. Electricity tariff in general for residential consumers is categorized into various slabs depending on the electricity consumed. Higher the electricity consumption (higher slab) more will be the energy charge. Electricity duty is calculated based on the units consumed. In some states it is a combination of electricity usage and fixed charge. The duty levied by distribution companies various across the states.

Table 1-2 Tariff types

Country	Consumption	Generation	Distribution	Transmission	Tax	Allocation/ Reconciliation
Austria	kWh-fixed		kW based fixed fee + kWh	kW	kWh	Synthetic profiles, Consumers > 100MWh metered
Netherlands	kWh-fixed, TOU	Net metering over a year maximized to consumption	kW_{max}	kW_{max}	kWh; with >0 base	Synthetic profiles
Switzerland	At least 70% kWh	No tariff, generator carries costs for connecting line to distribution network	30% kWh (total consumption) 70% kWmax	30% kwh (total consumption) 70% kWmax (effectively drawn)	KWh;	Consumers >100MWh measured via digital meters, consumers <100MWh measured up to 4 times year with Ferraris meters
Sweden	kWh	No tariff	kW based fixed fee + kWh	kW geographically based	kWh	
United States	kWh fixed TOU, CPC, PTR, Variable Peak Pricing	Net metering rate depends on state, retail rate, wholesale rate, value of solar rate	Per customer charges, kW, kW_{max}	kW, kW_{max}	Tariff dependent	
India	kWh + fixed , slab, ToU	Net metering	kW based fixed fee + kWh		Fixed percentage of total bill	

The cost structure could be a major driver for implementing a certain DR scheme. In the Dutch situation, due to the maximum capacity based tariff, the bill for distribution of electricity is the same for >99 % of the residential customers; allocation and reconciliation take place on synthetic profiles characterized for a small number of customer types. For enabling demand flexibility to be used by the grid operators, time dependent distribution tariffs would be needed as an incentive. Furthermore, the current net (over a year) PV metering scheme in the Netherlands does not incentivize using flexibility to achieve self-consumption, leading to a flattened load-distribution curve, as the grid can be used as a buffer without any additional cost. As such the end-customer tariff structure to a large extent determines the viability of flexibility business models.

1.2.3 Automation of the use of demand and supply flexibility

Generally speaking, especially on the longer term, customers are very reluctant to becoming an energy manager on a day-to-day basis and having to react upon tariff signals. Therefore, demand response automation is an important pre-requisite for successful deployment. Depending on the type of electricity consuming or producing process supported by the device and the contracts/tariff, automation can be achieved with hardware-architectures ranging from simple time switches connected to wall sockets, via local home energy management systems (possibly connected a communication enabled meter), to systems communicating either in a unidirectional or bidirectional way. Individual responsive distributed DF resources are built for integration and optimization locally.

Controlling electricity demand and supply devices from one customer is rarely interesting for a market player or a grid operator. Coordinating a larger "cluster" of devices or customers is more attractive. With increasing numbers of installations and devices, and with the advance of ICT technology - especially connected networked devices – the opportunity for central coordination will evolve. Figure 1-3 illustrates the automation layers for demand and supply management systems. Apart from the tightly coupled real-time SCADA-layer, used by grid operators, to monitor and control their equipment traditionally up to the MV-level, now more and more interest appears for coordination at the LV-level. Additional software application layers at the large generation and demand level (order of MW) are already in place using non-dedicated grid infrastructure components exerting influence on demand and supply.

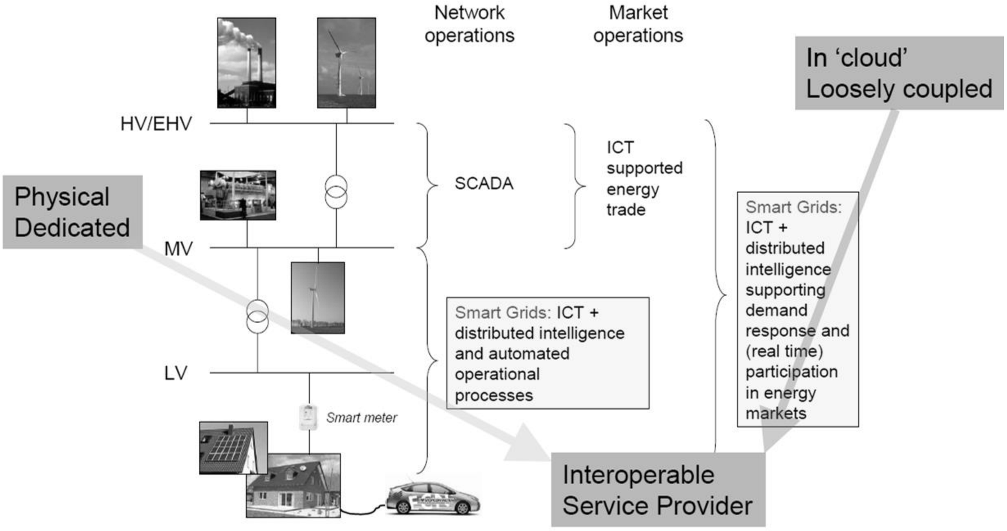


Figure 1-3 ICT and Automation layers influencing demand and supply for market and network operation

These automation layers operated by aggregation service providers now also find their way to the segments containing smaller customers. These layers enable active, automated market participation. Figure 1-4illustrates the possible interaction mechanisms between customer demand and supply and electricity system.

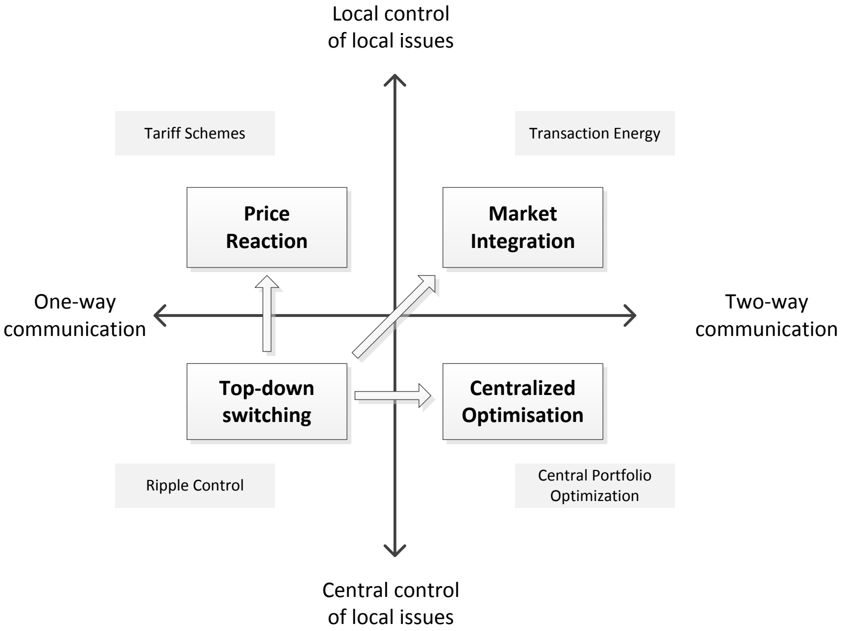


Figure 1-4: Demand Response evolution chart [13]

The picture shows the communication directionality on the X-axis and the decision making level at the Y-axis.

- On the lower left axis the grid operator managed ripple control can be seen. A frequency signal is sent superposed on the 50/60 Hz power frequency. Traditional application of this technique is switching off thermal loads for peak shaving. Ripple control is mostly used in vertically integrated utility operations. Also in curtailment schemes for PV, unidirectional signals are sent to customers that they have to facilitate. In liberalized electricity markets this mechanism is very difficult to apply because of the conflict of interest between commercial operation and grid operation. Also a guaranteed response and reconciliation of the response is cumbersome.
- On the upper left part, price reactive systems are plotted. Mostly time-varying tariffs are broadcast and automation systems locally adapt the demand or supply of electricity. Tariff schemes mostly used are TOU (time-of-use), RTP (real-time price), PTR (peak tariff rebate) or CPC (critical peak price). The highest and most persistent effect is reached if the response can be automated.
- The lower right part uses two-way communication to exert an optimal control scheme based on centralized decision making. Operating physical grids using SCADA e.g. via IEC-61850 and commercial portfolio optimization are examples of applying this scheme.
- On the upper right, with two-way communication and local decision making, customer electricity demand and supply control systems can interact in real-time and bi-directionally with external systems. In the larger generator/demand segment, real market integration by aggregation as part of portfolio of a BRP (balance responsible party) already is common. Also in the small customer segment, local aggregation is necessary for MV/LV distribution system services and is operated by a service provider. Further, location-sensitive aggregation is done by a service provider for wholesale market integration. In this way, the market power increases because the volume offered is appropriate for wholesale transactions and the central coordination leaves the individual control of the primary processes mostly unaffected. For example, within the U.S. GridWise® initiative, the transactive energy concept is currently under development as an approach to achieve market integration on all levels.

Aggregation of smart energy systems typically will happen at the application logical level of DSOs and BRPs and technically at the level of energy service providers and aggregators.

A number of new technological developments and architectural concepts are currently facilitating the development of distributed smart energy systems.

- Virtualization and cloud computing. Computing intelligence is no longer implemented in local hardware and software, but the local ICT hardware footprint is diminished in favor of centrally manageable Web-enabled ‘cloud’ solutions. Specific devices like the NEST-thermostat or an NGENIC heat pump interface simple tap a very limited number of signals like ambient temperature and temperature setpoint from the installation and transmit only the values of these signals via a tiny Webserver. The application/appliance optimization intelligence is remote. In this way a non-intrusive, loosely coupled way is created.
- Extension of the capabilities of telecomm networks/LTE. Wireless connectivity speed and ease of implementation closes the gap to wired networks. This means for DR applications new wires no longer have to be laid. In the EU reserving a part of the high-frequency radio spectrum for critical infrastructures as for instance the power system is currently being considered.

- Development of the “Internet of things”. IP connectivity and computing intelligence is possible at very small footprints.

Centralized control by aggregation of units has the disadvantage to expose a single point of failure (or attack). Approaches to introduce a networked, cloud based control are currently the focus of research and promise to overcome the mentioned disadvantages [14], [15].

1.2.4 The electricity sector common ICT architectural perspective

In ICT system development, going from the macroscopic stakeholder application logics to the device specific primary process of the electricity generating or consuming device, a number of layers have to be traversed. Use cases for demand flexibility are currently finding their way into international standardization efforts and frameworks in the utility sector.

In a number of business areas, since the 90s, architecture frameworks have been designed, that facilitate interoperability between utility business processes. In the US, NIST has developed a framework for standards to be used for the smart grid. In the EU the SGAM (Smart Grid Architectural Model) has been defined by CENELEC-ETSI (see Figure 1-5) [16]. SGAM discriminates business, function, information, communication and component layers in realizing ICT applications. This architectural model now is in the process of being further developed by collecting a database of use cases. Once the whole architectural model is in place, it is possible to build DR, DER and EES applications. The SGAM model helps in having a common interoperability framework for use cases in the smart grid domain**.**

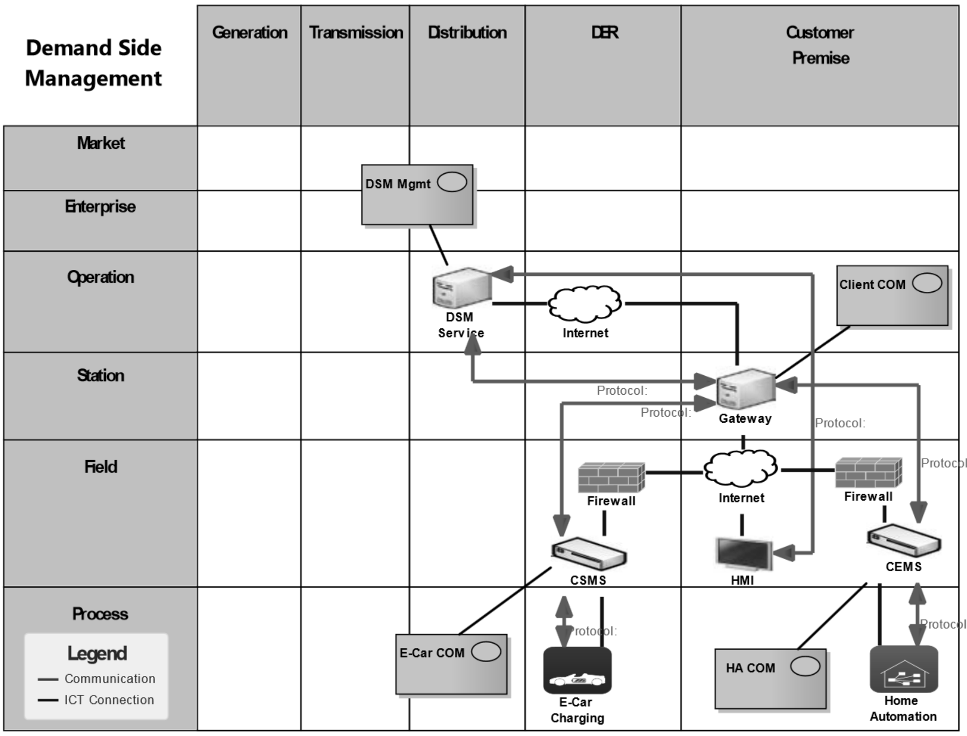


Figure 1-5 Example of SGAM [16] based architecture for DSM [17]

1.3 Policy Influences

The introduction of Information and Communications Technology (ICT)-enabled meters for retail consumers not only increases the possibility for consumer/prosumer feedback with electric system operations, but also allows for actively monitoring electricity usage and production by stakeholders to enhance overall system operation from a market and electricity distribution point-of-view. Instead of restricting retail customers to an energy consumption-coupled role, where they receive one overall yearly bill based on a fixed tariff, a smart meter can enable more direct exposure of the customer to the time-variable value of electricity in the commercial electricity market. With these economic signals, value creation as an asset in the operation of the physical grid infrastructure becomes possible.

EU Policy and Directives supporting DR

The Energy Efficiency Directive [18], Article 15.8 (energy transformation, transmission and distribution) emphasizes the strong support for DR and states the interaction of regulators and TSOs to pave the way for consumers' access to markets by means of DR programs. It explicitly stipulates the installation of service providers such as aggregators as a way to increase and establish market power. Furthermore, Network Codes (NC) being developed by the ENTSO-E, cover a part of the use cases for which demand side management can be used. The NC on demand connection (DCC) explicitly set forth rules for demand to be active on the transmission level for different purposes. Also the electricity market regulators (CEER) in 2104 attributed a large role to demand response in the future electricity grid.

European Commission's activities

The Smart Grids Task Force (SGTF) was set up by European Commission's Directorate-General for Energy in January 2010. It brings together under joint ENER/CNECT's chairmanship seven other Commission DGs (CLIMA, ENTR, ENV, GROW, JUST, JRC and RTD) and about 30 European organisations representing all relevant stakeholders on the Smart Grid arena, from both the ICT and energy sectors. SGTF was built taking into account previous Commission's initiatives such as the European Electricity Grids Initiative (EEGI) and the European Technology Platform for Smart Grids. The mission of the SGTF is to advise the Commission on policy and regulatory framework at European level to co-ordinate the first steps towards the implementation of Smart Grids under the provision of the Third Energy Package. The SGTF-EG3 is designed to provide a joint regulatory and commercial vision and recommendations for the deployment of Smart Grids taking into account accumulated experiences worldwide and the technological challenges to be faced mainly during next decade/s.

In 2015 the SGTF-EG3 published a report on "Regulatory Recommendations for the Deployment of Flexibility" [2] and an annex with refinements of the recommendations.
The report cover:

- Flexibility
- Regulatory and Commercial arrangements
- Incentives and
- Recommendations

and focuses on flexibility from distributed resources, including demand side participation, and seeks to identify flexibility services, relevant value chains, but also the necessary commercial and market arrangements, while it answers the question on how different actors can be incentivized to provide and use flexibility.

In the end 2014 concrete recommendations are provided to the European Commission, to policy makers and stakeholders, for removing regulatory barriers and incentivizing the uptake of flexibility from distributed resources.

R #1: Assess the Flexibility Potential and maximize the value of flexibility
R #2: Equal access to Electricity Markets
R #3: Contractual arrangements
R #4: Financial adjustment mechanisms
R #5: Definition of Balance Responsibility in a connection
R #6: Standardized measurement methodology for flexibility
R #7: Timely access to data while ensuring consumer privacy
R #8: Clear framework for domestic customers
R #9: Communication & coordination for secure grid operation
R #10: Open and interoperable standards for interfaces
R #11: Secure communication infrastructure and services & utility-telco synergies
R #12: Incentivize grid operators to enable and use flexibility
R #13: Improve price signals to incentivize consumers’ response
R #14: Smart appliances for end users

The aim should be to ensure the equal access of demand side to electricity markets, and equal treatment of all relevant actors. The existing market model should allow the integration of new actors under necessary commercial arrangements and adjustment of rules. Network operators should be incentivized to enable and use flexibility in order to optimize grid operation and investments, while further collaboration between TSOs and DSOs for secure operation, is necessary. Transparent and non-discriminatory provision of data from data managers to relevant service providers should be guaranteed, in order to support the development of new products and competition in the market. Finally, a clear framework and necessary protections for domestic customers should be in place, while end-user prices and consumers' policies should incentivize consumers' participation and rewards in providing flexibility.

European State specific perspectives

Austrian perspective

Decreasing electricity prices (partly due to renewables) conventional power generation become more and more unprofitable and new investments are deferred. These capacities will be needed in future to backup renewables; therefore capacity markets are discussed as a potential solution. Capacity markets can be facilitated to finance conventional generators for backup in case generation renewable is not sufficient. As a supplementary approaches demand side flexibility can be seen, to reduce the necessary additional installed backup power.

In 2014 several amendments have been made to regulation, which now allows for aggregating smaller units (pooling) and pre-qualification for balancing market participation of aggregators is now possible. Bilateral agreements with the BRP have to been arranged, which are still seen as barriers for the entering the market [19], [20].

Dutch perspective

In the Netherlands no special demand response promoting legislation is present. For PV-systems, net metering over a year is continued for accounting PV system production with load until 2020. If the production is not larger than the demand, there is no incentive for local storage of electricity at a retail customer site. In some trials experimental legislation space has been created to allow mutual power delivery and net metering at the community level. Another practical barrier is the artefact that a location with one EAN-code is not allowed to have more than one meter. Communicating meters are not mandatory, but it is the standard replacement procedure to exchange with communicating meters connected mostly by GPRS.

EV investments are heavily promoted by subsidies on the investment but also on the operational costs. Together with the short distances in a densely populated country this has led to the largest EV-penetration rate in Europe. Heat pumps are well valuated as part of the building performance indicator that has to reach a certain prescribed value in order to get a building permit. Currently, there is a discussion on how to create the opportunity to allow retail customers to get out of their synthetic, statistically averaged profiles and instead be allocated and reconciled based on their metered profile. In this way, a direct relation would be possible between purchase and selling of electricity and also self-consumption could be planned and optimized. For retailers new products would be available to escape the ‘commodity-trap’.

The Swiss perspective

Switzerland is not part of the EU. Hence, EU legislation as well as the network codes, specifically the Demand Connection Code (DCC) or the Capacity Allocation and Congestion Management (CACM) code are not automatically adopted and applied. Furthermore, the codes include a clause that explicitly denies the inclusion of non-member states. The framework and rules for utilization of demand side management in Switzerland are dominated by national regulations. The regulations do, however, take European legislation and technical concepts into account. Currently, the law on electricity supply does not explicitly cover the topic of demand side management. This is specifically due to the idea of subsidiarity, which is extensively lived and an important principle in Switzerland. Therefore, the electricity law only sets general guidelines for network operators such as to plan and operate the network in order to keep it efficient, powerful and secure. The ordinance regulates in more detail among other things the tasks of the regulator Electricity Commission (ElCom), the general network regulation, the accountable costs, the weighted average cost of capital for the network operators asset base, etc. Also, no further regulation of demand side management is found here.

Rules for operation, accounting, data exchange, etc. are developed in more detail by enterprises which are involved in the power supply sector, i.e. network operators, producers and other stakeholders. They are organized in an association open to anyone which is interested and involved in the electricity supply sector. Concerning demand side management, rules were being developed by this association and the TSO in 2013. The rules developed define the way how small production and specifically smaller demand side units can be aggregated and marketed on the ancillary services markets of the TSO and how the provision of these services is measured and accounted. Such marketing can be done by any party active on electricity markets.

Until these rules have been set about 90% of smaller demand side units on the consumer level - such as boilers - were widely controlled by distribution system operators using a ripple control. The units were controlled in a network friendly manor, i.e. the control is used to reduced peak demand and tariffs of higher network levels. The right to control the resources is based on rules of the Swiss distribution code. Formerly, the right to control the flexibility was therefore exclusively given dor network operators. The new rules set forth clearly define that stability of the distribution network is not to be jeopardized. Hence, all control devices utilized by market player can be overruled by the ripple control of distribution system operators. However, in practice the coordination between a network related use and a more market driven operation remains partly unsolved. Often market barriers can be tentatively detected.

Currently, the first package of the Energy Strategy 2050 is being discussed in the Swiss parliament. Amongst the main principles to replace nuclear with renewable sources like photovoltaic and wind and to increase energy efficiency, the electricity supply law may contain changes which aim at a better facilitation of demand side management in Switzerland. First, a regulation is being suggested to introduce smart meters and second, rules and frameworks for the use and coordination of intelligent control devices for consumers, producers and storages may be set. The idea is to have the opportunity to design clear guidelines on how coordination between network related controls (ripple control) and market related controls, e.g. DSM for ancillary services, can efficiently coexist.

US legislative directives supporting DR

When Congress enacted the Energy Independence and Security Act of 2007 (EISA), it directed the Federal Energy Regulatory Commission (FERC or Commission), an independent regulatory commission, to develop a National Action Plan that 1) identifies the requirements for technical assistance to states to allow them to maximize the amount of demand response that can be developed and deployed; 2) designs and identifies requirements for implementation of a national communications program that includes broad-based customer education and support; and 3) develops or identifies analytical tools, information, model regulatory provisions, model contracts, and other support materials for use by customers, states, utilities, and demand response providers.

In July 2011, FERC and the Department of Energy (DOE) jointly submitted to Congress a required “Implementation Proposal for The National Action Plan on Demand Response” [21]. The Implementation Proposal is for FERC’s June 2010 National Action Plan for Demand Response [22]. Part of the July 2011 Implementation Proposal called for a “National Forum” on demand response [23] to be conducted by DOE and FERC. DOE provided a large boost to demand response through the American Recovery and Reinvestment Act’s $4 billion of federal funds from DOE in the Smart Grid Investment Grant and Smart Grid Demonstration programs. In 2016, FERC Order 745 on incorporating demand response in wholesale markets was upheld by the Supreme Court, providing regional structures for aggregating DR according to markets that cross state boundaries.

Using DER for grid services still mostly falls to state policy decisions. California, Hawaii, and New York are examples of states who are actively perusing demand response policies. For example, in September, 2014 California enacted Senate Bill 1414 that accelerates the use of demand response. The Public Utilities Commission was given clear direction to consider demand response, not just fossil fuel investments, in planning how to balance and ensure reliability for the state’s power grid. The Bill requires, as part of resource adequacy planning (CA’s equivalent to i), establishing new or maintaining existing demand response products and tariffs. This requires the PUC to ensure appropriate valuation of both supply and load modifying demand response

[24]. Also, California PUC Docket 13-09-011 deals with demand response and AMI. It seeks to enhance the role of demand response in meeting California's resource planning needs and operational requirements through instituting a Demand Response Auction Mechanism (DRAM). In January 2016, saw the state's first auction to consider demand response as a capacity resource, with utilities acquiring more than 40 MW from a wide range of vendors. The state's DRAM was designed to allow a diverse mix of bidders from customer battery storage to electric vehicles to participants in wholesale markets for demand management as long as they could amass 100 kW of energy reduction [25].

1.4 Document Structure

This document derives DR and DG specific requirements in households, communities, functional (office) buildings and industrial processes from the micro and macro perspective. The macro perspective includes power distribution (link to telemetry, SCADA) and commercial operation (market, smart meter). An important aspect of this setup is the virtual aggregation and service provisioning. The strengths and weaknesses of ICT enabled aggregations of flexible demand and controllable DERs in the form of energy communities are evaluated. From general use cases, describing specific customer roles and interactions, potentials and technical implementations will be discussed.

2 Power System Actors and Roles regarding Flexibility

Flexibility can be used for several use cases like balancing, optimizing of the trading costs and minimizing costs from the imbalance settlement, whereby these use cases can be associated with different roles/actors. However, when using the flexibility for one use case several other actors may be influenced by this activation either positively or negatively. This interdependency is one main reason for the complexity of the flexibility valuation.

In the electricity market role model from ENTSO-E [26] the different roles are associated with one actor, hence, the number of actors equal the number of roles. In this document, the roles are assigned with the actor that typically is responsible for these roles.

2.1 General Definitions

The aim to analyze the actors, roles and domains is to analyze the underlying transactions. The definitions from the ENTSO-E market role model [26] are used.

The objective of decomposing the electricity market into a set of autonomous roles and domains is to enable the construction of business processes where the relevant role participates to satisfy a specific transaction.

Actor represents a party that participates in a business transaction. Within a given business transaction, an actor assumes a specific role or a set of roles. An actor is a composition of one or more roles and as such does not appear in the harmonized role model.

Role represents the external intended behavior of a party. Parties cannot share a role. Businesses carry out their activities by performing roles, e.g. system operator, trader. Roles describe external business interactions with other parties in relation to the goal of a given business transaction. A role must be able to stand alone within the model. In other words it must represent a relatively autonomous function. Business processes should be designed to satisfy the requirements of the roles and not of the parties.

Domain represents a delimited area that is uniquely identified for a specific purpose and where energy consumption, production or trade may be determined.

Service/Transaction is offered/conducted by a role. The value of a service can be either quantitative or qualitatively.

Value stream originates from lean-management principles. The association for operations management (APICS) defines it as “the process of creating, producing and delivering a good or service to the market”. A few examples of services that may be delivered by flexible producers and consumers include congestion management, voltage regulation, frequency regulation, portfolio management and others. The application of these services varies as they aim at fulfilling different purposes. Each service has its own set of characteristics, which shape their value stream. A particular service may itself present differences in value stream as it may be targeted at different markets, e.g., the financial or physical power market. Understanding the application dependency of value streams and the purpose of the service is important when performing a cost-benefit analysis.

2.2 Definitions of Actors

Actors are persons/units that fulfill one or more roles in the balancing market. In this chapter, actors will be defined in general. In chapter 2.3, roles and their respective services will be defined. Finally, in chapter 2.4, actors will be associated with their respective role(s) and country-specific differences will be presented in chapter 2.5.

2.2.1 Transmission System Operator (TSO)

The transmission and distribution system operator (grid access operator) are responsible for the provision of infrastructure and information, the operation of the grid and is responsible for the commercial handling of e.g. the procurement of grid losses, etc. Both actors are defined in the Directive 2009/72/EC [27].

The transmission system operator (TSO) can be defined as by ENTSO-E [28]:

> *“Transmission System Operators (TSOs) are responsible for the bulk transmission of electric power on the main high voltage electric networks. TSOs provide grid access to the electricity market players (i. e., generating companies, traders, suppliers, distributors, and directly connected customers) according to non-discriminatory and transparent rules. In the liberalized market context, transmission is the point of interaction for the various players. To ensure security of supply, TSOs also guarantee safe operation, maintenance, and planning of the system. In many countries, TSOs are in charge of the development of the grid infrastructure, too. TSOs in the European Union internal electricity market are entities operating independently from the other electricity market players (unbundling).”*

TSOs in some countries (B, NL, D, SE) also operate a number of markets related to balancing supply and demand; in other countries (UK, US) this is done by an independent party, an ISO. These entities ensure that before the day of actual operation, the forecasted demand will be met by the forecasted supply or import / export in accordance to schedules, which were handed in before. In most current market models TSOs do not have direct contracts with small customers; TSOs are accounted by a time dependent power based transport tariff. It is most likely that end-user response will be delivered as services provided by means of aggregated units from an aggregator or flexibility provider.

2.2.2 Distribution System Operator (DSO)

The DSO is defined in Directive 2009/72/EC:

> *“Distribution system operator means a natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity.”* [27]

DNO operations are indirectly contracted via a retailer or provided as a service at a connection capacity based tariff. The DNO role can be fulfilled by any party owning a distribution infrastructure. From an investment perspective, DNOs strive to improve asset utilization (ideally to have a flat load-duration curve with a fixed, stable load during the day and the night though this is hard to achieve in reality). In the evolution to a smarter electricity grid, DNOs, operating networks in an asset/CAPEX based manner, are expected to evolve to DSOs, operating systems interacting with other stakeholders also having OPEX in their business models. End customers may have difficulties to distinguish between retailer and the DSO they are connected to. Customer behavior or more precisely their energy consumption profile or pattern effect the network operation mainly, particular in residential areas. Depending on the settlement structure, urban vs. rural, loads of a network consist of a couple of buildings with many flats or up to 150-200 small houses. This makes it different for enabling flexibility as an aggregator from end-customers or from building operators (HVAC systems of functional buildings). DSO operations are driven by a long-term view on the management of their investments in assets. DNOs and DSOs operations are mostly accounted for on a peak capacity power based tariff. When going to a more energy system related function accounting on energy will also be part of the tariff.

2.2.3 Independent Aggregator

In future smart grids, the share of volatile and distributed generation is expected to expand. Therefore, local grid utilization is also expected to grow which makes it difficult to keep the system in balance. New market mechanisms are therefore needed. Smaller distributed generation plants will be able to contribute to system balance by only feeding in parts of their available power in the grid in times of high use. On the other hand, they will be able to sign contracts with virtual power plants (VPPs). In this concept, a new actor, the independent aggregator, is needed. Its aim is to be the coordinator between market and grid. [29]

The independent aggregator as the enabler of demand response is defined in [30]:

> *“European and international experience over the past decade demonstrates that competition around consumer centred aggregation services is the key enabler of investment and growth in demand response. These services can be provided either by an independent aggregator or a retailer, but it is important that these services can focus on the consumer’s willingness and ability to sell the value of his flexibility and can be unbundled from the sale of electricity. […] Competition between the retailer and the aggregator allows for the growth of a robust, competitive, demand response service industry and is a key component of a consumer centric electricity market. It is therefore critical that market regulations create clear roles and responsibilities between players, allowing consumers’ free choice over their demand response service provider, including the possibility to sell their flexibility through independent aggregators and retailers, offering dedicated demand response services. Without this, market competition does not grow and few services are developed.”*

The independent aggregator may sometimes be called flexibility operator, which is defined in [31]:

> *“A new role, the flexibility operator (FlexOp), can put incentives or requests to start economically based mechanisms to keep the grid in a stable and reliable condition, as well as to minimize the economic loss for flexibility providers. The balance of these two aspects is a central topic of the concept.”*

Flexibility platform provider provides the distributed information system communication facilities and interaction framework to a flexibility provider. It enables the aggregation of demand and production units, typically of small scale, into one unit of reasonable scale, large enough to participate in markets. Once the units are integrated in the information platform and can be controlled, the production is called a virtual power plant (VPP).

Flexibility service provider operates and coordinates distributed, small scale demand and supply units by using the flexibility platform. The flexibility provider actually schedules, i.e. uses, the distributed units to meet certain goals, such as minimizing schedule errors or relieving transmission or distribution grids from congestions.

Country examples:

In the Netherlands, as a test in the Hoogdalem pilot [32], distribution companies are allowed to give a fee for using heat pumps within a certain power bandwidth next to their capacity based tariff. Generally, aggregators are mainly operating in the industrial and commercial sector, because of small profit margins and other barriers. Some are successful with aggregating and contracting flexibility on the small consumer levels:

- A number of aggregators exist in the US. They are currently marketing a number of products to give further contours to the aggregator role.
- A number of aggregators are active in Germany. Often, the aggregate small scale back-up generation plants for tertiary control reserves. Recently, they begin to be active on secondary control reserve markets as well.
- Also in France, several aggregators are active on primary, secondary and tertiary control markets. Electric heating is used to avoid peak load in winter. Following the GreenLys [33] pilot, new tariff schemes are operational here. Another aggregator currently coming up in France aggregates electrical heater demands to the French primary reserve market.
- There are currently a number of aggregators active in Switzerland. While many companies, which have technological background in virtual power plants, offer white label products to utilities in order to aggregate load and small scale generators there are also independent aggregators. The biggest independent aggregator – in terms of the number of contracted loads – aggregates and controls several thousand heatpumps and smaller controllable loads for TSO secondary and tertiary control reserve markets.

2.2.4 Supplier, Retailer, Traders

Suppliers or Retailers are the usual contractors for residential customers to buy and sell electrical energy. The difference of the net energy price from the price on the total energy bill can differ from 20% to 50% according to the country and electricity generation situation.

The electricity, which will be consumed, is bought on the markets typically directly by retailers or by traders. Traders manage generation plants as well the acquisition of demand for the retailer. Traders, retailers as well as generators, are organized in balance groups managed by a balance responsible party (BRP). In some cases or countries there happens to be a consolidated end-user pooling which participates on behalf of small consumers.

Sometimes, suppliers may also be identified with energy service companies (ESCo). They are defined in [34]:

> *"An ESCO is a company that offers energy services which may include implementing energy-efficiency projects (and also renewable energy projects) and in many case on a turn-key basis. The three main characteristics of an ESCO are:*
>
> - *ESCOs guarantee energy savings and/or provision of the same level of energy service at lower cost. A performance guarantee can take several forms. It can revolve around the actual flow of energy savings from a project, can stipulate that the energy savings will be sufficient to repay monthly debt service costs, or that the same level of energy service is provided for less money.*

> - *The remuneration of ESCOs is directly tied to the energy savings achieved;*
> - *ESCOs can finance, or assist in arranging financing for the operation of an energy system by providing a savings guarantee.*
>
> *Therefore ESCOs accept some degree of risk for the achievement of improved energy efficiency in a user's facility and have their payment for the services delivered based (either in whole or at least in part) on the achievement of those energy efficiency improvements*."

2.2.5 Regulatory Authority

A detailed description of the regulatory authority in European energy markets, its power and duties, is given in Directive 2009/72/EC [27]. It is stated that each member state has to designate one independent (from other public/private entity) national regulatory authority (NRA). The objective of regulatory authorities is to develop competitive regional markets. Furthermore, a market opening and finally a competitive, environmentally sustainable and secure internal energy market should be achieved by national regulatory authorities between the member states. Therefore, transmission capacity needs to be expanded. Regarding demand response, the most important task of NRAs is

> *"helping to achieve, in the most cost-effective way, the development of secure, reliable and efficient non-discriminatory systems that are consumer oriented, and promoting system adequacy and, in line with general energy policy objectives, energy efficiency as well as the integration of large and small scale production of electricity from renewable energy sources and distributed generation in both transmission and distribution networks."* [27]

To achieve this goal, grid access has to be facilitated. NRAs have to identify possible barriers that could prevent access of new market participants or electricity gained from renewable resources [27].

2.2.6 Society – the Customer

In the "traditional energy market", society is a rather passive actor. As customers gain more and more possibilities to participate to the energy market (e.g. due to demand response) in modern smart grid systems, the roles that are associated with this actor will change in the future. Society then consists of consumers and prosumers.

Customers in general (consumers, prosumers) have a wide range of interests and expectance patterns regarding energy monitoring and energy costs. From a decision making and marketing perspective, consumers can be subdivided according to their decision styles [35] (hierarchic, integrative, decisive, flexible, single/multiple focus) in buying energy services (Figure 2-1).

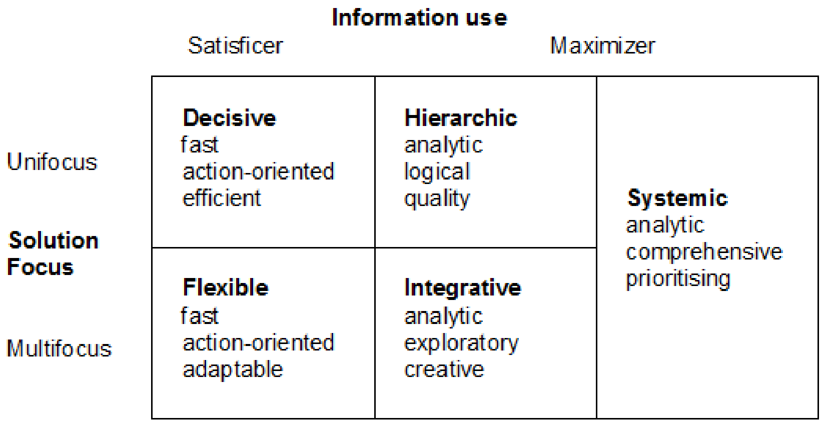


Figure 2-1 Decision style partitioning [35]

According to the decision style theory, the styles are attracted to different satisfaction variables, which mean that they value these primarily. The following combinations show what they prefer:

- Best Quality (Hierarchic)
- Great Deal (Integrative)
- Most Innovative (Integrative)
- Speed/response (Decisive)
- Flexibility of offers and time frames (Decisive/Flexible)
- Participation in Design/Production (Integrative)
- Simple Solutions (Decisive/Hierarchic)
- Complex Options (Flexible/Integrative)
- Extended Offers (Flexible/Integrative)

So, in the usage of energy services, taking care of these styles facilitates interaction. Customers pay for the electricity they have used and the use of the electricity system infrastructure via kWh- and kW-tariffs. kWh and kW based tariffs can be time-dependent, fixed per time-slot or varying in real-time. kWh real-time tariffs can be dependent on the current spot or day-ahead market price. kWh real-time tariffs try to map the real cost of energy to the end-consumer. kW real-time tariffs typically follow the load or generation pattern in a physical distribution area. Demand response via kW tariffs tries to achieve a flat load-duration curve. Maximum kW penalties are also used on top of kWh-tariffs as an indirect incentive.

Prosumers:

Consumers with their own generation unit (e.g., roof top PV system) can provide or feed-in energy in times of low internal consumption. Different ways for compensation exist, such as excess infeed or separate infeed remuneration funding regimes. For different European countries, infeed is accounted for by an infeed subsidy larger than the kWh-tariff via net metering over a year up to having to pay a penalty per kWh or kW. In some countries, such as Germany, the utility company for the PV-panels and the utility company for the household demand are different and have their own metering infrastructures. In case of excess infeed, it sometimes is more profitable for the prosumer to use the generated energy locally (increase self-consumption coverage), which fosters the use of shiftable demand or home storage systems.

2.2.7 System integrators / Technology providers

Success of DR is also strongly technology and innovation dependent. Vendors and providers of connecting and controlling devices need to invest into research and development to provide appropriate solutions. Especially cost-effectiveness and benefit for consumers need to be target. Competition in the consumer electronic and smart home sector is very high and development initiatives are of high risk.

2.3 Definition of Roles and Services

The ebix [36] and SGAM [16] define detailed role and domain models for the electricity sector. In this model apart from energy and capacity, flexibility services in the form of energy or capacity reserve are also subject to trading and are added to the responsibilities of actors.

An overview of “roles and relations in the market” can be found in the SWECO-study made for the EU in 2014 [37] and in the ebix electricity sector role model [36]. The model is reproduced in Figure 1-5 as a UML use case/class diagram. The diagram describes the relations, roles and interactions in power system operation. The upper part of the picture indicates the bare associations and inheritance relations for reference. In the lower part of the figure, the 8 categories of activities exerted in the operation of power systems are indicated. The roles and activities include:

1. Connected parties: There is no distinction in size or location of generation or consumption. The role model defines the Party connected to the Grid, which is subtyped by the Consumer and Producer roles.
2. Grid access provisioning and operations: In this category the main domains and roles distinguished are the Metering grid area and the Grid Operator and Grid Access Provider. The distinction between grid operations and providing access to the grid allows mapping these responsibilities in various ways to support modelling national legislations, e.g. a supplier which has the responsibility to provide access to the grid and act as a single desk for the Party connected to the Grid.
3. Balance responsibilities: The model distinguishes a number of roles related to balancing responsibility on a PTU basis; the difference between parties responsible for firm energy contracts and those which are responsible for non-firm energy contracts, i.e. the actual consumption and production minus what has been sold under firm contracts.
4. Market operations: This category contains all roles and domains related to (wholesale) markets. The most important are the market balance area and the market operator. Note that depending on the specific legislation, the market operator role may be allocated to different parties (e.g. combined with the System Operator as in the Netherlands or an instantiated as a separate party as in the UK).
5. System operations: The roles and domains in this category relate to the system operations and define a structure of domains for system control on the transmission (TSO) and the distribution (DSO)-level.
6. Reserve power coordination: The elements of this category relate the reservation of capacity used for balancing the system on the intra-PTU level; this does not include the actual control of reserve resources; this falls in the balance responsibilities and system operations categories.

7. Metering: A large number of roles are distinguished related to e.g. Metering Points and Registers. This category includes the definition of domains which relate to points in the grid which are metered.
8. System level settlement: The responsibilities for the reconciliation and settlement on the system level of energy transactions fall in this category. Settlement and reconciliation typically take place within 8 days.

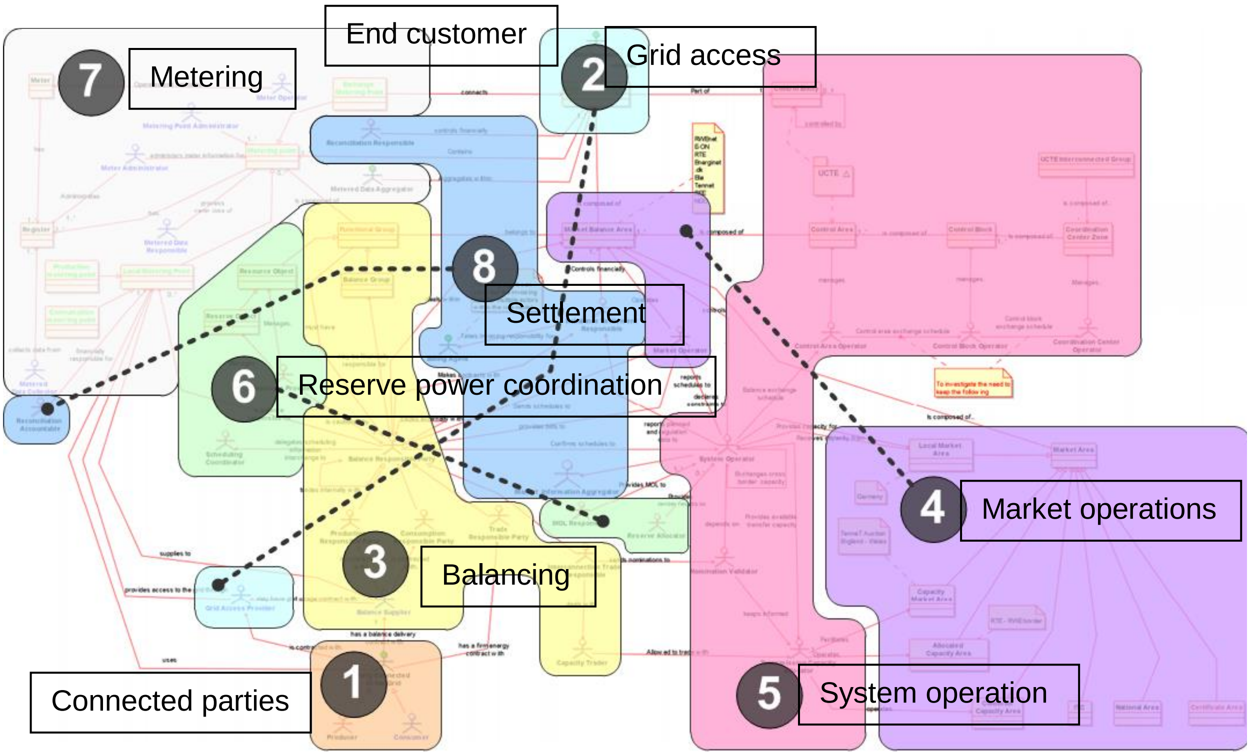


Figure 2-2 Sectoral use case diagram and activity area partitioning

To enable flexibility on the consumer side and effectively integrate it to markets, roles and interactions are changing. The impact of new responsibilities on the different roles will most likely evolve as described below in a generic manner, where the details may vary from market regime to country or continent.
In the following chapters, roles and their associated services will be presented in more detail.

2.3.1 Balance Responsible Party (BRP)

A BRP is, according to ENTSO-E [26],

> *“A party that has a contract proving financial security and identifying balance responsibility with the imbalance settlement responsible of the market balance area entitling the party to operate in the market. This is the only role allowing a party to nominate energy on a wholesale level.”*

Or shortly:

> *“A market market-related entity or its chosen representative responsible for its imbalances.” [38]*

The BRP can be associated with two parties [26]:

- **Production responsible party**: The BRP is (financially and legally) responsible for imbalances between nominated and produced energy at each associated accounting point.
- **Consumption responsible party**: The BRP is (financially and legally) responsible for imbalances between nominated and consumed energy at each associated accounting point.

Associated services/transactions of the BRP:

- **Responsibility for schedule**: To keep their position balanced, forecasts about the expected production/generation and consumption of a BRP are necessary. The values for the (expected) consumptions lead to respective production values. Both of them need to be fixed in a schedule (that is agreed with the TSO) which the BRP is then responsible to fulfill.
- **Providing information to the system operator**: BRPs have to inform the system operator about the transactions they have planned (schedule). An imbalance means the difference of the value fixed in the schedule and the actual measured value for the transactions of a BRP. If a BRP is not in balance over the imbalance settlement time, he has to pay charges.
- **Imbalance settlement**: As consumption and production cannot be perfectly calculated/estimated, BRPs will have to face imbalances (possible in both directions) in their position. These imbalances can be compensated by imbalance settlement, where the BRP has to pay the imbalance price to restore balance (imbalance settlement is not conducted by the BRP, but it is a service in which this market party is involved as it is contracted to the imbalance settlement responsible).

2.3.2 Balancing Service Provider (BSP)

The BSP can be defined as in the network code on electricity balancing [38] as

> *“A market participant providing balancing services to its connecting TSO, or in case of the TSO-BSP model, to its contracting TSO.”*

The BSP corresponds to the role of the balance supplier, which is defined by ENTSO-E:

> *“[The balance supplier is] a party that markets the difference between actual metered energy consumption and the energy bought with firm energy contracts by the party connected to the grid. In addition, the balance supplier markets any difference with the firm energy contract (of the party connected to the grid) and the metered production.”* [26]

Associated services/transactions of the BSP:

- **Providing balancing services:** BSPs’ balancing energy bids are assigned directly to units of one or more BRPs. In case of imbalances in a BRP’s position, the market operator decides which of the bids are activated. Furthermore, market and system operator set the prequalification criteria and rules for becoming a BSP. A BSP has to provide relevant data to its connecting (or contracting) TSO.

2.3.3 Grid Operator

Parties that are responsible for operating one or more grids are called grid operators. These parties are responsible for grid losses in most countries (in some countries, this is the suppliers' responsibility).

Associated services/transactions of the grid operator:
- **Grid maintenance and expansion:** The focus of the grid operator is on maintaining its grid on the long using planning methods and system analysis. Investments have to be made to expand the grid while keeping it secure in operation. [39]
- **Data exchange:** For the expansion of a grid, an advanced information exchange between TSOs (on national and international level), DSOs, large consumers and producers is necessary. This data exchange is also prerequisite to ensure that a network is technically compatible with another one (by defining connection requirements). [39]

2.3.4 Grid Access Provider

The grid access provider is defined in [26] as

> *"A party responsible for providing access to the grid through an accounting point and its use for energy consumption or production to the party connected to the grid."*

Associated services/transactions of the grid access provider:
The role of the grid access provider can be seen in two ways: On the one hand, grid access has to be provided in a transparent and non-discriminatory way. On the other hand, grid access has to be technically provided. These two sides of the role are reflected within the services of the grid access provider.
- **Creation of fair and equal conditions to allow grid access** to consumers and producers have to be set by the grid access provider and controlled by the regulatory authority. This service gains importance in modern smart grids as more and more distributed and small generation plants are going to be integrated to the grid. Parties connected to the grid have contracts with the grid access provider.
- **Administration and maintenance of accounting points** to allow and maintain actual grid access to parties connected to the grid have to be guaranteed by the respective TSO or DSO.

2.3.5 System Operator

The system operator is defined as

> *"A party that is responsible for a stable power system operation (including the organisation of physical balance) through a transmission grid in a geographical area. The system operator will also determine and be responsible for cross border capacity and exchanges. If necessary he may reduce allocated capacity to ensure operational stability. Transmission […] means the transport of electricity on the extra high or high voltage network with a view to its delivery to final customers or to distributors. Operation of transmission includes as well the tasks of system operation concerning its management of energy flows, reliability of the system and availability of all necessary system services. Additional obligations may be imposed through local market rules."* [26], [40]

Associated services/transactions of the system operator [39]:

- **Definition of technical criteria:** Secure system operating has to be guaranteed by the system operator. Therefore, technical requirements of the grid need to be defined.
- **Data exchange:** To make forecasts and estimations about the (global) grid situation in the following year, an intense data exchange between system operators hast to be conducted. This information exchange is prerequisite to secure system operating, as system operators have to forecast the amount of necessary transmission capacity to be available between the borders and on a national level.
- **Capacity allocation and congestion management:** The system operator has to manage the capacity allocation within an allocated capacity area. Furthermore, common procedures for possible congestions have to be implemented.
- **Maintaining balance:** If a BRP fails to fulfill his schedule, system balance between production and consumption has to be maintained by using automatic frequency control and the regulation market (DR) in the respective control area of a system operator.
- **Definition of technical prequalification:** The system operator is also responsible for setting the technical prequalification criteria for balancing energy/capacity bids.

2.3.6 Market Operator and Imbalance Settlement Responsible

The market operator is closely related to the system operator. He is defined within [26] as

> *"The unique power exchange of trades for the actual delivery of energy that receives the bids from the balance responsible parties that have a contract to bid. The market operator determines the market energy price for the market balance area after applying technical constraints from the system operator. It may also establish the price for the reconciliation within a metering grid area."*

This last function of the market operator corresponds with the role of the imbalance settlement responsible. According to [26], the imbalance settlement responsible is

> *"A party that is responsible for settlement of the difference between the contracted quantities and the realized quantities of energy products for the balance responsible parties in a market balance area."*

The "core activity/service" of the imbalance settlement responsible is defined within [39]: The imbalance settlement responsible has to "*execute the national balance settlement by setting* ***imbalance pricing*** *and* ***settlement principles*** *for imbalances and by setting routines for measuring and reporting*."

Associated services/transactions of the market operator:

- **Setting the imbalance price and principles** is a key service as imbalance settlement responsible of a balancing area. Imbalance principles include fair and transparent rules for participating in the balancing markets.
- **Reserve allocation**: The market operator has to inform the market about reserve requirements (data exchange with the system operator is prerequisite). He then receives the bids that need to comply with the prequalification criteria. Finally, he assigns the bids that meet the requirements of the market [26].
- **Determine the merit order list**: The correct order for balancing energy/reserve capacity bids has to be established and fixed in the merit-order list by the market operator so that the order of their activation is defined. This corresponds to the role of the MOL responsible of [26].

2.3.7 Data Provider

According to [26], the data provider is

> *"A party that has a mandate to provide information to other parties in the energy market. […] A data provider may be a transmission system operator or a third party agreed by a TSO.*"

Associated services/transactions of the data provider:

- **Publication of data**: The data provider has to collect relevant data from market participants and provide them to other market participants. This data may therefore be published on a public information platform. Fair and equal data access for all market participants has to be ensured. Data collection and publication needs to be conducted in a transparent way.

2.3.8 Meter Responsible

The role of the meter responsible can be identified with two parties: One is responsible for the hardware and its operation (meter operator); the other one is responsible for the collection of data (meter administrator). They are defined within [26]:

- The meter administrator is *"a party responsible for keeping a database of meters."*
- The meter operator is *"a party responsible for installing, maintaining, testing, certifying and decommissioning physical meters."*

Associated services/transactions of the meter responsible:

- **Metering point administration:** All parties linked to a metering point within a metering area need to be registered. Technical requirements of the metering point need to be maintained and new metering points need to be installed. [26]
- **Operation of meters:** This is the core service of the meter responsible regarding its function as meter operator.
- **Metering data administration:** The meter responsible has to collect and administer relevant data from meters in its respective metering area.

2.3.9 Resource Provider

The resource provider is defined as *"a role that manages a resource and provides the schedules for it, if required.* [26]*"* A resource provider can therefore be a large power plant but also a small scale distributed generation plant.

Associated services of the resource provider are:

- **Procurement of raw materials and electricity generation**: The resource provider has to procure the necessary raw materials if there is need to (exceptions are e.g. wind power plants). Then electricity is generated by using appropriate installations.
- **Maintenance of the power plant**: The resource provider has to ensure that his power plant complies with security regulations at each point of time. New technologies may have to be installed and maintenance work has to be constantly done.
- **Transfer of electricity to the grid**: The generated electricity has to be fed into the electricity grid at an accounting point.

2.3.10 Grid connected Parties

A party connected to the grid can be either a **consumer, a prosumer** or a **producer/generator** of electricity. The party connected to the grid is contracted to a grid access provider so that electricity can either be consumed or produced at an accounting point.

Associated services/transactions of producers/consumers:

- **Providing flexibility**: As soon as demand response is implemented to the grid, residential consumers have the possibility to participate in balancing energy markets by amending their consumption because of the present grid utilization. Therefore, a high level of data exchange, organized by the independent aggregator/flexibility operator, is needed. Customers can then receive signals from the aggregator and either increase or lower their present electricity consumption. For larger electricity generators or consumers, no aggregator is needed, as these parties are already able to participate in balancing markets.
- **Consummation of electricity**: Consumers have contracts with retailers in order to receive the electricity they need.
- **Electricity generation**: A party connected to the grid can also be a generator who feeds in electricity to the grid at an accounting point.

2.3.11 System Integrators / Technology Providers

Success of DR is also strongly technology and innovation dependent. Vendors and providers of connecting and controlling devices need to invest into research and development to provide appropriate solutions. Especially cost-effectiveness and benefit for consumers need to be target. Competition in the consumer electronic and smart home sector is very high and development initiatives are of high risk.

2.4 Assignment of Actors and Roles

In this chapter, it is aimed to assign roles to the respective actors of the electricity market. It has to be stated that this role assignment is not always clear, as (market) systems strongly vary in Europe and the world. Table 2-1 shows a listing of actors and roles that were presented and described in chapter 2.2 and chapter 0. A possible role assignment is displayed.

Table 2-1: Actors and their respective roles

		Actors						
		TSO	*DSO*	*Indep. Aggregator*	*Supplier*	*Society*	*Other independent market party*	*Regulatory authority*
Roles	*BRP*				x		(x)	
	BSP			x	(x)			
	Resource provider				x			
	Data provider	x						Control function
	Grid operator	x	x					Control function
	Grid access provider	x	x					Control function
	System operator	x	(x)					Control function
	Market operator and imbalance settlement responsible	(x)	(x)				(x)	Control function
	Meter responsible		(x)	x	(x)		(x)	
	Party connected to the grid			x	x	x	(x)	
	Technology Provider				(x)		(x)	

x … General role of an actor

(x)… A role that is only held by an actor in some systems / under some certain conditions

The **TSO** is generally the data provider of a system and therefore responsible for establishing a common platform for sharing market information in a transparent and non-discriminatory way. Furthermore, he acts as grid access provider for the transmission grid and as the transmission grid and system operator. Often, the TSO also holds the role of the market operator. In some countries, there are more than one TSO and so only one of them may hold the role of the market operator.

The **DSO**'s main roles are the ones of the distribution grid operator and grid access provider as he connects consumers and producers to the grid. With a low share of distributed generation, the DSO is not involved in the balancing market processes. However, with an increasing share of demand response and distributed generation, the DSO gains new roles and acquires new significance as an actor. Even the creation of new (local) markets with a high need of the DSO's participation are possible. Therefore, a high level of information exchange/interaction between TSO and DSO will be needed, which will be discussed in. In some cases, the DSO holds the role of the meter responsible (if this role is not held by the aggregator or an independent party).

The **independent aggregator** administrates the flexibility of its contracted customers/demand facilities. He is allowed to use this flexibility on the energy markets. He can therefore act as BSP and participate in the balancing market by providing its customers' flexibility to its respective TSO. Therefore, he has to send signals to its customers' entities that are then resulting in a higher or lower energy consumption. This process can mainly influence the balance state of a BRP. The resulting costs and benefits should therefore be allocated between demand facility, aggregator and BRPs in a fair way. The interaction between these market parties will therefore be treated in detail in IEA Task 17 Subtask 11 – Valuation analysis of residential demand side flexibility.

The two actors aggregator and **supplier** are not always independently of one another. A supplier can operate as an aggregator in some systems. He is then able to act as a BRP and use the aggregated flexibility to balance himself. On the other hand, he can act as BSP and provide balancing services to its respective TSO. If the aggregator acts independently from the supplier, the latter acts as BRP and aims to keep balance between the supply of its customers and its generation plants (role of the resource provider). The supplier can use power plants that fulfill the prequalification criteria to participate in the balancing markets and act as BSP. In some cases, the supplier may not act himself as BRP (and BSP) but delegate these roles to another (new) actor who then accepts the responsibility for keeping its position balanced. The supplier is responsible for the administrative aspects of electricity supply to its customers. He sets the energy price for its customers and has therefore a main influence on the success of demand response (e.g. due to flexible tariffs).

Society consists of consumers and prosumers and is therefore a party connected to the grid. Because of the flexibility that customers can provide due to DR, they are closely linked with the flexibility operator that uses their provided flexibility on the market. It is important that the resulting benefits from this cooperation are allocated in a fair way.

The **regulatory authority** holds the control function of the system and has to guarantee that the system is secure, cost-effective, customer oriented and efficient. To guarantee that RES can be implemented in the system and that each market participant can participate under equal conditions in different markets, the regulatory authority has to approve and control the decisions/rules that have been defined by grid operators, market operators and system operators.

It has to be controlled if the data provider publishes market data in a non-discriminatory and transparent way and if there are any barriers caused or not eliminated by the grid access provider that could prevent some market parties from getting access to the grid.
In some systems, several roles may not be held by the actor they are assigned to in **Table 2-1**.

Then **additional independent parties** may be commissioned with a role. Some examples are given:

- In some systems, the role of the market operator is independent from the TSO. Its functions/services and some of the functions/services of the system operator are then handled by an independent actor.
- Some suppliers engage other market parties to be their BRP. The BRP is then no longer a role but an independent actor.
- The independent aggregator might not be the meter responsible itself. This role can as well be handled by an independent market party, who then provides its data to the aggregator.
- The technology provider can be a supplier who is interested in providing its customers' flexibility on the markets and therefore make investments in technology research or an independent party (technology companies).

2.5 Country specific differences

Partitioning this model heavily depends on the particular national situation regarding market operation and regulations regarding responsibilities. In the following, the partitioning with focus on the aggregator and prosumer/consumer and community role in a number of specific country situations will be described.

Switzerland

In Switzerland, the development of aggregators started just a few years ago. However, it quickly gained momentum. Accelerated by low electricity market prices, many traditional companies are looking for new income sources but also new incumbents, often driven by knowledge in ICT, were entering the electricity markets. After establishing guidelines on how poolers could offer products into ancillary service markets operated by the TSO, the number of such aggregators increased substantially. Currently, there are about 10 companies either already prequalified for ancillary services or becoming so. Often, these aggregators do not only aggregate loads but also emergency electricity supply generators or other flexible production assets in order to offer products which are conform with product specifications. In order to not introduce an increased amount of balancing energy to the balancing groups in which the aggregators are active, the TSO is in charge to account for the energy they called upon from the aggregator. The aggregators therefore send the information on how much energy was delivered from each balance group to the TSO. In this way, the aggregators do not need to perform an individual accounting of their scheduled energy with each balance group.

The Netherlands

In the Netherlands, the ICT enabled aggregator/concentrator role is well-established. Aggregators for wind generation, CHPs in the horticultural sector, street lighting and cooling and freezing stores are the most prominent examples. In the end-customer segment, home energy management systems only have the confined context of the home. A home energy management system, Toon [41], has been marketed by Eneco since 2012. The system is connected to the electricity and gas meter and to the central heating system. It takes the form of a tablet-like user interface and gives insight in real-time energy use and provides advice on energy efficiency. Furthermore it functions as an intelligent clock-thermostat. Competitors have similar offers using Anna [42], marketed by Plugwise, and Nest, in version 3 also supporting the European standard for heating boiler communication, OpenTherm. Applications going one step further by performing control and coordination are only in the test phase with rollouts of 500 -1000 households. These include Couperus, a residential apartment building near the Hague, Hoogdalem, Lochem, Hoogkerk and Zwolle.

United States of America

Engaging demand-side resources in system operation takes on many different forms in the United States [43]. The nation includes vertically integrated utilities regulated by states and the federal government, municipalities and public utilities locally regulated, and regional transmission organizations and markets, all of which have differing structural elements. Residential DR figures in each of these organizational structures. In all cases, distribution system operation is an important component and the role of a DSO is emerging with respect to the physical and financial coordination of DR. Figure 2-3 provides a simplified perspective of the various roles relevant to a DSO and residential DR that is being recognized and discussed in many areas of the country. In this model, the Customer/Merchant DER encompasses the energy users' resources. This entity works with device providers to procure equipment and systems that contribute to DR flexibility. They also work with non-energy retailers who can package agreements with aggregators (energy retailers) or they can work with them directly. Aggregators compete by working with higher level (wholesale) markets and they coordinate with the appropriate DSO for distribution services for their customers.

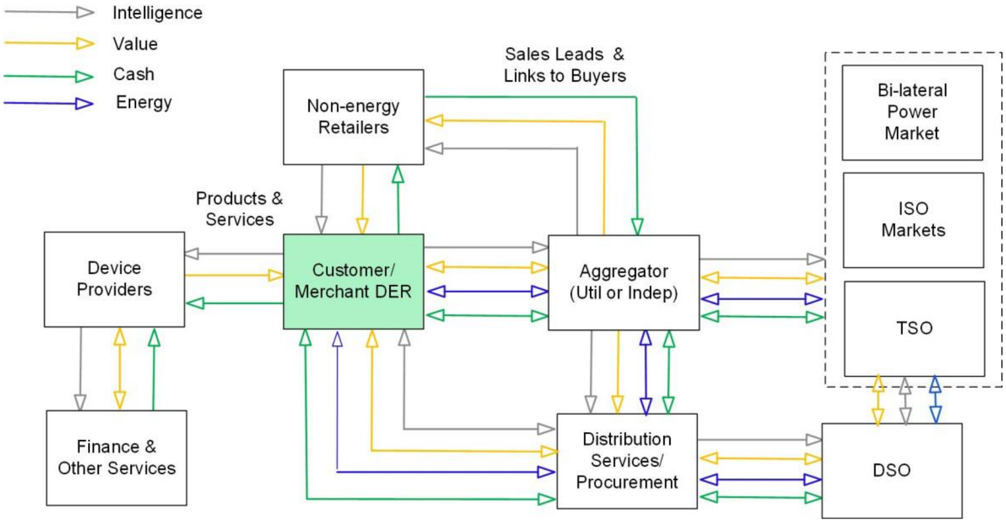


Figure 2-3: DSO Value Stream Structure [43]

Sweden

The development of aggregation services in Sweden has been rather slow. The availability of large amounts of flexible production in the form of Hydropower generation in the Nordic system makes the price competition for flexible resources fierce. On the power reserve market – which is an annually procured portfolio of production and demand reduction services to be used in situations of extreme power shortage – some examples exist. For example AV Reserveffekt AB [44] have provided aggregation of distributed generation, mainly back-up diesel-driven units pooling up to 70 MW. For more real-time related markets, a number of pilot projects have been initiated and concluded, an example here is Upplands Energi [45] where 500 residential heat-pump units have been aggregated to provide demand response services at a pilot level. Similar pilots have been performed in the Smartgrid Gotland [46] project operated by Vattenfall in order to investigate the potential of demand flexibility. None of these pilot cases have however been taken to the level of commercial operation on the existing electricity markets.

Austria

The business case for DR in Austria is not very high. Some industrial customers with high amounts of loads are participating with flexible loads. Mainly due to low revenue streams pooling of small customers are still not in place. One aggregator uses others incentives for utilizing electric boilers for provision of secondary control.

India

The main focus is on energy efficiency in DSM and DR is still at concept stage. At present there are no proven business cases available in the context of demand response. Some utilities have tried implementing DR (manual/auto) in small commercial establishments, IT park, Hotel etc. The concept of aggregator model is tried on a pilot basis.

France

France has enabled DR to participate in all existing market structures (ancillary, balancing, energy, and capacity) and is considered as one of the most advanced countries in developing DR. As an example, in France are about 15 service providers and one for distributed DR. 10% of the French frequency containment reserve (FCR) is procured through DR. In the balancing market 50% of 12GWh in 2014 is provided from residential load [47],[48].

3 Assessing models of Residential DR Resources

3.1 General Characteristics of DR Resources

For characterization, metrics can be introduced to specify a certain resource with respect to its capability. In [49] different approaches for defining flexibility are discussed where the three main aspects identified are:

- Ramp magnitude
- Ramp frequency
- Response time

Additionally for DR resources the following more detailed characteristics are also important for modelling the resource:

- Ramp up / down
- Max power / min power / discrete / continuous
- Energy / Capacity / duration
- Recovery / rebound
- Availability

While generators and large resources can be described by the first characteristics, smaller responsible demand resources might need to be characterized using more details. In the case of aggregation of resources, restricting criteria (e.g., max power, duration) can be overcome due the statistically varied properties of the pooled resources.

3.1.1 Energy Flexibility Interface (EFI)

Flexibility can be sourced from a range of generators, storage and demand. This flexibility can be characterized according to Figure 3-1, provided by the Smart Grid Coordination Group SG-CG/M490/L, which shows a progression in the extent to which an energy resource can be controlled. This categorization can apply equally to generation as well as demand and storage devices.

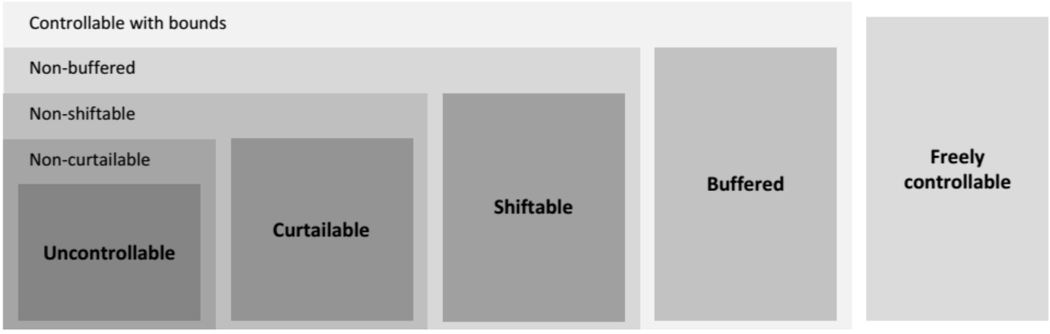
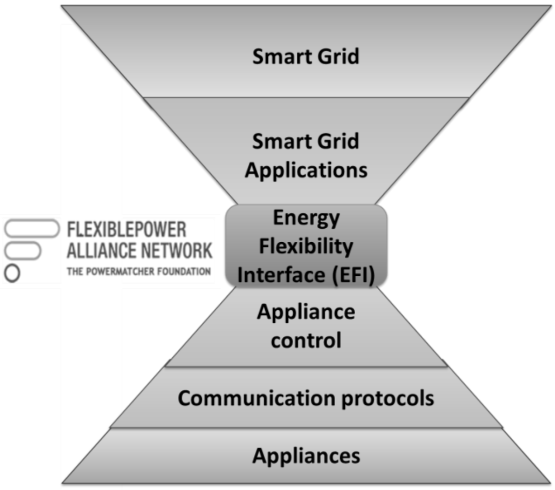


Figure 3-1: Categorisation of flexibility sources [50]

One of the most promising emerging standards in this area is the Energy Flexibility Interface (EFI) which has been developed by TNO and is governed by the Flexible Power Alliance Network (FAN). The Energy Flexibility Interface defines a standard set of control spaces for four type of devices, using a similar categorization concept as shown in Figure 3-2 (where curtailable and uncontrollable categories are merged for simplicity). Within EFI it is not the device that is modelled but rather its energy flexibility. Four control spaces are sufficient to cover all device types. The control spaces are:

- Uncontrollable. Has no flexibility, is measureable and may provide a forecast. Examples are Photo voltaic panels, Wind Turbines, TV, indoor lighting, etc.
- Time Shiftable. Operations can be shifted in time, but it has a deadline. Examples are a Washing machine, Dishwasher, etc.
- Buffer/Storage. Flexible in operation for either production or consumption however operation is bound by a buffer. Examples are a Freezer, Heat Pump, CHP, Batteries, EV, etc.
- Unconstrained. Flexible in operation for production. The operation is not bound by a buffer. Examples are Gas Generators, Diesel Generator, etc.



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- **Figure 3-2: The Energy Flexibility Interface couples Smart Grid applications with appliance control to enable the Smart Grid.**

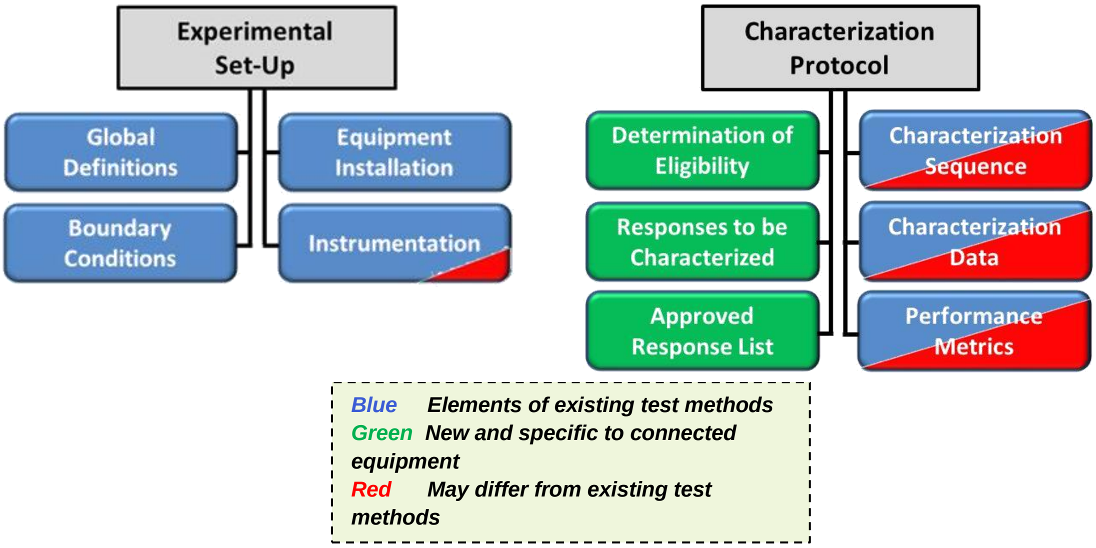
In essence, a control space is a way to put the information that is contained within a device into a generic structure, such that Energy Apps, for example the PowerMatcher™ smart grid control algorithm, are able to understand that device from a generic energy model. A Control Space defines the freedom in which the appliance can be started, and how much energy is consumed or produced when started. The appliance driver is a specific mapping of the specific control space of a particular appliance to the standardized Energy Flexibility Interface. Using the Control Space of a device, Energy Apps can determine the usage profile of the devices, i.e. when a device should start or stop etc. The Energy App sends a control signal, or Allocation to the device based on certain events. In case of the PowerMatcher a control signal to the device would be the result of receiving a new market price.

The appliance driver receives the Allocation and based on this it decides the optimal way to control the device. At this point the user preferences are also taken into account. Where Control Spaces form an abstract representation of a device, Allocations are used to express what a device is requested to do. For each Control Space, there is also one Allocation type.

3.1.2 Physical Characterization of DR Resources and End-Use Equipment

The US Department of Energy developed and published a framework for characterizing Connected Buildings equipment [51]. One of the main objectives is to enable services by understanding and characterizing equipment behavior. The formalism which will lead to services follows the definition of the ***performance metrics***, specification of ***characterization data*** and the description of ***characterization sequence***. This framework structure shows how the experimental set-up and characterization protocol are essential for evaluating the ability of connected equipment to deliver services.

The characterization framework relies on existing test methods and uses established testing elements. It is divided into the experimental setup and the characterization protocol category (Figure 3-3).



Blue ***Elements of existing test methods***
Green ***New and specific to connected equipment***
Red ***May differ from existing test methods***

Figure 3-3: Characterization framework for Connected Buildings end-use equipment [51]

- *Determination of Eligibility:* Qualification depends on supported features (e.g. two way communication)
- *Response to be Characterized:* Approved list of responses is defined. Some examples are illustrated here:
    - Load: adjust, schedule, delay
    - Consumer: threshold and limits
    - Equipment: cycling, overloading
    - Reporting: alerts, history, mode, status
    - Applications: measurement and validation, forecasting, diagnostics
- *Approved Response List:* approve value and reflect services, requirement of an entity may be required
- *Characterization sequence:* informed by services and may exist for controlling profiles, data collections, switching modes, auto-responses
- *Characterization data:* Physical and informational data to be collected
    - Physical: Voltage, current, phase angle, time, response duration and time, recovery time, number of cycles
    - Informational: availability, modes, states, sensor values, set points, failures, lock out
- *Performance metrics:* needs to be computed
    - Physical: kW, kWh, kVAr,, Energy consumption as percentage of the baseline, power reduction and increase in percent, availability, duration of response, deficit and recovery of service
    - Informational: availability, correct/incorrect, time lag

Characterization sequence*, *data*, *and metrics are performed, measured, and calculated for each response selected from the approved response list. This will require the necessary ***experimental set-up*** to be in place for each characterization.

Example: Characterization for a room air conditioner (RAC)

Determination of eligibility:

✓ 2-way communication (WIFI/SEP 2.0)
✓ Automated response (Load curtailment)

Responses to be characterized:

Load – Adjusts thermostat upward 5^{o}F when mode is activated
Consumer – 5-hr time limit on load management mode
Equipment – Mode persists for 2 minutes to prevent short cycling
Reporting – Reports operating modes
Applications – Forecasts remaining off time when in mode
– Diagnostic warning for low refrigerant charge

Approved response list specific to RACs

Responses to be characterized are selected from an approved list that is maintained by an entity having authority to do so.

Characterization sequence protocols are used to test e.g., load curtailment responses (Figure 3-4 a) and load following (Figure 3-4 b). From these tests metrics can be derived, like absolute power reduction, time lag, verification of maximum temperature rise (e.g 5°F), recovery energy and more.

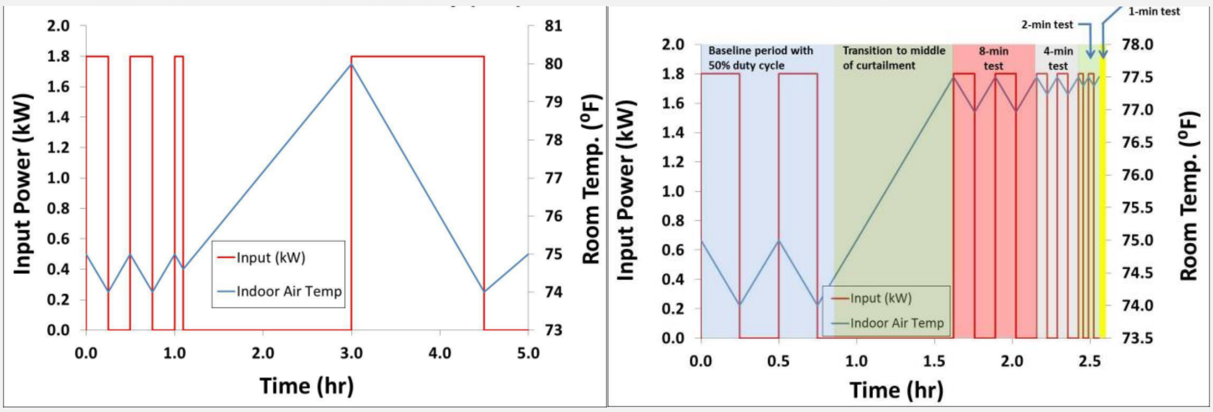


Figure 3-4: a) Load Curtailment Characterization and b) Load following protocol

3.2 Application of DR in the Electric System

3.2.1 Categorization

Consumer load categorization

According to the report "Shift, not Drift" from the EU funded THINK project [52], appliances, devices and other end-user equipment can be categorized into five load types. Additionally to categorization into DR programs, the focus is on the aspect on how they are used to provide end-use services (**Error! Reference source not found.**). Load characteristics of these categorizes re:

- *Storable/non-storable*: possibility of decoupling input from output/withdrawal, including both electrical and thermal inertia
- *Shiftable/non-shiftable:* delay or bring forward consumption; service should not be influenced and could be done manually or automatically
- *Curtailable/non-curtailable:* interrupt, decrease or switch off power consumption; service is affected;
- *Base load:* end-use services which are constantly online or cycle;

- *On-site generation:* renewable and distributed generation; sometimes dispatch-able or curtailable

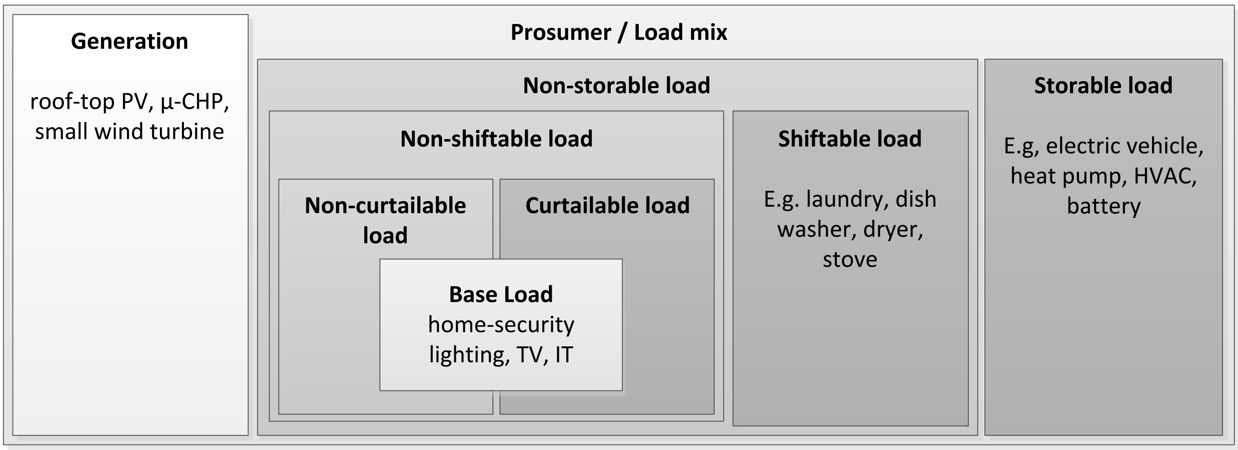


Figure 3-5: Prosumer - Generation and load (load mix) made up of different shares of storable, shiftable, curtailable, base and self-generation (load reduction) [52].

Demand Response evolution

A possible categorization of DR programs can be done from the evolution point of view (Figure 1-4). Starting from top-down switching (e.g. ripple control), which has been in place for several decades. Implementations for a price based local control of local issues (e.g. dynamic tariffs) and central controllability (e.g. central portfolio optimization) are realized by various programs. Further development, or the highest complexity and best integration approach is the market integration based on two-way communication channels and local controls (e.g., transactive energy).

Price tariff schemes

Most common price tariff schemes are:

- *Time of use Tariffs* (ToU), to change behavior in order to improve base load profile; these time-of-use components can be part of the distribution/transmission component or of the BRP managed commodity component
- *Real Time Pricing* (RTP), react on short term externalities like spot prices or balancing needs
- *Critical Consumption Pricing* (CCP), including critical peak pricing (CPP) – tend to reduce grid congestion and *Critical Peak Rebate* (CPR), to increase demand in times of excess generation (e.g., from DER);
- *Consumption based* pricing, which tends to foster energy savings and general load reduction

Comprehensive information about dynamic pricing approaches can be found in a report from Breukers and Mourik [53].

Scale and domain categorization

Integrating residential DR resources requires the coordination of large numbers of residential devices. While each piece of equipment may have small capitalization cost, the relative costs of ICT technology and integration and maintenance cost can be relatively high compared to large commercial and industrial loads. Synergistic usage of multi-purpose communications and high levels of standardization and interoperability are needed to control deployment costs at scale [54].

3.2.2 Demand response functions

In the previous section we discussed the macroscopic flexibility perspective of the electricity system. In the current section the microscopic perspective that will be aggregated to uncover the macroscopic perspective will be treated. In most current electricity systems a layered set of coordination systems is operational to guarantee equilibrium between demand and supply at any moment in time. Lund et al [49] give an extensive overview on flexibility and the role to play in grid functions to compensate the current and projected participation of variable output renewable energy resources. Referring to the DENA II grid future study [55] a potential calculation is given of capacities per device type, that can clustered and be made available. The percentage that can be compensated by decreasing or increasing demand relative to the minimal and maximal power from variable renewable energy resources is specified per device type. In the study for Germany and Finland, this potential is compared to traditional fast acting generators, typically gas-fired, that might serve as an alternative to compensate for the variability. Most positive business models, storage capabilities and adequate capacities appear for electrical night storage heaters. Heat pumps also have positive business models, but lack the required total capacity requirements; their application mostly affects increasing the energy efficiency compared to resistive heaters. Other types of loads typically either have too large investment costs or fixed costs due to ICT and communication requirements. Similar studies were done for the service/commercial and the industrial sectors. However, the potential there was considerably lower.

3.3 Specific DR Equipment Capabilities

In the previous Phase 2 of Task 17 a detailed analysis of DER technologies has been conducted and reports published. This section gives some updates with respect to recent developments and the evolvement into DR services.

3.3.1 Thermostatic controlled loads (TCL) with thermal storages

Thermostatic controlled load are usually operated between an upper and lower thermal limit by sensing the actual temperature by sensor. Such loads typically include boilers, for domestic hot water (DHW) or large cooling plants like refrigerated warehouses. If the limits are exceeded the thermostat controller starts or stops the cooling or heating process. The activation time can be in the rage of seconds to several minutes, depending on the characteristic of the load.

White goods and appliances

Technical capabilities of providing flexibility

From the power view point, white goods like washing machines and dishwashers have to be considered, since their potential for automated DR is substantial especially on a short timescale during the water heating cycle. The impact of the DR action on the quality of the primary consuming process however provides a risk factor.

Availability

The availability of white goods and appliances is, like for many equipment types, largely dependent on the use case. AS long as automated schemes are used, the availability is very high, since white goods are used in almost every household or larger living community, i.e. shared facilities. However, the flexibility can only be used when the white goods are used, i.e. when they are switched on. This poses some challenges in taking advantage of the flexibility of these sources.

Driven by requirements on proper operation of the washing program and optimal use of detergents manufacturers do not allow interruptions. Only the whole washing program can be shifted [56].

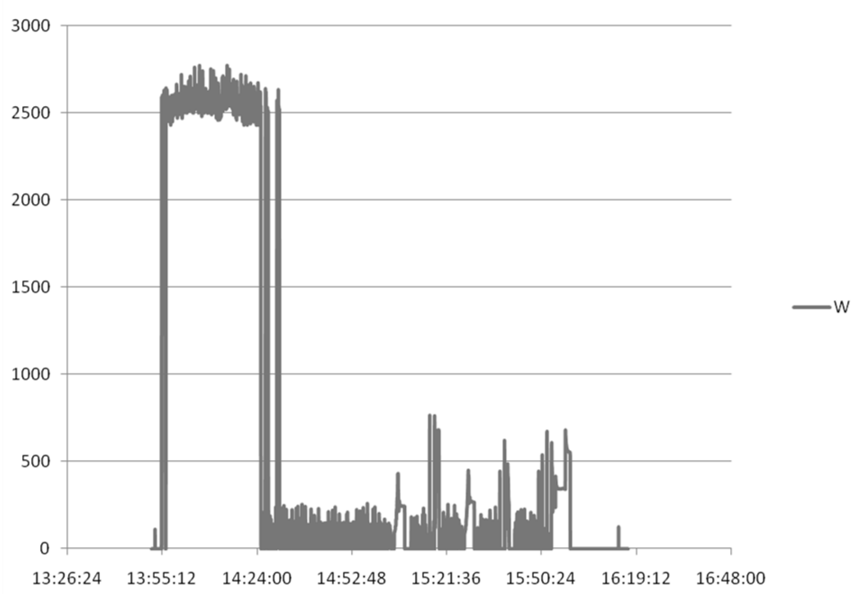


Figure 3-6 Typical power consumption profile of a washing machine (active power in Watt)

Figure 3-6 gives an example of the typical power consumption of a washing process. We can assume 2 to 2.5 kW during 30 minutes is the major DR-potential. From an energy perspective, studies showed that potential exists particular in combination with interaction or changes in consumer behavior, by shifting the start of the operation (e.g. washing machine or dishwasher) in times of low energy prices or avoiding curtailment of PV ("Washing with the sun").

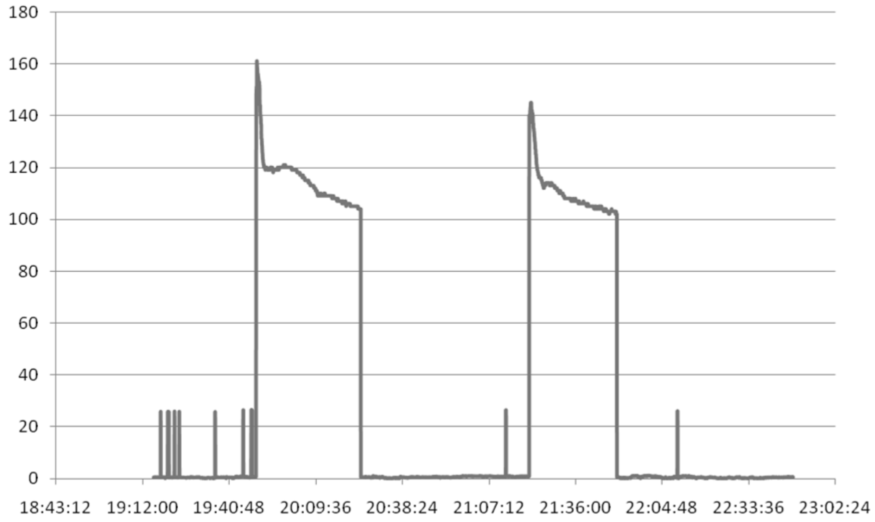


Figure 3-7 Domestic refrigerator electricity usage profile (active power in Watt)

The power and energy potential in domestic refrigerators is small also due to the recent reduction in consumption achieved by the manufacturers. A characteristic power consumption pattern is shown in Figure 3-7. A future use case could be providing rotating inertia to stabilize the frequency.

<u>Thermal storages (boilers; domestic heat water DHW)</u>

Storage decouples the process of provisioning and consuming the energy. The main objective is to serve the consumer's requirements for the various forms of energy (warm water, heating, cooling, driving range, etc.), which must include some reserve for managing higher than normal consumptions. Otherwise the consumer's experience would be negative and counteract DR participation.

Figure 3-8 shows the charging and discharging of a boiler thermal process with alternative increased upper bounds for the control operation area. Tradeoffs to higher self-discharge in terms of decreasing degree of efficiency have to be evaluated against such a mechanism. The same principle can be applied to cooling or freezing processes, altering the lower operational limits.

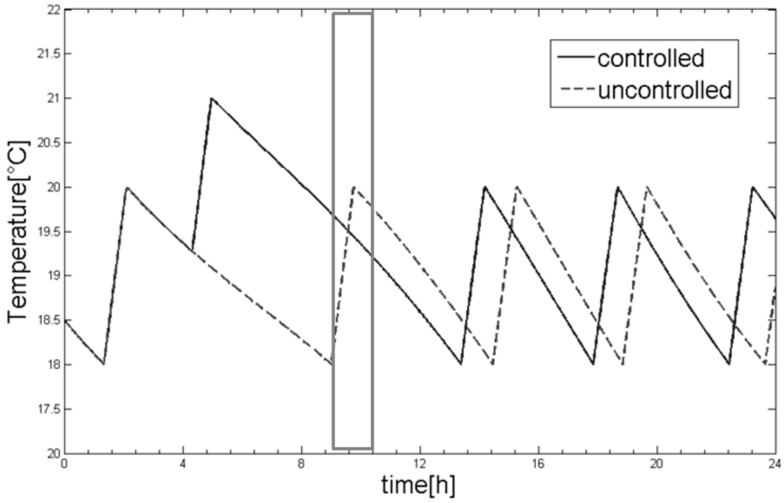


Figure 3-8: Building Management System shifting heating load by preheating a building. The load is shifted from the time interval marked with the green frame to 4h in the morning [57]

Availability

In general the availability of TCL with thermal storages is very good, similar to other types of local storages. The availability depends largely on the use case and the requirements. Ripple control, boilers and thermal storages can be used to reduced peak load in distribution networks or reduce demand based on electricity prices. Besides these well-known use cases, boilers can be used for provisioning of control reserves [58]. The availability decreased rather fast, when more than one use case should be implemented simulataneously.

Switzerland – Boiler for Demand Response

The objective of the project *WARMup* was to make an economic assessment of the versatility of thermal storage facilities. In the project the thermal inertia of boilers and buildings was used to take advantage of different prices for energy at different times of the day. The added value potential of optimal management of the thermal storage unit was determined by its flexibility being assessed on all the prevailing markets through optimal commercial transactions. All simulations were focused on an operation without limitations of use for the inhabitants.

For this purpose an ex-ante simulation with the aggregated use of 5000 units and 22 flats with real market data was carried out. It simulated optimal use of the boiler and trading on the day ahead or intraday market and found a cost reduction and additional income of 40 CHF per flat (-5%) compared to the base use profile for the boilers. All simulated capacity trades were offered at the ancillary service market and a trade was only counted as accepted if it would have been in the real world.

95% of Boilers in Switzerland are already ripple controlled, but remote control is not possible for individual units.

India – Thermal Storage in Hotels, Commercial Complex and IT Parks

A private utility in Mumbai (Tata Power) has successfully demonstrated use of thermal storage for peak shifting in hotels, commercial complex, IT parks etc. The consumers have installed this technology at their premises and are able to achieve savings in their electricity bill by taking advantage of ToD and peak shifting. All this was possible without compromising on the comfort of the guest/visitors/users. This utility was successful in enrolling thermal storage of about 15000 TR- Hours which would achieve shifting of more than 3.6 MU of electricity from peak to off peak.

With increasing economic growth there would be significant increase in commercial complexes, IT Parks and Hotels in the country. There is a significant potential for DR using thermal storage in India.

3.3.2 Battery Electric Storage

Apart from DR, the EU-commission [3] states, that self-generation and self-consumption are the cornerstones to aid and supplement the existing electricity infrastructure. Electric Energy Storage or Battery Energy Storage Systems (BESS) can be counted as a flexible or storable load. Depending on the operational strategy of the storage system BESS can fulfill various DR services. Because the energy is not consumed but stored, flexibility of storage systems is very high with respect to their operational limits (e.g. maximum charging/discharging power, capacity).

Typical home energy storage systems operate ‘locally’ to store on-site or self-generated electricity from PV or other sources. A typical strategy is to store surplus generation and use it later to supply the local demand, to increase the self-coverage or direct-use of the PV system. Discrimination has to be made between consumer owned storage and district storage.

Availability

Typically, BESS are well available for providing flexibility. However, it must be considered for which purpose the batteries have been installed at the first place. If the BESS have been installed in order to increase self-consumption, the availability for other flexibility purposes like control reserves is limited to some extent. Intelligent algorithms can harvest the flexibility left besides the main use case of self-consumption. Aggregators have already taken advantage of it in several European countries like Germany or Switzerland. Furthermore, different requirements arise when trying to use BESS for self-consumption and network services, such as resolving congestions. In such cases, the availability of BESS appears to be almost not existent unless an emergency option is implemented so that the network operator can take advantage of the BESS at all times.

SmartStorage

Within Enexis [59] and Stedin [60] in the Netherlands two pilots have been conducted. A SmartStorage unit pilot close to a transformer station has been setup by Enexis to gain experience in using district storage to support DSO activities. In Hoogdalem, Stedin has rolled out a test with Consumer electricity storage.

Energy Storage vs. Demand Response

BESS are anticipated as complementary to the need for demand flexibility, since they can be used to help balance, store or mitigate the energy system. There are differences between storage systems and demand response, which one is clearly the capital costs for BESS.

In Figure 3-9 a simplified input and output flows of power to a) a battery system and b) demand response resource is shown. A battery has the basic operation mode of charging and discharging, where a DR resource has only the ability to use or not use energy, while some have the ability to offer continuous or discrete levels of energy use in-between. One major difference is, that the DR resource’s ‘discharges’ is dependent on the user behavior’s demand. Since this is a stochastic behavior (which can somehow be described statistically) the energy level or state of charge (SOC) is usually not known.

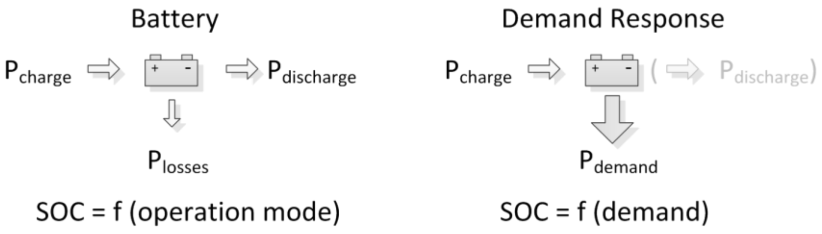


Figure 3-9: Power input and output of a) Battery Storage System and b) Demand Response Resource

Other differences between these two technologies are discussed in
Table 3-1.

Table 3-1: Battery operation vs. Demand Response requirements

Category	Battery	Demand Response
Operation	charging / off / discharging	(forced) charging / off
Self-discharging	(small) losses	losses = customer demand
SOC range	determined by previous operation	usually unknown available capacity
Rated power	charging = discharging	usually withdraw > charging
Storage time	short to long term	(short term) “shifting”
Availability	dispatch-able	external factors (demand, T, …)
Purpose	dedicated system	part of demand side (load)
Control	energy management system	simple control (e.g., thermostat)
Objective	storage of electric energy	shifting of energy
Scale Levels	small to large / utility scale	settlement, building, households Large scale = industrial services
Capital costs	High	Low (with ICT in place)

3.3.3 Heat pumps (HP)

Technical capabilities of providing flexibility

Heat pump operation can be shifted to times where electricity surplus exists from e.g., renewable energy sources. Thermal energy can be buffered either by activating a thermal storage capacity, often offered by the masses of the house to be heated or by applying higher temperatures to the buffer storage for room heating and domestic water. The latter is inherently connected to potential reduction of the HP efficiency (due to higher operation temperatures) and increase in storage losses [61]. Heat pumps have a number of operational constraints. Modulating the power, i.e. operating the heat pump on partial load, leads to a lower energetic efficiency. Furthermore, wear increases if heat pumps have too many start/stop cycles.

Constraints on flexibility are the available storage buffer size and the decreasing temperature due to longer operation times and inefficiency, backed up by direct electric heating. Higher temperature increases the load shifting potential [61]. A study [62] shows that uneven operation of air source HPs because of DR participation reduces the efficiency or COP by about 5% and increases the power consumed by 10% to 25% (Figure 3-10).

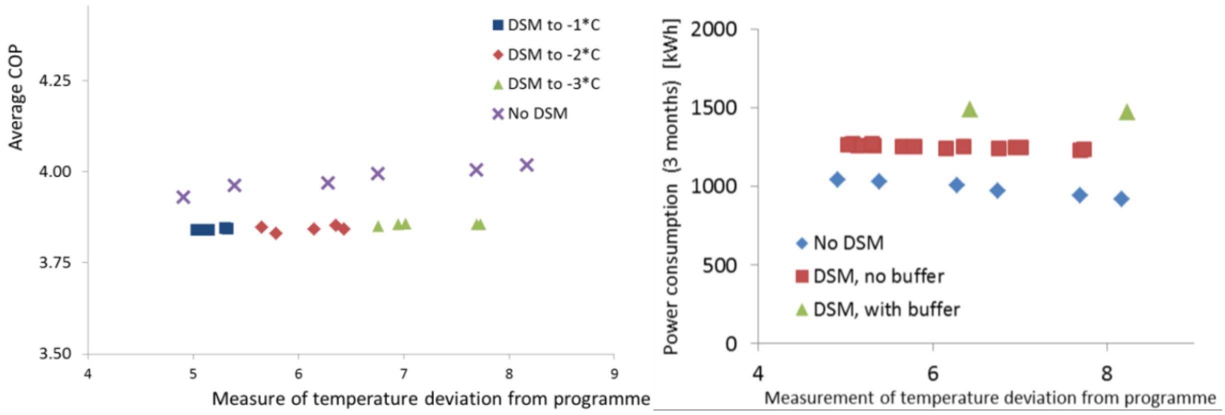


Figure 3-10: Air Source HP a) performance and b) power consumption [62]

Manufacturers of HPs are starting to enable an external control signal. Two approaches exist: either to increase the set point of the temperature, or to start heating prior to reaching the lower temperature set point of the storage buffer or the temperature buffer of the house itself. A so called *'SmartGrid Ready'* product can be found from, amongst others, Ochsner [63] and IVT [64].

Availability

For utilizing a HP as a flexible load the operation times have to be considered. Typically in the winter seasons the heat pump is used for heating and alternatively for warm water, where in the summer season only warm water is produced. Hence, the availability for demand side management is substantially decreased in summer time. Figure 3-11 shows the operation intervals for a typical sole-water HP over one year for every 15 minutes of the day. For system efficiency it would be optimal for the HP to run over the entire heating period. For reserve reasons and also at low temperatures where the additional direct electric heating is activated, it is not always in operation and therefore not always available as a DR resource. However, the activation time can be shifted to some extent, i.e. minutes, which offers some flexibility that can be harvested.

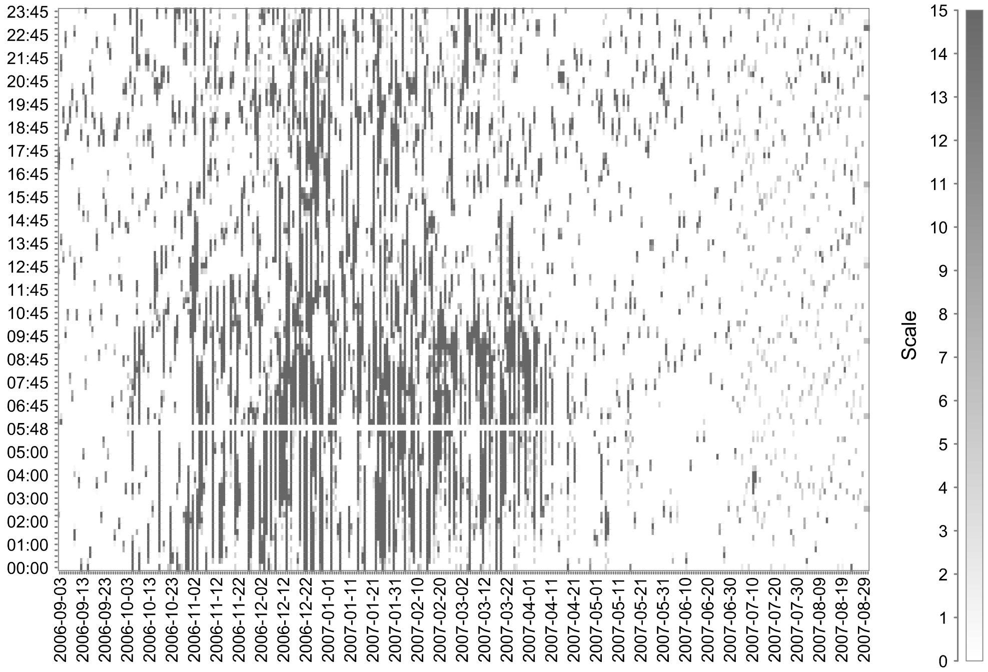


Figure 3-11: Duration heat map for a typical sole-water HP for heating and warm water. It shows how long the HP has been on for the interval, where the color of one interval indicates the utilization within the interval [65].

The Netherlands: PowerMatchingCity

Figure 3-12 is from the buffer optimization in the Hoogkerk living lab case [66] at residential customers using the B-Box strategy. Via a stepwise combinatorial approach filling, the central heating system the heat-buffering strategy is calculated within the required comfort constraints of the users. On the X-axis the time of day (0-24) is shown. The cost gain depends on the price pattern (red). For typical price patterns in the Netherlands the cost benefit is about one third from prefilling the buffers.

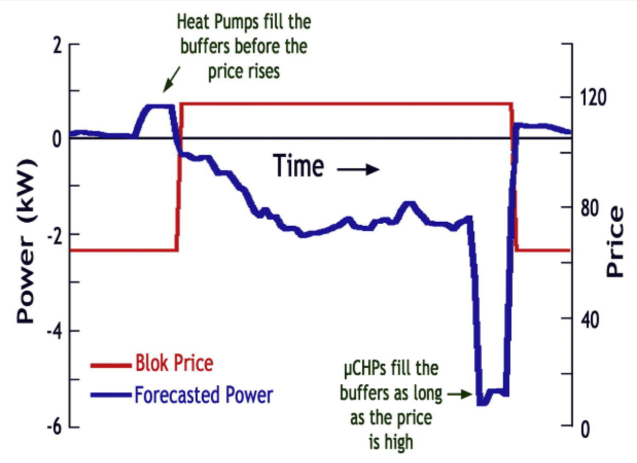


Figure 3-12 Electricity consumption price optimization for HVAC using heat buffers and forecasted power (Hoogkerk, 2012)

Pilot projects like *Couperus* and *PowerMatchingCity* have significant amounts of heat pumps controlled by PowerMatcher [67] for use cases pertaining to DSO and BRP operation. In the pilot *Your Energy Moment* (Enexis), heat pumps are utilized to gain experience with consumer behavior within a dynamic tariff setting.

U.S.A.: gridSMART Project

The US demonstrated the flexible operation of HVAC equipment in approximately 200 homes using a distributed control approach with the AEP Ohio gridSMART® project [68]. The project implemented a double-auction, real-time market that accepted bids and cleared supply and demand every 5 minutes. The supply was a function of the nodal locational marginal price (LMP) from the regional wholesale market so the equipment responded to energy and flow constraints from the bulk power system. They also responded to local distribution feeder constraints that could be imposed by temporarily setting the feeder capacity limit so that it was below the actual power flow on the feeder.

The households were able to individually set their comfort sensitivity to price with a smart thermostat. The greater the comfort, the smaller the temperature dead-band about the desired setting. The greater the economy, the larger the temperature dead-band. A software agent in the thermostat bid into the market based on these household preferences. The occupants were also able to override or change the settings at any time.

Figure 3-12 shows the operations display for the system. The top chart indicates the power flow on the feeder over time. The second chart indicates the state of the population of HVAC units in each market cycle over time. The third chart shows the market clearing price. And the last chart depicts the observed temperature averaged over all of the participating households.

The project successfully demonstrated how independent decision-making can work to satisfy regional and local objectives without direct control. For example, as market prices rise, some HVAC units did not run. As market prices rose to the price cap, all bidding equipment stopped running. Operational behavior such as a deterioration in the amount of HVAC load to drop out over time were also witnessed as was a small amount of household fatigue based upon a rise in thermostat overrides if the duration of a feeder capacity event was too long.

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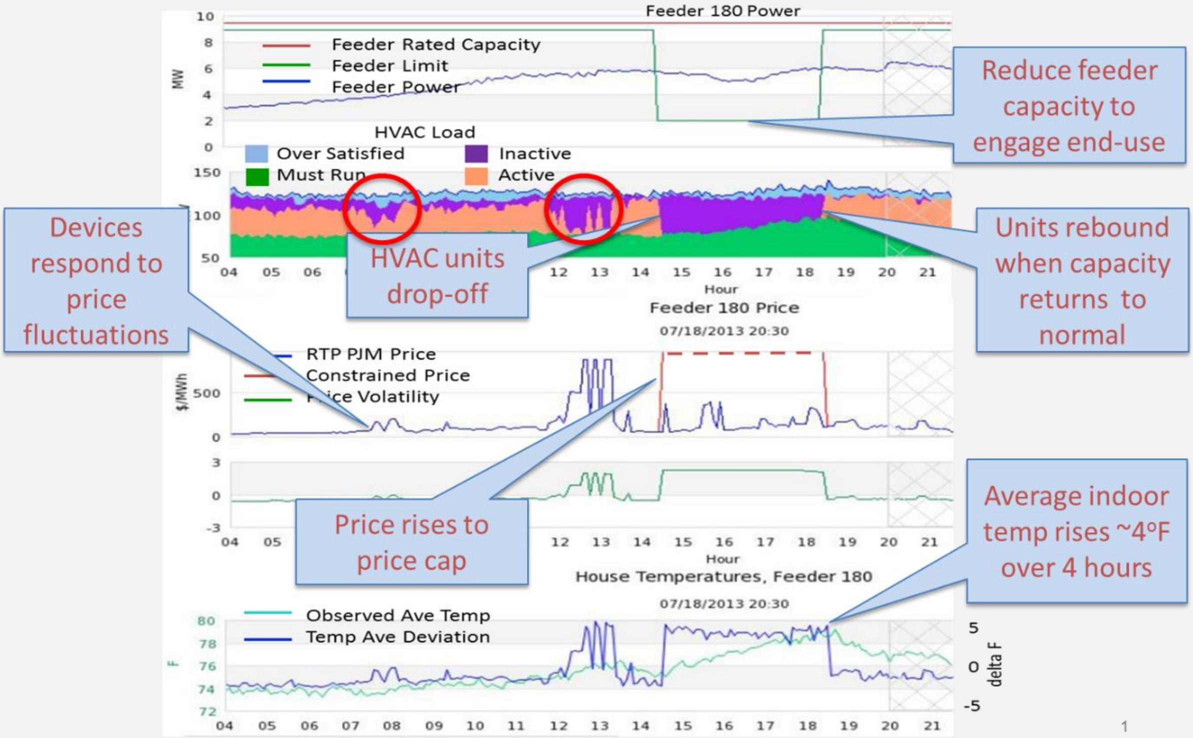

Figure 3-13 Operations dashboard for AEP Ohio gridSMART demonstration project

3.3.4 Electric Vehicles (EV)

Technical capabilities of providing flexibility

Energy demand for electric vehicles (EV) is dependent on the range and driving behavior of the users. The charging process can be controlled using various mechanisms, from simple on/off controls to continuously adjustable set points of the charging power [69]. Mostly, such charging algorithms aim at relieving network stress and avoiding congestions or the need for grid expansion. Currently available EVs provide options for controlled charging on the basis of the standard IEC 61851 [70]. Even if IEC 61851 was not intended or designed for fulfilling smart charging or demand response applications, it provides a significant degree of freedom in controlling the charging activities of EVs. As a follow-up to IEC 61851 the standard ISO 15118 [71] or OCPP [72] are some of the options which will provide extended smart charging capabilities in the near future.

Currently available EVs show specific differences in their charging behavior and their impact to the local power grid. Deviations exist in respect to maximum and minimum of accepted charging power, usage of phases and time delays. All investigated cars showed also a distinct deviation of the power set point and the power which was actually consumed by the car. This fact has a direct impact to DR applications and is caused by the onboard charge controller of the individual car. The figures below show characteristic behavior of the initial phase of a charging process and a step down procedure.

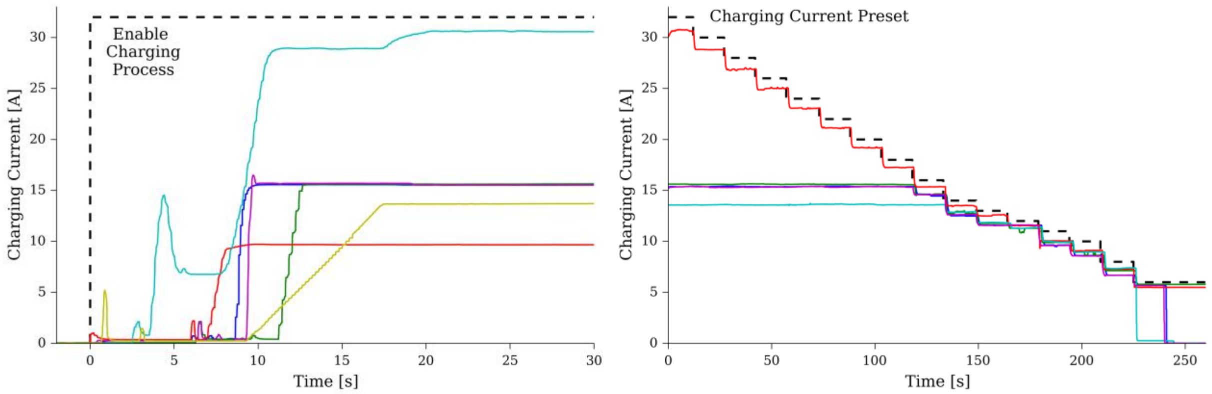

Figure 3-14: Behavior of different cars charge controllers a) during the initialization of a charging process and b) when decreasing the charging current stepwise

In general, the characteristics of charging EVs can be described as averaged values as shown like in table Table 3-2 (the values do not apply for fast charging capabilities):

Table 3-2: Example characteristics for charging EVs

Maximum charging current	**16A**
Minimum charging current	6A
Time delay for initialization of the charging	7sec
Time delay for a positive change of the charging current	2sec
Time delay for a negative change of the charging current	1sec

The impact of EV charging on the electricity grid depends on the number of cars at a certain location, the available charging power at the spot and the total energy demand needed to charge the batteries. Different studies show that charging when arriving at home (end-of-day) has less impact on networks than a controlled charging scheme which incentivizes charging to a fixed moment in time, e.g. 22h because of a transmitted signal of low prices. However, in general, any uncontrolled charging leads to large disadvantages in the power system such as increase of peak load or network overloads [73]. In general, pilot project show that technical capabilities are already applicable to EV in order to take advantage of this flexibility sources. Even simple ripple control technology or charging schemes based on local voltage measurements can be applied. Since EVs are basically BESS which change locations, the capabilities of providing different flexibility measures are very good.

Vehicle-to-Grid (V2G)

The charging direction can be in principle reversed as to feed energy back into the network when needed. For such a use case the technical capability is also already apparent, similar to the case of BESS. However, there are concerns mostly about battery lifetime degradation. Hence, the capabilities are currently limited by the battery management systems. The degradation costs are opposed to revenues for providing services like peak power or balancing reserves. In the Netherlands in Utrecht, the *Lomboxnet* [74] pilot was started by Stedin for a V2G power application, which is part of a regional electrical energy system also including local charging of PV-systems. Other investigations show a substantial potential to provide local or even system wide reserves for balancing purposes, e.g. for renewable energy sources infeed [75].

Availability

Figure 3-15 shows fleet charging profiles for different penetration levels (of approximately 6000 cars) when individual EVs have the opportunity to charge also at locations away from home, e.g. workplace. In general, one can see, that the availability of EVs is high. Especially during night time when EV users arrive from work, there is a large demand for energy, which could be basically shifted to later times. In the figure, the needed charging power decreases as more and more EVs are fully recharged in the night hours. However, the vehicles typically stay connected during the night, resulting in a large, aggregated resource that could be used when recharged based on a different scheme [76]. The spread within the shown profile accounts for different summer and winter demands. The spikes in charging are due to the higher charging level of 43kW [77],[78]. An intelligent control scheme could be used to ensure that energy demands for individual travels are met while enough space is left in the individual batteries to perform balancing services scheduled by an aggregator. In summary, vehicles are parked more than 90% of the time, making the resource highly available for flexibility usage.

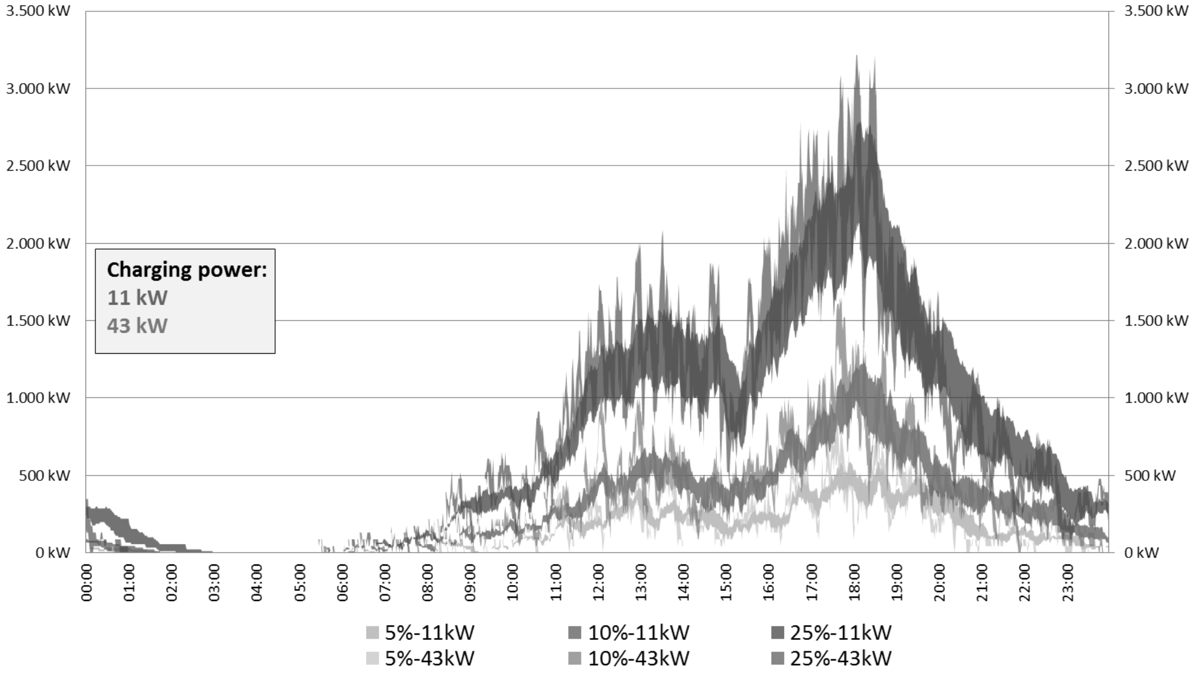

Figure 3-15: Impact of different charging powers for approx. 6000 cars forr summer and winter and opportunity charging **[78]**

3.3.5 Photovoltaic Systems (PV)

Technical capabilities of providing flexibility

Photovoltaic Systems (PV), since they are generators, are not a classical DR resource in the sense of controllable load. But since they can be also controlled in a sense of varying their output of active and reactive power, they can be incorporated as a distributed renewable energy resource (DRES) on the demand side.

Control capabilities include

- the possibility to reduce the active power output
- the possibility to increase active power output to the maximum available from the primary energy source (solar irradiation) if the system has been curtailed before.

- the variation of the output of reactive power (e.g., ancillary services like reactive power provisioning or voltage control). Typically grid codes give the range of operation, where the operation point may or may not impact the active power output.

In combination with a HEMS system generated power could be charged into battery, used for shift able load (e.g. heating) or in-feed into the system, since changing the total net power used from the electricity network.

Availability

Figure 3-16 gives the production of a domestic PV-system over a year at the specific location of Vienna, Austria. It can be seen, that there are significant variations over the seasons in a year, over the hours in a day. Only during approximately half of the operational time power is generated. The generation duration curve for the data is shown in Figure 3-17.

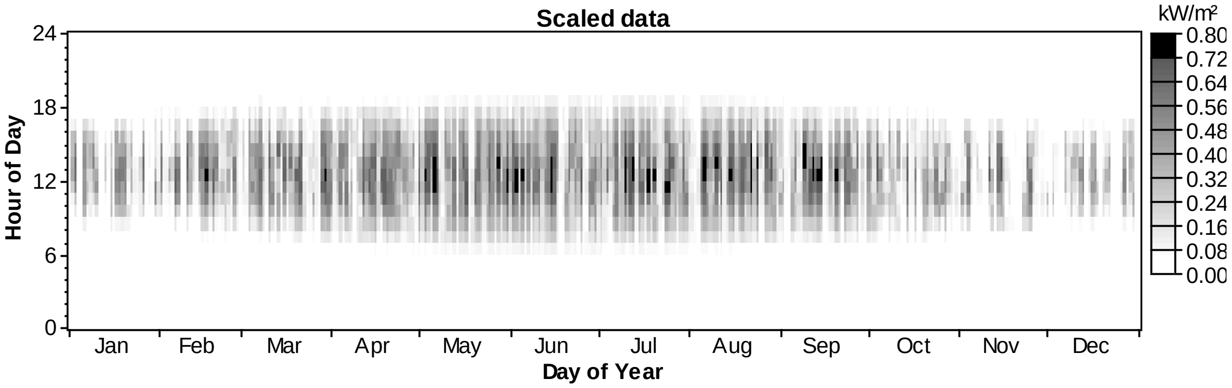

Figure 3-16 Generation of a 1 kW PV-system over a year

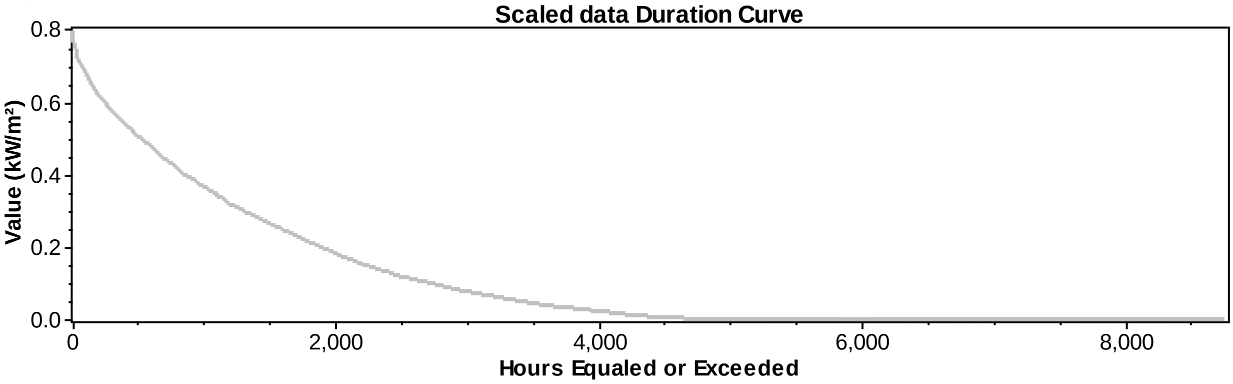

Figure 3-17 Generation duration curve of 1 kW PV-system over a year

4 Assessing Potential Capacity of Residential DR

4.1 DR Potential Capacity Categories

There is a distinction between technical-theoretical and actual-realizable potential. Depending on the nature of the study, many criteria and parameters are considered. As an example the micro-scale potential of the load-shifting of washing machines can be considered as realizable since it can be done by the consumer, but studies showed, that participation in DR programs (e.g. dynamic pricing, ToU tariffs) is low. It is also dependent on the targeted DR services (e.g. balancing, portfolio optimization, network congestion management) if a resource can participate or not. The metering of the consumption of an electric-boiler can be necessary for one application (DR contribution) and be a barrier in terms of costs at the same time and for other DR applications not necessary at all.

Top down and bottom up Approach

The top down approach starts from the identification of the overall energy consumption per sector. Processes will then be analyzed and DR potentials identified. From the available capacity per process this is then extrapolated to a total sum of DR potential.

In the bottom up approach a single technology or device is investigated and the typical DR potential in its process and operational context is analyzed. Starting from current levels of availability or market penetration numbers this can be extrapolated a total DR potential or based on market scenarios estimated for future penetrations [79].

4.2 General DR Potential

4.2.1 Potential in the USA

In the report for the national assessment of DR potential [80] in 2009 different scenarios have been investigated. Beside the business-as-usual scenarios, achievable participation and full participation with advanced metering infrastructure, dynamic pricing tariffs and other DR programs in place, are shown in Figure 4-1 for the top ten states. Total peak demand reduction from 38 GW to 138 GW equals 14% of the total peak has been estimated for 2019.

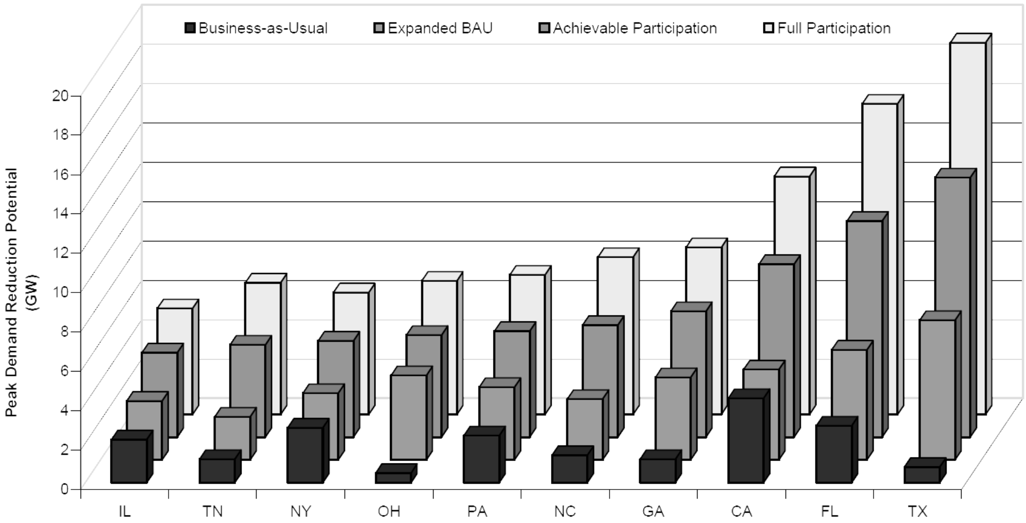

Figure 4-1: Top ten U.S. states by achievable potential in 2019 (GW) [80]

The potential by program type is shown in Figure 4-2. The highest potential has been estimated for “dynamic pricing with enabling technology” (pricing w/Tech) where prices change in response to events such as high-priced hours, hot days or network conditions (e.g., congestion, reliability). It is assumed that advanced metering is in place as well as that residential and small to medium commercial and industrial customers are equipped with automated technology (e.g., programmable communicating thermostat) and large customers with automated demand response systems.

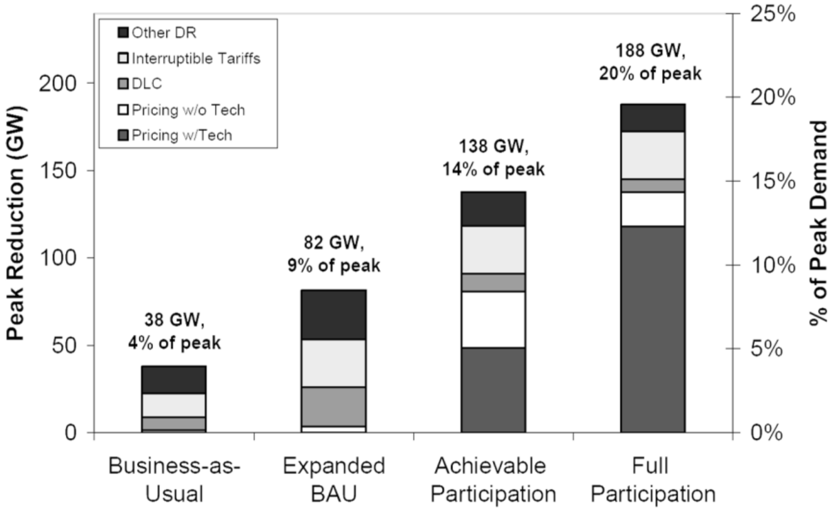

Figure 4-2: U.S. Demand Response Potential by Program Type (2019) [80]

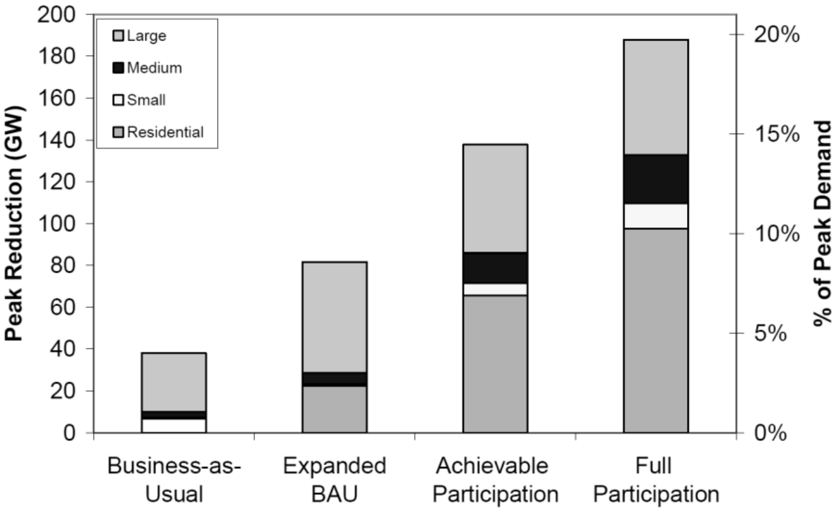

Figure 4-3: U.S. Demand Response Potential by Class (2019) [80]

Faruqui et al [81] have investigated the effect of the rate design on the achievable DR-potential in households based on a study of 109 pilot cases (see Figure 4-4).

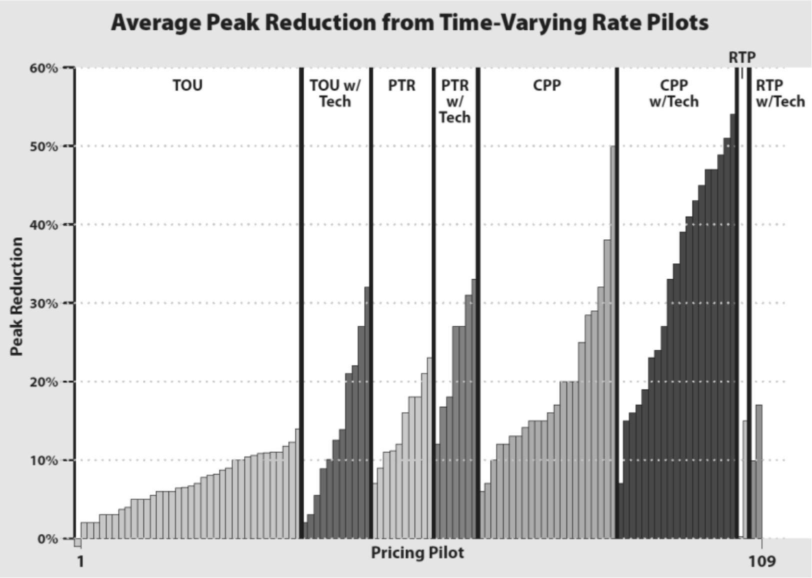

Figure 4-4 Peak reductions achieved in time varying tariff pilots (from [81])

They come to the conclusion that CPP-schemes can offer a potential up to 28% on reducing the peak load. The effect can be seen to vary dependent on the max-to-min ratio. Using enabling technology adds considerably to the achievable potential (see Figure 4-5). TOU tariffs yield a 0-12 % (6% average) reduction.

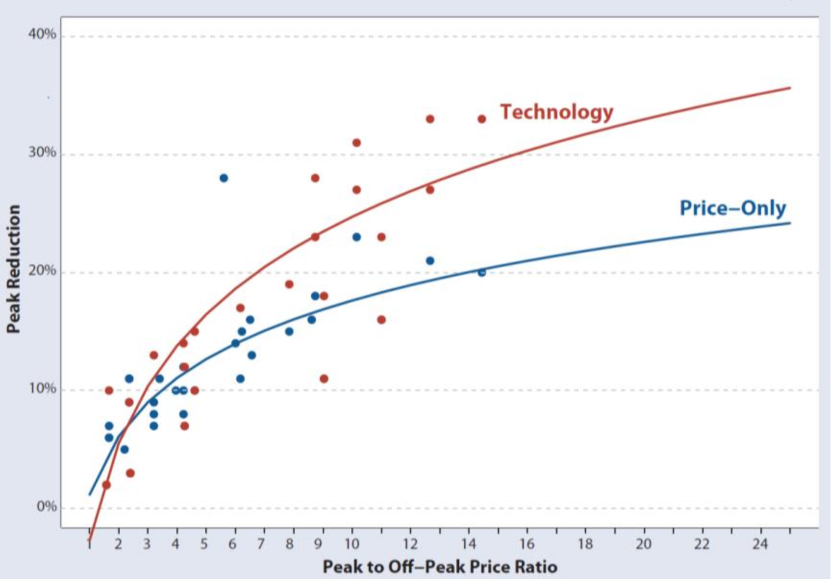

Figure 4-5 The effect of enabling technology – Pilot impact vs price ratio (from [81])

Here also an even higher additional gain by automation can be seen (average 15%). Peak time rebate (PTR) tariffs achieve a reduction of 15% which increases to 22% with automation technology.

In all studies, it appears that tariffs lead to behavioral change. Automation increases the effect and also leads to a greater chance on persistence.

4.2.2 Potential in Europe

A recent communication of the European Commission to the parliament [3] overall retail demand response is estimated to have cost savings up to 24% and electricity consumption potential between 10 and 36 %. Key to achieving these figures are price signals that reward flexible consumption. Customers in countries, where these types of mechanisms are used like Finland and Sweden, already reach this percentage. The pending revision of the Energy Efficiency Directive and the development of legislative proposals implementing the new market design present an opportunity to assess how to increase the availability of time differentiated contracts.

A study from SIApartners [82] estimated the total DR potential in Europe (Figure 4-6) and per country (Figure 4-7). In the top-down approach, starting from sectoral energy consumption and main process identification, DR potential in terms of installed and available capacity has been analyzed on a per process level. In the residential areas thermal storages by cooling or warm water

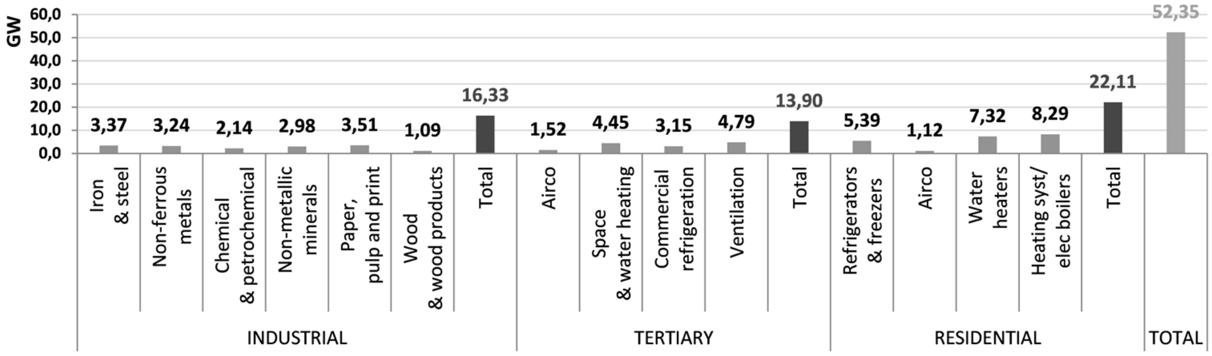

Figure 4-6: Total DR potential in Europe [82]

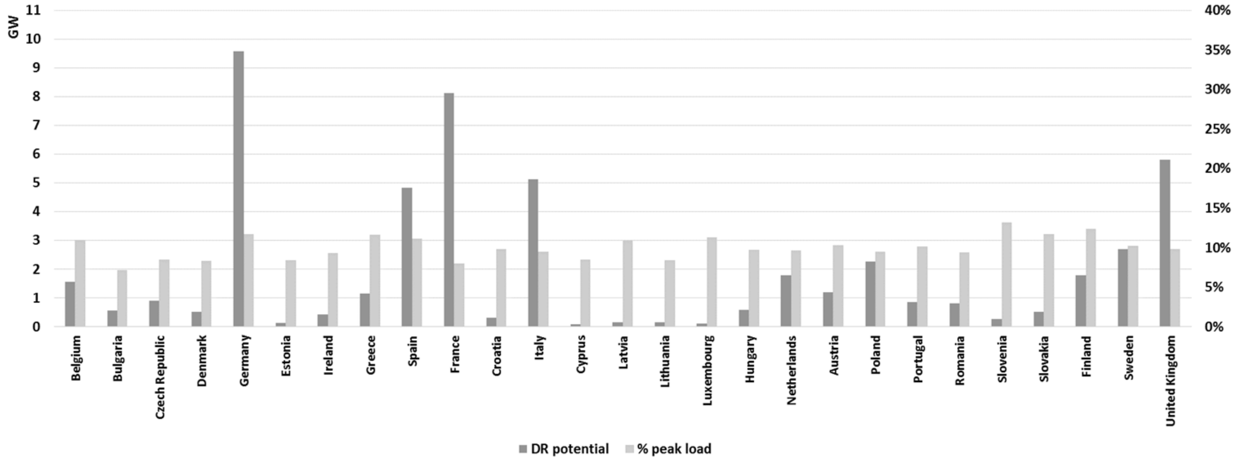

Figure 4-7: DR potential per country in Europe [82]

4.3 DR Potential in Households

4.3.1 Austria

A comprehensive study of load shifting potential of individual appliances in residential homes has been conducted in [83]. The achievable potential has been derived in three steps:

- Choice of the tariff program: only a certain amount of consumers will participate
- Theoretical potential: averaging effects need to be considered
- Achievable potential: partly change of behavior as a reaction on the price signal

In Table 4-1 the load shifting potential for increase and decrease of load is shown.

Table 4-1: Load shifting potential in households in Austria (adapted from [83])

	Device	0-5min	5-15min	15-60min	1-4h	4-12	12-24h
Status Quo	washing machine, tumbler, dish washer	+0/-9	+0/-9	+0/-8	+/-0	+/-0	+/-0
Smart Home	washing machine, tumbler, dish washer	+0/-26	+0/-26	+0/-24	+/-0	+/-0	+/-0
	freezer, refrigerator	+38/-23	+24/-15	+4/-8	+0/-2	+/-0	+/-0
(Automatic) Load control	warm water	+481/-30	+380/-30	+233/-30	+35/-30	+35/-30	+/-0
	electric heating	+0/-53	+0/-53	+0/-45	+/-0	+/-0	+/-0
	heating (night hours)	+500/-0	+500/-0	+100/-0	+/-0	+/-0	+/-0
	heat pump	+105/-105	+255/-255	+255/-255	+/-0	+/-0	+/-0

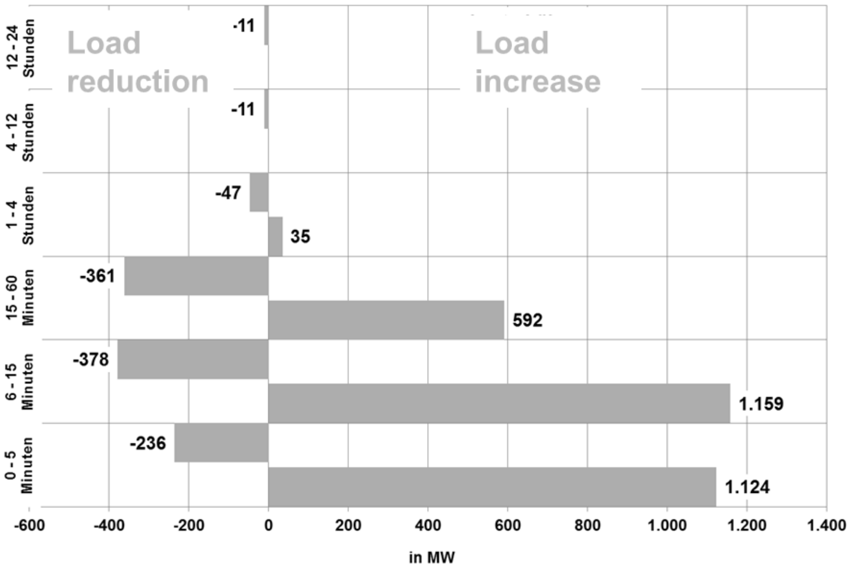

Figure 4-8: Load shifting potential in households in Austria ([83])

Load Shifting potential of HiT (SGMS, Austria) [84]

In this project demand response was achieved by utilizing HVAC-systems (heating, hot water) in a residential building in combination with warm water storage. Separate usage of different energy sources are used for thermal buffering. The objective is to use energy which is most efficient for the grid: biogas (CHP), PV, electricity from the grid, district heating to form a grid friendly building, while the comfort must be preserved. Three network-based tariffs have been introduced.

Automated as well as manual demand response (via visualization) was used as well as an intelligent optimization strategy for usage of different energy sources (Table 4-2).

Table 4-2: Potentials for automated load shifting

Heat source	Red	Yellow	Green
CHP	+17 %	-11 %	-6 %
HP	-12 %	+9 %	+3 %

Cost savings show that optimization of usage of energy sources can additionally save operation costs and perform best when considering the network-based tariff (
Table 4-3).

Table 4-3: Costs for different operation modes (project HiT) [84]

Operation	Full- infeed [€/kWh]	Electricity substitution [€/kWh]
normal	0.65	0.5
CO2-optimized	0.68	0.52
Smart Grid cost optimized	0.6	0.45

4.3.2 Switzerland

Several studies on Demand Side Management potential have been performed in Switzerland, in order to get a clearer picture of the potential available [85],[86],[87]. The numbers for the potential vary but show a conversion to a potential. Hence they seem to be quite reliable. Unfortunately, the studies vary in terms of assumption and methods. One study estimates an average of 1.000MW load management potential shift able over one hour. This demand side potential is mostly found for processes in industry, commercial services and communal infrastructure [88].

Furthermore, studies on the impacts of introducing a smart metering infrastructure in Switzerland on a nationwide scale attempted to assess the potential. The results show that about 10% of the peak load of Switzerland (around 11 GW) could be shifted for one hour using smart metering, i.e. in the year 2035 [88]. More specifically, between 1230 GW and 969 GW, depending on the capabilities of the smart metering infrastructure, can be shifted over one hour. A third study, aiming at understanding the economic situation and development potential of pumped storage hydro power plants , assess the potential of DSM in Germany, Switzerland and Austria [89]. Here, a slightly higher potential of 1497 MW shiftable over one hour in the year 2035 is found. Figure 4-9 shows the results of studies on DSM potential in Switzerland. In summary, it can be concluded that the DSM potential in Switzerland lies in the area of 1 to 1.5 GW shiftable over one hour.

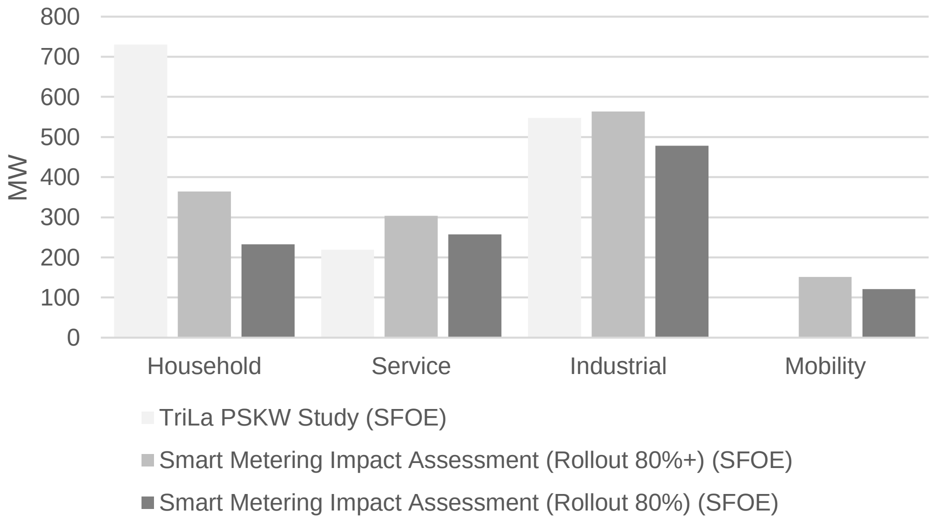

Figure 4-9: Potential for DSM in 2035 for Switzerland

Obviously, the time over which the demand needs to be shifted impacts largely the overall DSM potential. The assessment of smart metering offers a number of results for different time intervals. Table 4-4 summarizes the results, assuming that of the overall industry potential in the study 35% is found in commercial services while 65% is found in industry. The numbers for the potential of 1h are already depicted in Figure 4-9 as well.

DR Potential enabled by Smart Metering

Considering the impact of SM on DSM, it was found that the electric grid will slightly profit from the rollout of smart meters. In the best case lower load peaks could be achieved due to incentive programs (DR). These lower peak loads lead to a reduction of 0.5% in network costs compared to a base scenario without any DR. However, DR can also lead to higher peak loads, especially when loads are only controlled by systemwide market signals without any intervention by network operators. In such a case, load peaks wil increase and network costs will rise. Subsequently it is argued that a proper coordination between market and network needs to be developed. Further estimates show that the rollout of smart metering will offer a shift in peak load of up to 1GW for 1 Hour, i.e. about 10% of total energy consumption. This can have a substantial impact on the generation plants and import costs.

Table 4-4: Load shift potential in the year 2035 with comprehensive introduction of smart meters

Load Shift Potential	15 Minutes	1 h	2 h	4h
Private Homes	258-364	256-364	175-280	175-280
Industrial	250-1414	174-564	111-428	51-266
Services	134-762	94-304	60-231	28-143

Recently, another comprehensive analysis was carried out. It offers a bottom up approach. Individual loads, potentially suggesting to incorporate DSM potential were modelled for winter and summer time scenarios and assumptions based on the energy perspectives until 2050 [90].

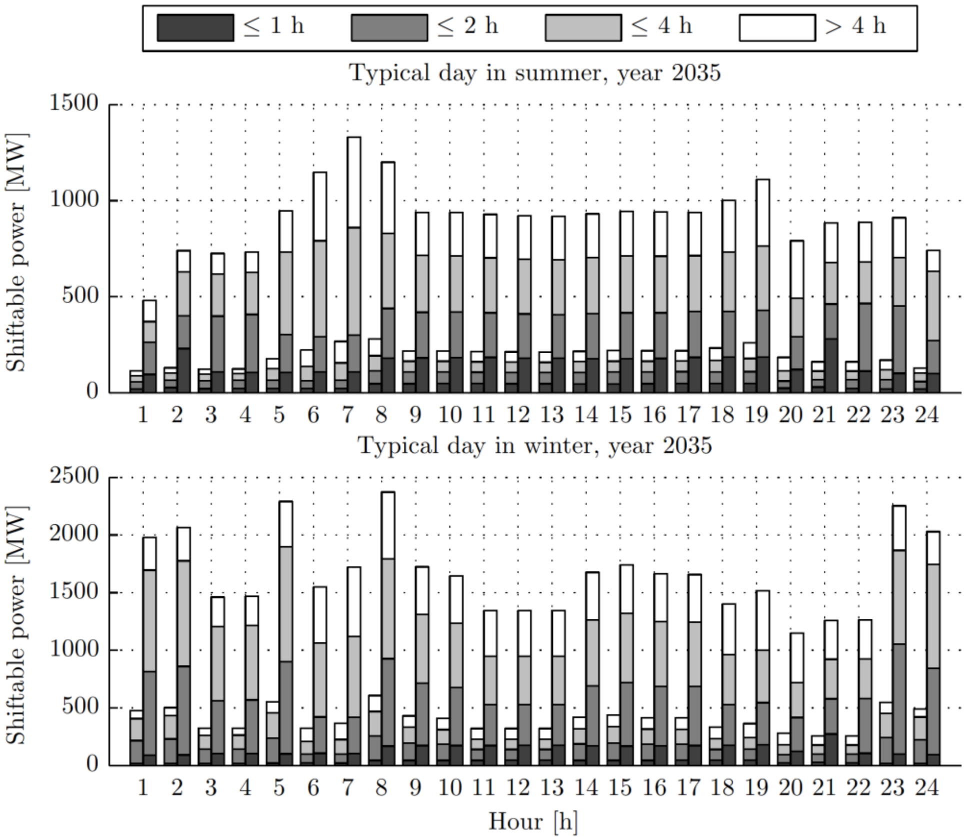

Figure 4-10: Projected combined load-shifting of Swiss loads on a typical summer-and winder-day in the year 2035. Each hour, the left bar corresponds to the business-as-usual scenario and the right bar to the scenario new energy policy (NEP) [87].

With similar time intervals over which demand can be to be shifted as in the smart metering assessment study for Switzerland, the study finds a much higher potential for DSM. During summer time there is an overall potential of around to 1 GW of shiftable load in 2035 which corresponds well to previous findings. However, the potential for DSM is much larger for the winter season. Here, in several hours of the day, an overall potential of up to 2.5 GW can be found. The much higher DSM potential in winter is due to e.g. space heating through heat pumps. The potential of 2.5 GW seems to reflect the best case of DSM potential in the smart metering impact assessment. Therefore, it does seem not completely unrealistic during winter time and for shorter time periods.

Electric mobility plays an important part in Switzerland in terms of energy efficiency but also for offering DSM potential. Figure 4-11 already had a look at DSM potential from electric mobility and identified some conservative values of up to 151 MW in 2035 shiftable over one hour [87]. The study [85] finds somewhat higher potentials for electric mobility of up to 400 MW for summer and winter time, especially during night time. During the day time, the potentials are somewhat similar for the both studies.

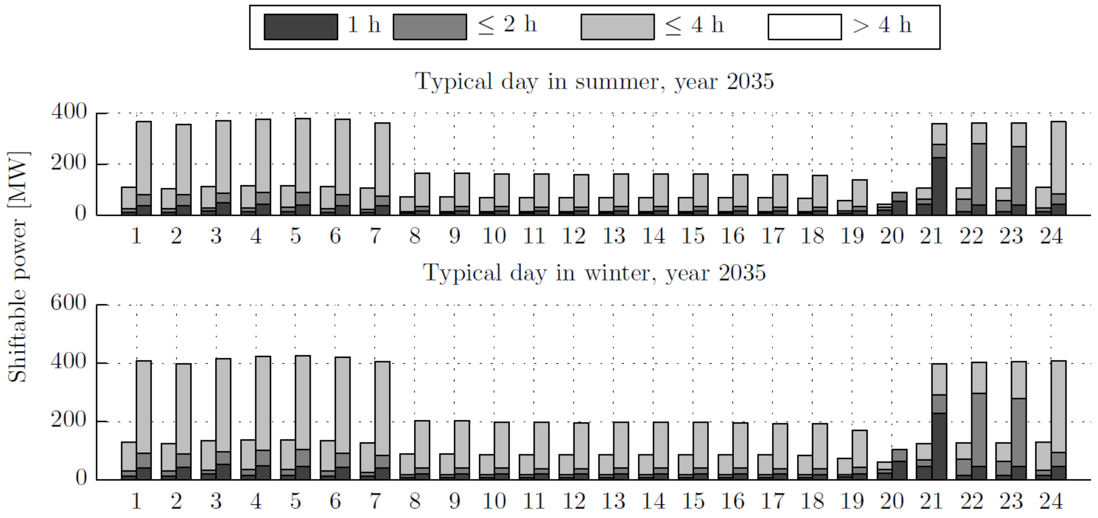

Figure 4-11: Estimated shifting potential of electric vehicles for the year 2035. The left bar represents the business-as-usual scenario (wwb) and the right bar the progressive scenario called “new energy policy (NEP)” [87].

4.3.3 Netherlands

Several pilots and studies have been conducted in the Netherlands on the potential of DR. The pilot Your Energy Moment showed that the smart controlling of heat pumps in combination with dynamic tariffs (TOU) can result in a 50% peak reduction. The same pilot provided participants with PV-systems and smart washing machines (next to a dynamic price) and studied the potential of shifting the energy use of the washing machines to hours where PV-production was high. The results show that the average energy demand of washing machines of the participants was 18% higher than the reference group during high PV-production and 31% lower when the energy prices were high. Furthermore, the pilot showed that a 48% peak-reduction is possible for those who used the automated washing programs [91].

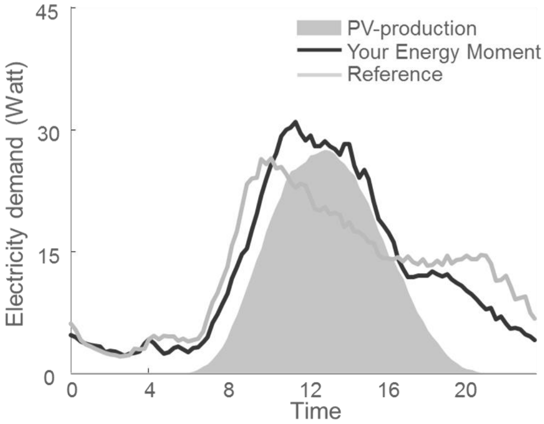

Figure 4-7: Electricity demand of the washing machine during the day for participating households and for the reference group with the average PV production.

Experiences of pilots in Netherlands show the potential of DR, however it also shows some barriers that need to be removed. Examples of this are social behavior, tariff structure and technical capabilities of appliances. Consumers need to change the behavior of their energy use patterns. Are they willing to? Will it be a structural change? On the other hand what can the consumers be offered? Which incentives provide the consumer the needed step to live up to the potential of DR? Third aspects are the legacy devices, which are not yet capable of DR. Several pilots conducted show interesting results, however upscaling seems difficult. The pilot Couperus showed a nice paradox: on one hand consumers wanted to be in control (which leads to a lower incentive), on the other hand the financial incentive offered was too low. So the potential exists yet execution is very difficult.

4.3.4 Sweden

A number of studies are currently ongoing in Sweden to assess the overall DR potential in the total Swedish system. A recent such study estimates the total available flexibility to be in the range of 3000-4500 MW for both industrial and residential consumers [92] with obvious variations in duration and endurance. A more comprehensive, but slightly older, study estimates the total flexibility available in the household sector to be 2000 MW [93].This is obviously dependent on time of year, since the main usage is for space-heating during the cold winter-months. Detailed studies at the household level estimate the potential for demand response in one individual household to a flexibility of up to 15kWh that can be moved within the day with negligible impact on comfort levels [94]

Furthermore, according to study [95] the maximum flexibility in load during one hour in Swedish single-family dwellings with electrical space heating is estimated to be 5.5, 3, 1.5, and 4.5 GWh/h for the different seasons (winter, spring, summer and autumn).

4.3.5 India

Demand Response is at pilot stage in India. There is no specific report indicating overall DR potential in India. However, a study conducted by a private utility (TPDDL) mentioned that fully air-conditioned commercial buildings contribute significantly to the peak shortage of power and air-conditioning in commercial and domestic buildings put together is about 40%. The demand for electricity is growing at 12-15% annually in the commercial sector. It is expected that the requirement of electricity would increase with time and is significant in commercial sector. This would create a lot of opportunity for demand response for peak shifting.

4.3.6 U.S.

In the US a number of projects have been analyzed by the Rocky Mountain Institute [5] regarding potential and cost/benefit. These are referred to in the subtask 12 deliverable.

4.3.7 Germany (E-Energy)

A detailed study of five E-Energy projects within the project EcoGrid-EU was recently published in report D7-2, (Annex B) [96]. The analysis shows that DR potentials are dependent on the specific DR tariff scheme. Highest potentials have been achieved by rare price events (CPP) in combination with TOU tariffs (20%-30%), as opposed to complex tariff schemes (3-10%).
Further influencing factors are:

- time interval (weekdays, weekend, and season),
- fatigue effect
- motivation of customers (for manual response)
- degree of automation

Figure 4-12 shows an overview of different DR schemes with different characteristics like motivations and automation mode. Note that the aforementioned factors influence the results as well as the number of participants.

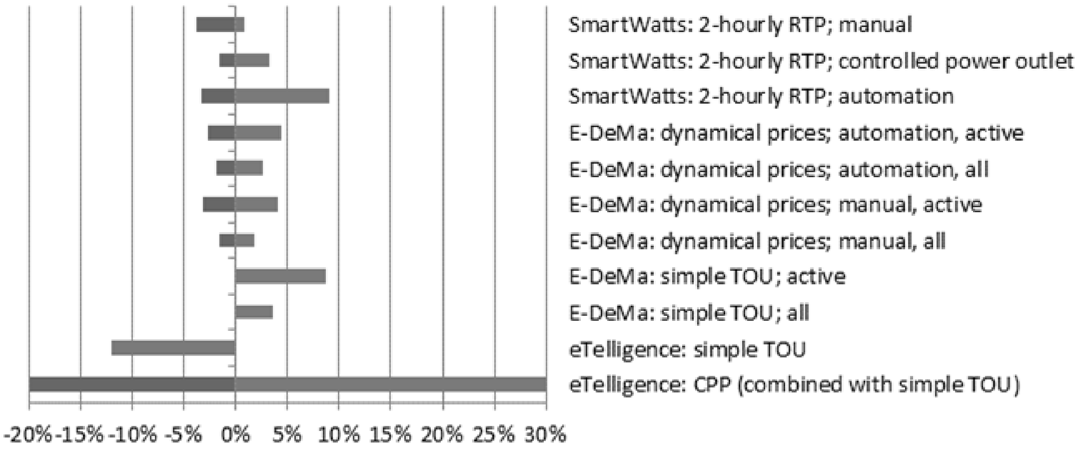

Figure 4-12: Comparison of reported load shifting potential (in %) - from high to low price periods - of DSM tariffs with different characteristics in three E-Energy projects [96].

Load shifting potential of Moma (E-Energy)

The price elasticity was examined in detail in the project moma. moma was the only E-Energy project that introduced random real time prices independent from prices at the energy exchange, weather or time of the day.

The highest share of the participants (45%) reported to react to the price information for the current and next day provided by the app / metering portal, whereby 25% reported to react to price categories and 20% to the precise prices. On average the price elasticity[4] is -10.6% for all participants, but these elasticity results mainly from strong reductions from highly motivated consumers. It could be shown that the season, weekday and time of the day influence the flexibility of the participants. During summer

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[4] In the analysis of moma the own-price elasticity measure is used. The value of the price elasticity is given as a percentage for a better understanding.

the flexibility is higher than during winter time. The flexibility potential is high during transition periods in case thermal storages like heat pumps are included.

The elasticity is further analysed for **different groups:** manual and automation, manual, automation and nothing (see Figure 4-13). The highest price elasticity of -23.6% on average was reached by the group that shifted the loads manually as well as used the energy management system to shift loads automatically. During the evening hours the price elasticity went up to -35%, as can be seen in Figure 4-13. The group with only manual shifting had a relatively high elasticity of -19.5%. In the group with only automation most probably the participants are less motivated than the ones that use both automation and manual load shifting. One more reason could be that they are not aware of their ability to influence their consumption further.

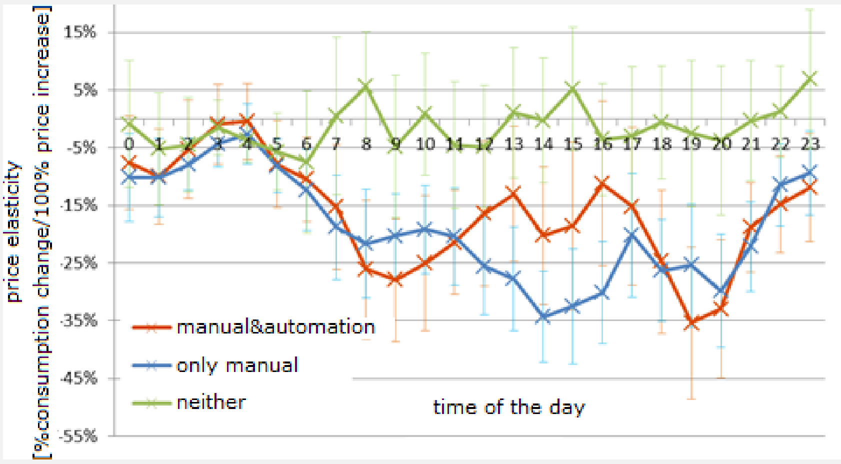


Figure 4-13: Price elasticity per user groups during week days in project moma [97]

Load shifting potential of eTelligence (E-Energy)

In the simple time-of-use tariff (TOU) the participants reduced their load on average by 12% during the high price time from 8 am to 8 pm. The **event tariff** in eTelligence was announced between three and one day ahead of the events. Malus events triggered a reduction of -20% on average, bonus events triggered an increase of +30%. As a consequence in total more energy was consumed than saved with event tariffs. With CPP a load shifting of 20% from times with high prices to low prices could be achieved.

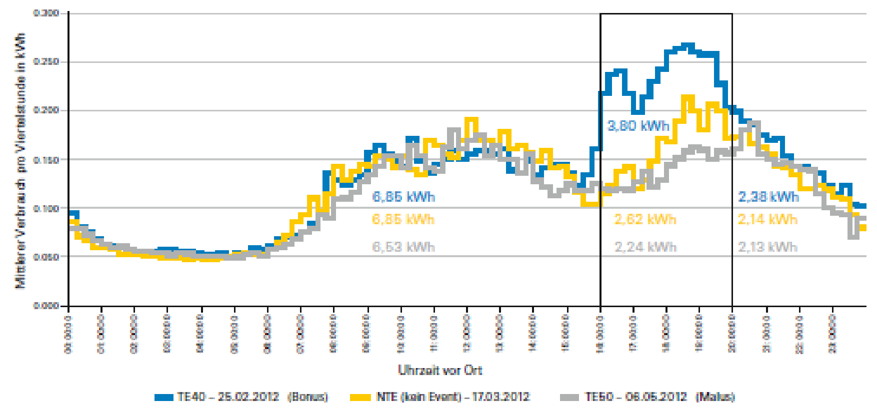


Figure 4-14: Changed load profiles with CPP during day on weekend (blue=bonus; yellow=no event; grey=malus) in project eTelligence [98]

5 Implementing Residential DR

5.1 ICT Enabling DR Automation and Integration

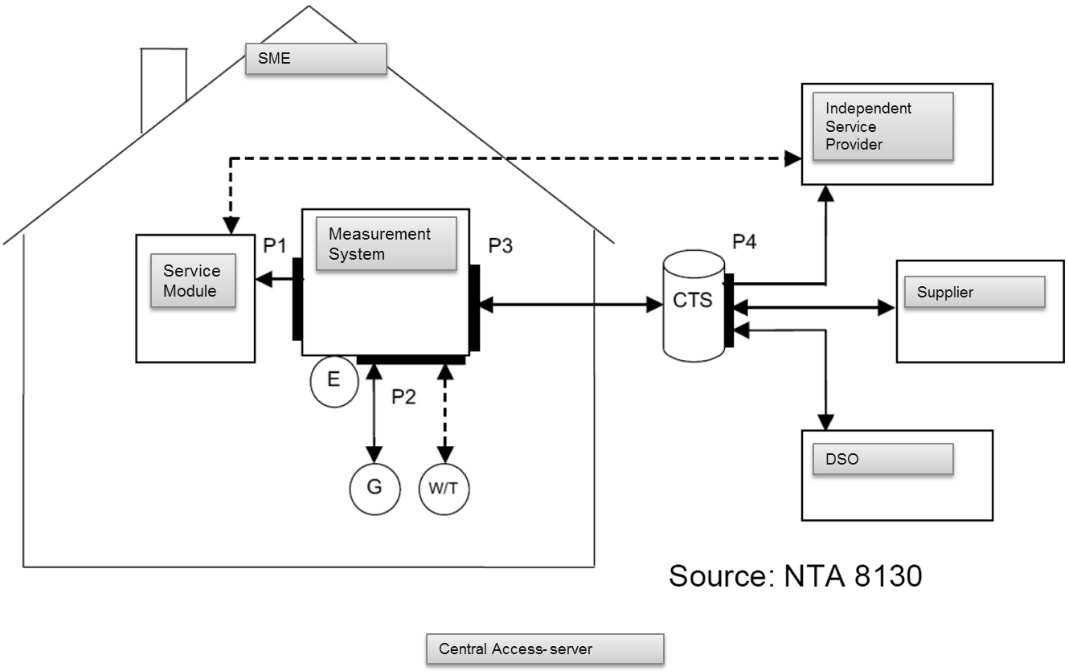
5.1.1 Smart Meter (SM) or communicating meter

Role of Smart Meters

Communicating meters, able to measure, store, send and receive data with a small time resolution, play a pivotal role in activating the demand. Such meters are commonly referred to as smart meters. Mainly, smart meters are being introduced out of energy efficiency reasons. By increasing the information feedback and the billing frequency to the end consumers, the meters together with relevant visualization tools will help to increase efficiency and reduce electricity consumption. Increasing the perception and knowledge of end consumers is the key. The amount to which extent such energy efficiency measures will be realized is widely debated in Europe and ranges from 1% to up to 5% or so.

Though energy efficiency is a main driver, there are many other benefit which smart meters offer. They offer a better planning, operation and management of electricity networks, a better management of renewable energy infeed, a support and a better management of self-consumption, new tariffing possibilities and finally, smart meter support liberalized electricity markets as data provision for switching processes is simplified. Market barriers are reduced. Therefore, regulation in many countries strives to introduce smart metering. Often minimum technical requirements for this new technology are defined by regulations in order to ensure the realization of the anticipated benefits and create a homogeneous platform for electricity markets. Besides ensuring privacy and data security of smart metering systems, these minimum requirements are designed to support DSM to some extent as large benefits in harvesting demand side flexibility are assumed. Depending on the functionalities of the meter, it can utilize dynamic pricing and can therefore assist demand response schemes transmitting the price signals to consumers.

In general, the SM infrastructure creates the basis for providing measurements faster, more accurately and with a higher granularity than today. That enables more advanced control schemes than for instance the ripple control offers; individual loads can be controlled in contrast to large numbers and clusters of loads at once. The communication technology used for SM is however often limited e.g. in bandwidth, as the main purpose of the infrastructure is to provide measurements in the range of 15 minute load profiles. Different technologies exist to connect to the smart meter with a central data management system that often also performs control. Technologies include optical adapters, PLC or wireless media. An example of a communicating meter definition is NTA-8130 [99] in the Netherlands. The standard prescribes the requirements for manufacturers in the Netherlands. Initially, there were also proposals to implement control requirements in the definition. However, only the remote disconnect functionality is mandatory. Hence, it must be kept in mind that the SM does not constitute the most optimal path of communication to the individual appliances for all purposes. In many cases, alternative means of communication to appliances are more cost effective and offer a larger potential for using the appliances for DSM.



Source: NTA 8130

Figure 5-1 Hardware architecture smart meter in NL

The architecture discriminates 4 communication ports, from which one (P1) produces 10 sec readings of the momentary electricity production or consumption. The latter port has a simple serial interface to be used by local energy management systems. The P2 port serves gas and water readings, while via P3 metered data with sufficient quality for taxation are collected within 15 minute intervals. Finally ‘P4’ presents the outside world database collection of these data. Not all countries have the defined the architecture to this extent. Some countries leave this rather open and only demand general functionalities, supporting important use cases.

SM supports also the use cases in the area of ancillary services in terms of measurements and billing. For providing ancillary services to the TSO, it is necessary to prove that loads really reacted to the control signals fed to them and provided the necessary service. SM further supports DSM use cases in the area of home automation. It is necessary to transmit measured quantities of energy or actual power consumption to a home or customer energy management system along with incentive signals –such as for instance prices – in order to perform optimization and demand response. Different technologies exist to connect to the smart meter with a central data management system that often also performs control. Technologies include optical adapters, PLC or wireless media. An example of a communicating meter definition is NTA-8130 [99] in the Netherlands. The standard prescribes the requirements for manufacturers in the Netherlands. Initially, there were also proposals to implement control requirements in the definition. However, only the remote disconnect functionality is mandatory.

Data security and cyber issues are of big interest and bear substantial risks. Implementing the remote disconnect functionality in a secure way led to an increase in the cost of a communicating meter by 50%. Access to quarterly P4-data by energy service providers is currently blocked by the Dutch grid operators because of security and privacy reasons.

5.1.2 Smart Homes, Smart Appliances and Home Energy Management Systems

Smart Homes can be considered as a superordinate concept. Smart Homes consist of controllable appliances, connected to a central control entity referred to as a Home Energy Management System (HEMS). The HEMS or the building is connected to a SM, which is the interface of prosumers with the electricity grid and the markets. As discussed for SM, ICT is essential to activate consumers and harvest flexibility. Smart Home solutions can be used to interconnect appliances in buildings and control them with respect to a preset goal. Smart home solutions are widely available for commercial buildings and can be counted as an enabler for DR programs [37]. In order to establish a Smart Home, appliances need to become more and more equipped with communication and controls to connect with a central control unit. Examples of devices, which are currently equipped with ICT (smart devices), are:

- Heat pumps
- Boilers
- Refrigerators/Freezers
- Air conditioning systems
- TV and entertainment systems

The HEMS has the central role of coordinating different resources within the smart home according to the present optimization objective. Most of the time, it will keep the comfort of the owner within predefined settings while achieving also other goals such as increasing cost savings, energy efficiency, self-consumption of generated energy or reacting to DR signals from external actors. HEMS in combination with SM may act as a gateway from the smart home to the smart grid and enable the participation in grid based DR services [97],[100]. In the following, several examples of control objectives are given:

Example 1: Energy management and optimization

According to the given objectives the optimizer tries to plan and schedule shift able loads in advance, which includes the need for forecasting of the usage. This can lead to pre-charging of energy storage (buffers) like warm water tanks or charging of electric vehicles prior to times of use. It requires to have detailed information about usage of individual devices and requirements (e.g. heating, air-conditioning), thus needs to adapt to consumer behavior, as well as detailed information about weather and other influencing factors (e.g. weekday). Algorithms based on different methods have been proposed in research and realized from manufacturers.

Typical tasks of the optimizer includes modeling of the HVAC system and thermal coefficients of the building as well as non-intrusion based detection of house occupancy or by dedicated sensors for motion, thermal heat or vibrations [101]. Additionally a dedicated button can signal the presence of the user.

Example 2: Optimization of self-consumption: increase direct use of generation

Many investigations and research efforts are done to investigate potentials of various controllable demands to shift demand into times of excess generation (e.g. PV). By using the net difference between generation and demand (e.g. smart meter measurement) the resources are operated to match the surplus or shortcoming of supply. In [102] investigation on self-consumption by use of smart meter data and a variable speed HP shows that it can be increased. The thermal storage is utilized with PV excess only in summer, because in winter it is directly used by the load.

Example 3: Optimization of self-consumption by model predictive control (MPC)
Increased use of excess electricity by optimization with model predictive controls looks promising as various studies demonstrate [103]. MPC has influence on the energy efficiency as well as the load shift behavior of the thermal inertia of the building. The choice of the prediction horizon is a compromise between the load shift potential and the dynamic or stability of the room temperature.

For the automation and control of DR, generation and battery systems through HEMS, it is important to define use cases carefully. A possible architectural implementation of a HEMS is shown in Figure 5-2. The system interacts with a smart meter (SM) and has connections to individual power consuming or producing devices and appliances within the building. It also interacts with other external parties, such as aggregators and/or distribution system operators through a communications interface, likely provided via the SM. Given the advancement of technology, applications can be developed, which enable the harvesting of more and more flexibility. Cloud-based ICT architectures can decrease the hardware footprint of the local HEMS and use the local ICT only as a gateway that supports a service protocol (e.g., OSG-i).

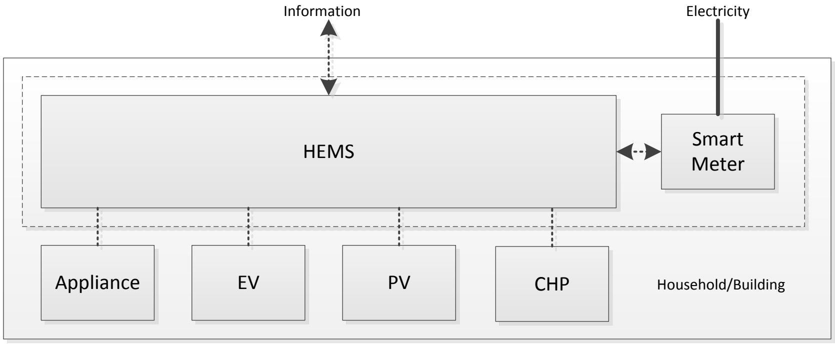


Figure 5-2: Possible interaction of a Home Energy Management System (HEMS)

Figure 5-3 shows an example of a HEMS [101] and potential communication protocols and formats for exchanging measurement and control signals. The main components are the interfaces to the smart meter system for monitoring the consumption and receiving price signal information and the interfaces to the home appliances to dynamically shift the load according to the objectives. Also a Digital Living Network Alliance (DLNA) network is depicted to represent multimedia applications.

Another main issue is providing connectivity and interoperability between different devices and controllable loads and the user for configuration, parametrization and monitoring. A major concern is the implementation of various different non-compatible smart device standards from different manufacturers. Currently used standards are Zigbee SE, Z-Wave for Home Automation or OpenADR for interfacing building management systems.

HEMS inherently offer the potential to connect to other systems via Ethernet (and VPN), like an aggregator or central controller for coordinated, pooled operation on energy markets, depicted as the box titled Service Provider. Currently most commercial information systems have moved to the ‘computing cloud’. This means, that the HEMS application logic also easily can be moved as well to a hosting provider, leaving just a very tiny information system necessary at the residential premises controlled by an app. This is where the current developments regarding the IoT also come in.

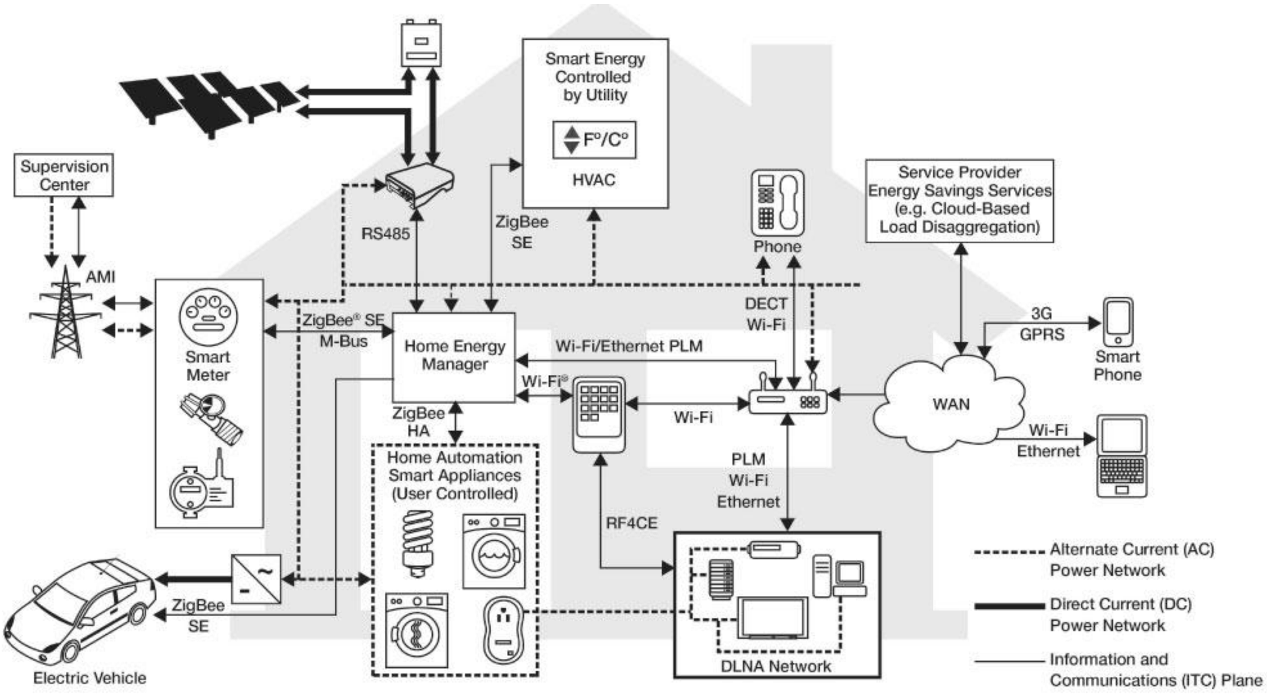


Figure 5-3: Example architecture of a Home Energy Management System (HEMS) [101]

In multi-residential buildings equipped with HVAC systems, it has been shown that intelligent operation of the building energy management system with respect to external DR signals (grid or market based) lead to an improved operation and cost savings [84].

5.1.3 Connected Buildings

Integrating energy consumption and production by installations in buildings into electric grid coordination for grid operation- and other energy infrastructure like gas and heat – can enable larger energy and business efficiency. Interoperability is seen as an essential requirement for intra and inter-building information exchange of equipment and systems. The following key functionalities define a connected building:

- Enables transactions for negotiated energy services across the customer connection point
- Integrates automated, connected, “smart” equipment (energy sources and sinks) to coordinate buildings operations for energy efficiency and financial benefits
- Supports the scalable integration of energy efficient technologies, such as PV and EV chargers
- Provides awareness, visibility, and control to serve the flexible preferences of its managers, operators, and occupants

5.2 Consumer Participation and Automation

5.2.1 Services for energy consumers

In 2001 an extended market survey was done in the Netherlands regarding services to energy end-customers [104] under 1700 end-user consumers for a customer segmentation with four groups.

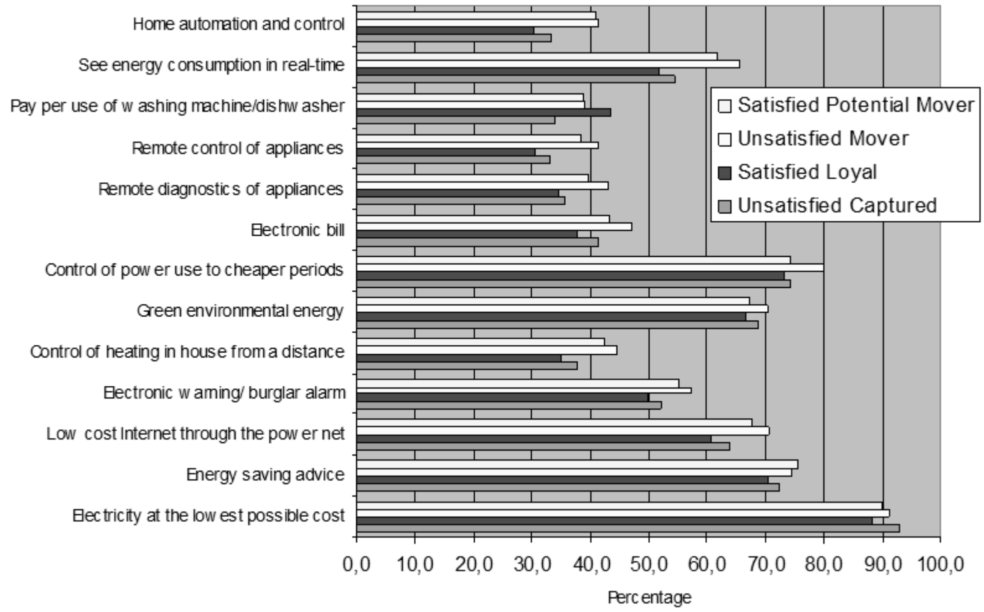


Figure 5-4 Customer perspectives on new services

The results of this survey can be found in Figure 5-4. A well-articulated demand was found for the energy services also now in discussion. In the same survey (see Figure 5-5), a price elasticity was found of 5-10 percent for 30 % of the customers allowing these services to be implemented. After 15 years, this demand from customers for energy services has only been fulfilled partly in some countries. A number of products now are on the market using this price-elasticity window. A number of hurdles, however, still have to be overcome. The main hurdles have to do with shared benefits for stakeholders, that complicate business models, privacy issues, constraints from regulatory and energy market design, taxation and subsidies and lack of interoperable technical standards.

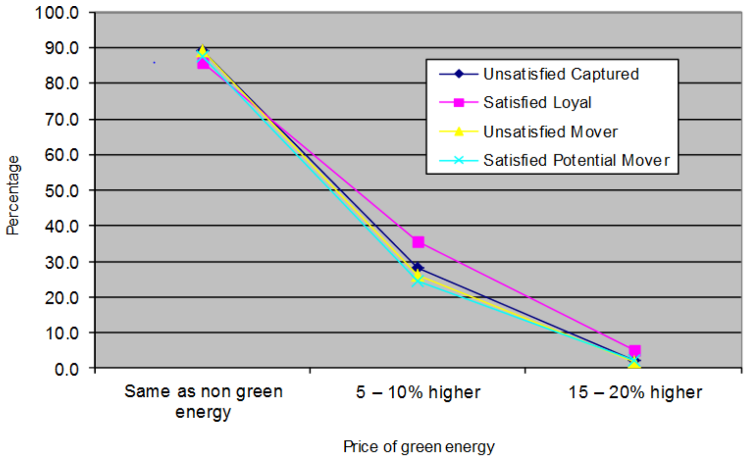


Figure 5-5 Price elasticity for energy services

5.2.2 Consumer participation and behavior change

Behaviour change and the drivers of persisting adaptation in usage and investment behaviour has been the subject of other tasks in the IEA/DSM programme [105]. Ways to uncover the energy efficiency potential and also the relation to demand response has been analyzed. In one of the cases in the Netherlands analyzed in task 17 some preliminary experiences have been collected.

The Netherlands

In PowerMatchingCity-II [66], together with the inhabitants, two energy community services were developed. With ‘smart energy saving’ costs are kept to a minimum. Together with comfortable renewable the need from the inhabitants to live using renewable energy resources is key. Three control schemes are used: Automatic (HVAC), semi-automatic (washing machine) and by-hand (dish-washer/dryer). Solar panels generate electricity. 40 households are involved. An energy monitor helps the inhabitants to fine-tune the energy services. In one of the streets of PowerMatching City, Thomsonstraat, a residential area monitor is installed. Analysis of the results indicates a yearly flexibility potential for each micro-CHP of 21 EUR, for each heat-pump of 28 EUR and for each electric car of 58 EUR [106] .

A similar infrastructure has been built in Hoogdalem, where heat pumps and electricity storage are used extensively in an even wider setting of 32 homes. The average load factor per household there is much larger than for a traditional Dutch household. The grid is laid out to adapt to this. Hoogdalem features an USEF implementation of an all-electric district.

5.2.3 Automated DR

Many studies came to the conclusion that automated demand response has a higher success and acceptance can be achieved if certain requirements are met [84],[107], [98], [80]. One main aspect is to preserve the comfort, while the interaction with the DR runs automatically without need for user interaction. Opt-out possibilities give the customers a feel of control and security.

5.3 Aggregated Behavior of DR Resources

Large numbers of DR resources can be aggregated and controlled as one resource for the power system. This is necessary as the product design in electricity markets is often focused on larger power and energy amounts. Products which are too small, say in the area of several hundreds of kilowatts increase the cost of market operation and transaction costs substantially and can still be considered inefficient. Though there several use cases for such a resource often the first possibility which offers a business case is marketing such a resource on ancillary service markets of the TSO. Also there, product design is focused on rather large quantities of power and energy, say in the area of megawatts. Hence an aggregation is a must. Furthermore, the aggregation offers a robustness in offering reliable services to the TSO or to the market, as individual demand is often determined by a rather stochastic behavior and hard to predict. Ancillary service markets offer a rather high price level and hence set forth the needed signals for investments.

Austria/Switzerland: Aggregation for frequency control with electric boilers / heaters and heat pumps

As an example of providing DR service to the secondary control market, the flexibility of electric water heaters for domestic usage is tapped, preserving comfort without customer impact. The market has been recently opened to allow pooling of (very) small units. Boilers of a certain manufacturer are prepared and can be equipped with GPRS connectivity. The status of storage is permanently communicated and monitored for system control purposes. The new market player from the telecommunication sector knows to deal with secure data and customer involvement. Figure 5-6 depicts the concept for providing flexibility with electric water boilers.

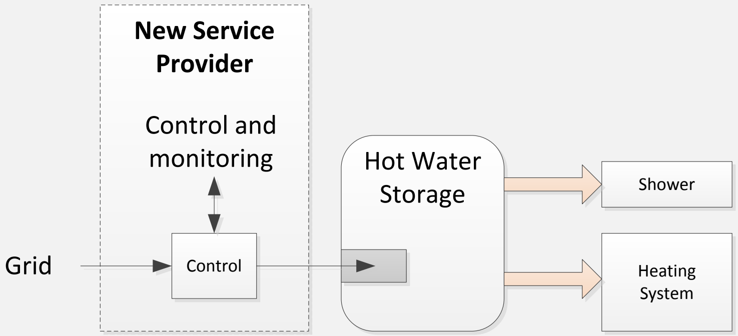


Figure 5-6: Example for providing balancing reserve with electric water boilers [37]

5.4 Evaluation, Measurement, and Verification

EM&V is a key requirement for establishing successful DR programs. The following topics need to be covered with respect to this requirement and the difficulties associated with it [108], [109]:

- Quantification of expected gains
- Identification of customer's baseline demand/usage
- How are energy consumption reductions measured – no common standards exists.
- Different evaluation criteria between TSO, BRP and retailer may exist
- Level of M&V: aggregator vs. household (pre-qualification requirements)
- Lack of EM&V is seen as a market barrier for consumer centered DR services
- Costs of EM&V, which might be different between approaches and might even need different levels of EM&V

One of the *main objectives* of EM&V is to quantify the provision of a service according to the product specification:

- Qualify potential resources as an entry gate to participation
- Verify resource conformance during and after participation
- Determine amount of product delivered as part of financial settlement

From the above mentioned issues the following EM&V *requirements* can be derived in order to qualify and deploy DR services and products:

- Methodology of baseline metering (i.e. metering configuration), if approach needs it.
- Measurement / Metering of DR product delivery
- Communication requirements i.e. availability, control signal response, security
- Exchanging the metered information, including format and protocol
- Measurement interval, reading frequency / sampling and accuracy
- SLAs of the DR product

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