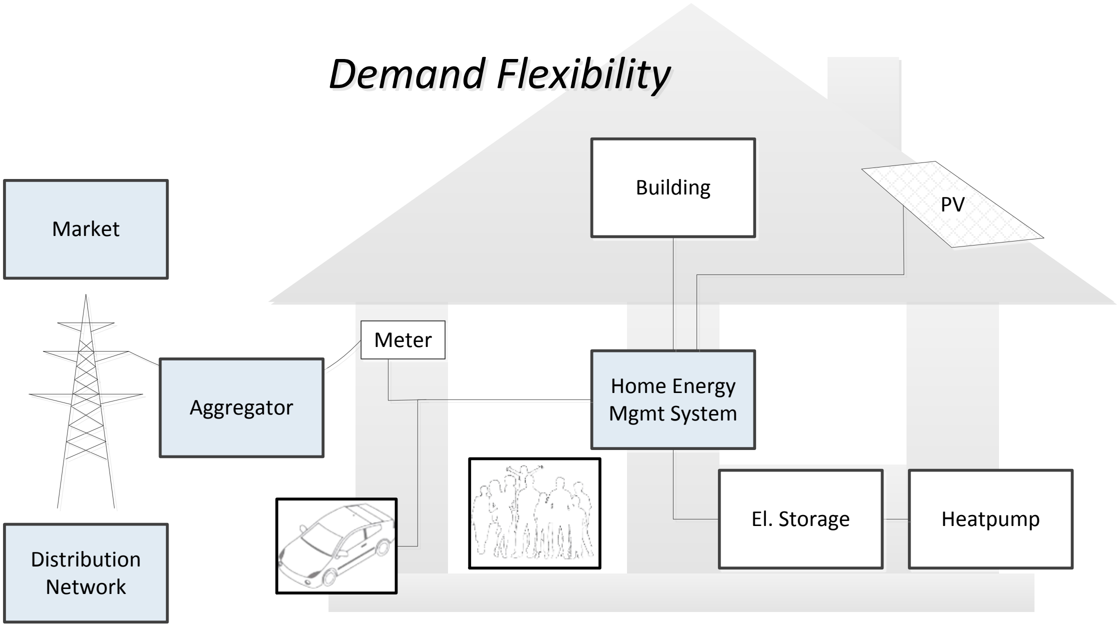

IEA DSM Task 17

Conclusions and Recommendations

Demand Flexibility in Households and Buildings

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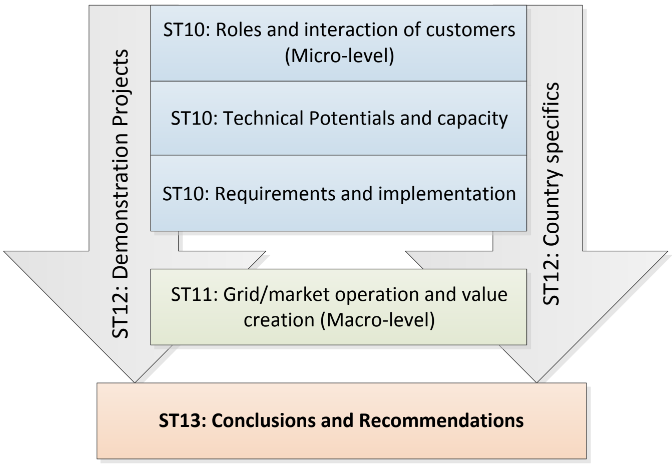
Contents

Foreword

Context

Task 17 phase 3 of the IEA/DSM program has provided an analysis and assessment of the use of demand response, distributed generation and storage for electrical energy systems operation [1]. The project consisted of four subtasks. A document has been delivered for each of the subtasks. Subtask 10 described the context and covers the current role and the interactions of flexible consumers and producers in the energy system. Subtask 11 covered the changes and impacts on grid and market operation once optimally using demand flexibility and includes cost/benefit analyses. Subtask 12 collected experiences and described best practices in several countries in Europe and the US. This document finalizes subtask 13 and gives the conclusions and recommendations.



The scheme above illustrates the working process in the task with a micro- and macro-context level covered in subtasks 10 and 11 respectively and a demonstration projects assessment track, also handling country specifics in parallel in ST12.

Aim of the document

This document aims to formulate general conclusions and recommendations for applying and implementing demand flexibility to increase the penetration of DG-RES, DR and storage in electricity grids.

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 bi-annual workshops. The document starts with an introductory context description of the use of end-user electricity flexibility resources. Then, DR-automation and aggregation at several levels are discussed, followed by the potentials of different flexibility offering technologies in terms of kWs and kWhs. Then, the lessons learned on valuation of these potentials and on cost-benefits in grid and market operation are given. The report ends with a number of recommendations to come to an optimal societal benefit for the upcoming end-user demand response mechanisms and distributed and dispersed generation and storage technologies.

Executive Summary

Use cases for combining application of DG-RES, DR and storage technologies in commercial and grid operation for providing demand side flexibility on various timescales and aggregation levels have been assessed in IEA DSM Task 17 Phase 3. Technologies have been also investigated in terms of financial and technological implementation potential as well as their availability.

Driven by energy efficiency measures, traditional uni-directional end-user demand response applications, like ripple control activation for hot water production and thermal storage are beginning to transform in most countries. As a successor, most promising use cases can be found by local controlled heating, ventilation and air-conditioning (HVAC) applications utilizing the inherent thermal storage capability of buildings, in some cases combined with dedicated heat storage (e.g. water tanks). These allow significant flexibility in energy delivery time and momentary power that can be utilized in commercial or grid operational settings, respectively. The next step on this evolution is seen as the bidirectional – or transactive approach where the optimization and utilization is a mixture between local and central application (e.g. balancing market or grid congestion services).

The boundary conditions for implementation and the business case for the end-customer segment are quite different from the commercial customer HVAC segment. In the end-customer segment, technology readiness levels, ICT-interfaces and business model viability have come very close to a level allowing massive rollout. Key here is the embedding and establishing of the aggregator role in the regulatory and market context. Uncovering energy flexibility in the commercial HVAC segment, where interfacing of technologies to building management systems and compliance to user comfort requirements have a higher complexity, have more potential but are more difficult to achieve.

'Wet' end-user appliances also allow for significant energy flexibility potential, but are more bound to customer behavior and manual control as opposed to automated control applications. Dish washers, washing machines and laundry dryers, in this order, have the most potential. The overall increase of energy efficiency of these devices in the last decade however has led to a decrease in the possible volume of energy that can be shifted. Predominantly, use cases for these technologies are at the optimization of self-consumption, community energy balancing and ancillary services on the distribution level. Examples are: usage of the washing machine when the PV system generates electricity or transformer life extension serving the distribution system operator by congestion management (e.g. active power curtailment). A similar energy efficiency improvement holds, even to a larger extent, for end-user freezing and cooling appliances. For these appliances, use cases can be found in load shedding and post-blackout startup scenarios in future high DG-RES electricity infrastructures. The potential for the use of commercial customer freezing and cooling is much higher. In this sector demand response applications are already known and in operation.

The optimal voltage level and the size requirements of electricity storage, for commercial and grid operation applications, strongly depend on the market design and the grid topology and operation scenario. At this moment, high cost of electricity storage are found to lead to an emphasis on hybrid energy systems with heat storage, allowing decoupling of electricity market operation and heat demand driven operation, and new operational concepts like main grid coupled micro-grids.

Coordinating non-fast charging of electric vehicles at user premises represents an additional option for creating electricity flexibility at lower grid levels. In some regions the requirements for controlled charging is much higher, since the impact on the grid could be negatively influenced by certain grid tariff structures (e.g. night-time tariffs). From the contracted rated power of the end-customer’s grid connection a local optimized controlled charging will be needed as soon as EVs are connected at household levels.

Due to the increasing level of connectivity through the internet, barriers to the implementation of DR aggregating applications, like the cost of ICT connectivity and lack of communication protocols and standards to uncover demand flexibility, are becoming much lower. Coordination mechanisms of large numbers of devices have been shown in several pilot projects to be implementable, well-received by end-users and operational during several years. Bottom-up decision making combined with bidirectional communication mechanisms here provide most functionality and improve resilience.

In the current market design and the regulatory context, the role of the new stakeholders and participation of new actors, like prosumers, are not fully reflected or are even blocked. Improving market access for end-customers and better mapping of tariffs to the actual impact on grid components are recommended.

Abbreviations

AC	Air Conditioning
ADR	Aggregated demand response (openADR)
BRP	Balance Responsible Party (EU)
BA	Balancing Authority (US)
BACNET	Building Automation and Control Network
BEES	Battery Electrical Energy Storage
B2B	Business to Business
BEMS	Building Energy Management System
BRP	Balance Responsible Party
CAPEX	CAPital EXpenditures
CBA	Cost Benefit Analysis
CHP	Combined Heat and Power
DER	Distributed Energy Resource
DF	Demand Flexibility
DG-RES	Distributed Generation with Renewable Energy Resources
DHW	Domestic Hot Water
DNO	Distribution Network Operator
DR	Demand Response
DSF	Demand Side Flexibility
DSM	Demand Side Management
DSO	Distribution System Operator
DF	Demand flexibility
DG	Distributed Generation
EE	Energy Efficiency
EF-Pi	Energy Flexibility-Platform and interface
EMS	Energy Management System
EV	Electric Vehicle
FSP	Flexibility Service Provider
HEMS	Home Energy Management System
HVAC	Heating Ventilation and Air Conditioning
ICT	Information and Communication Technology
IoT	Internet of Things
ISO	Independent System Operator

LV	Low Voltage
MV	Medium Voltage
MO	Market Operator
OPEX	OPerational EXpenditures
PRP	Program Responsible Party
PTU	Program Time Unit
PV	Photo Voltaic
RES	Renewable Energy System
RPM	Rotations Per Minute
SCADA	Supervisory Control and Data Acquisition
SDF	Supply Demand Flexibility
SOC	State-Of-Charge
TCL	Thermostatically Controlled Load
TNO	Transmission Network Operator
TRL	Technology Readiness Level
TSO	Transmission System Operator
UCTE	Union for the Coordination of the Transmission of Electricity
VPP	Virtual Power Plant
VPN	Virtual Private Network
V2G	Vehicle to Grid

1 Introduction

1.1 Context

Within the DSM program of IEA a number of tasks already have been devoted to studying different aspects of end-user demand response. The behavioral aspect has been studied by task 24 [2] showing that applying DR is not only trying to find a technical solution but also requires close interaction with stakeholders. Multi-stakeholder innovative business modeling is covered by task 25 [3]. Task 17 [4] [5] [6] focuses on an inventory from the market and grid operational perspective and on technological implementation aspects and assessment of field trials. Furthermore, alterations in commercial and grid operational strategies and cost-benefit analysis methods are part of the task. Task 17 thus far has seen two earlier more qualitative phases, that laid the basis for a more quantitative approach followed in phase 3.

In order to reach carbon dioxide reduction targets, renewable energy resources deployment, with 50+ % renewables in the total real-time electricity production at some times, has increased to a level that has a definite impact on managing the electricity infrastructure for the TSO and for the DSOs in more and more countries. Furthermore, this infrastructure needs to accommodate significant new electrical load types due to substitution of the traditional energy carrier to renewable energy. The most prominent new application types here are HVAC applications, where heat pumps are replacing gas-fired boilers, and mobility applications where fossil fuels are substituted by electricity leading to an increase of the number of high-volume and, for fast-charging, high capacity EV chargers connected to the grid.

To handle these new developments, in the electricity sector, interconnectivity between electricity systems via high volume transmission lines is increasing. In this way balancing demand and supply across time-zones or climate zones is facilitated. This also creates possibilities for international market connections over control zones leading to more and better competition. On the other hand, micro-grids and increased energy autonomy at the lower voltage levels in the grid are receiving a larger interest from the grid operator and the energy community’s perspective. So, both ends are part of the solution to the problem of integrating large-scale wind and distributed and dispersed DG-RES generation like PV in the electricity system. The MV-part in the middle, being the domain of the DSOs, also is heavily involved in the transition. In this new realm, energy and electricity supply/demand flexibility is considered to substantially increase the renewable electricity uptake potential.

1.2 Evolution in stakeholder’s roles

The electricity system is in a transition from a hierarchical top-down system with high volume electricity generation facilities only at the higher voltage levels to a more distributed system with electricity production facilities at all grid levels. Apart from the technical operation perspective, this also has consequences for the societal context of power systems and thus for the way actors interact regarding the utilization of flexibility and who has to pay for what. Figure 1-1 depicts the societal context of power systems for end-user flexibility. Using electricity flexibility in commercial operation mainly involves exchanging volumes (kWh) in a predefined period (PTU). Using this flexibility in operating transport and distribution grids mainly involves managing instantaneous power (kW). With the advent of DG-RES, especially PV, investments are done by end-users and they are connected to revenue flows via feed-in and net metering schemes.

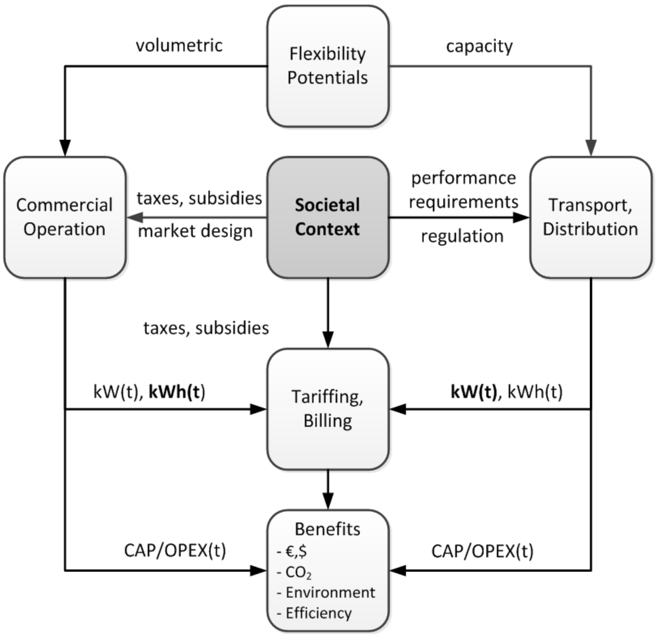


Figure 1-1 Context of flexibility in power systems

From an energy system and societal point of view, optimal use of demand flexibility in such an electricity system in transition is a multi-stakeholder/actor, multi-objective problem. Handling the challenges due to the increasing degree of embedding of electrification of DG-RES, HVAC and transportation electrification mainly has to be handled by the distribution system operators that currently are transforming to actors having an increasingly active role in operating and stabilizing grids on the local LV and MV level.

Traditionally, DSO business is driven for the most part by asset management. These assets require investments traditionally with a payback horizon of over a period of 30+ years. In their new role, they will become less asset driven with reduced investment horizons and more system operation focused trying to retain flat load curves as much as possible postponing or avoiding new investments and reducing losses. In that respect, they are becoming competitors for electric power and energy flexibility services to BRPs that act on the EntsoE control zone level. In this new context, consumers of electricity are transforming to *(pro-)active consumers*, providing demand flexibility or *prosumers* with net production surpluses at some times at the connection point. Local DG-RES production is supported by tax reductions, subsidies or feed-in tariffs that currently are decreasing in most countries because of their lack in financial sustainability.

The attribution of the cost of operation of the electricity system from the market and distribution perspective to supply and demand actors depends on the scale. For reconciliation of market operations to small customers, mostly, statistical averaging methods are used with aggregation of a large number of customers with an averaged synthetic profile. Customers, however, will have higher individual differences in their electricity consumption/production profiles. In the commercial/market dimension and the dimension of cost recovery, which is usually done via tariffing the end consumers, an evolution has to take place to achieve also fair settlement and reconciliation. From the transport and distribution perspective, maximum connection capacity based fees still form a major component instead of dynamic tariffs.

1.3 The opportunities raised by information and communication technology

The use of information technology, especially the communicating/smart meter, opens the perspective to include the individual, time-dependent electricity consumption/production behavior into account. Also to use real-time, measured values in operating an aggregated number of consumers/producers (VPP) on the electricity market or for grid operations is becoming possible. The advent of smart meters also allows attributing cost, depending on the price or near real-time electricity market position or the operational grid status, more accurately. Information systems are also found to allow increasing end-user feedback and interaction leading to increased energy efficiency. In the sub-division between commercial and system operation per country or state - analyzed in this task - the picture varies from vertically integrated utilities with all the actors in one company to multi-actor liberalized settings. In countries with liberalized energy systems, retailers play a new role in the articulation of the bare electricity consumption or production energy (kWhs) to individualized products, enabled by ICT, linked to renewable or efficiency targets. The interaction between stakeholders in the new settings, required for increasing the DG-RES embedding potential, is changing and new players are appearing. New services, specifically applicable to demand flexibility in the residential sector, are able to enrich the aggregator role, which is already in operation in the small-business and commercial sector of BRPs. Aggregation also is occurring at the community level where it unites consumers or producers with common financial targets or renewable energy objectives like using local, green electricity. These types of communities are operating in the US and certain countries in Europe.

1.4 Business models

Business models in the electricity sector have become more transient in the past decade. Commercial operation in this sector requires increased agility and dynamics. In North-Western Europe, overcapacity due to energy efficiency measures, low fuel prices and competition with an increased (subsidized), priority feed-in supply of cheap renewable resources has lowered the overall level of electricity prices but also of the dynamics/price peaks in the day-ahead markets. Profitable business opportunities on these markets have decreased. Business models in the new high DG-RES electricity system also involve multiple stakeholders with conflicting interests minimizing OPEX or CAPEX cost leading to the possibility of not equally sharing infrastructure costs and creation of free-rider effects.

Essential in the market context are electricity programs. An electricity program is a schedule of the amount of electricity to be consumed/produced per PTU in the future, at the connection point for a certain number of timespans ahead. To guarantee balanced schedules between supply and demand, according to the electricity law in most countries with a liberalized electricity system, program responsibility is defined for each connection point of a customer in the grid. Programs have to be submitted to the system operator a certain time-ahead period before actual delivery or consumption of the electricity. Mostly, especially for low-volume connection points, program responsibility is delegated to program responsible parties. Actual compliance to the programs is checked by reconciliation procedures using metered data at the connection point during the PTU or via synthetic profiles after production or delivery, if the per PTU metering data are not available. The synthetic profile method, in which the electricity consumption/production profile of a certain category of users is assumed to be represented by values measured in a small subset of the population, is mostly followed for small consumers and producers. With the advent of smart meters also to the level of households, opportunities exist for direct individual reconciliation of the time-dependent consumption or production of electricity.

According to electricity laws, balance responsibility, maintaining the instantaneous power balance between supply and demand of electricity, closely related to 50 or 60 Hz frequency control, is attributed to the TSO. A number of commercially operating markets and some legal obligations of large producers help the TSO to achieve this via a four time-step reserve mechanism using primary, secondary, tertiary and contingency reserves. Dependent on the electricity system stability properties, these typically can be activated within 2-60 seconds, 15 minutes, 15 minutes to 1 hour and once every few years respectively.

Meeting the high volume wind and DG-RES variable output requirements, value created by aggregation is shifted to target short-term markets related to balancing and application in contingency services. Also in new market designs, deemed required to increase the DG-RES uptake potential, creating markets operating in near-to real-time and having a more local operational scope are specifically targeted. This opens an opportunity for aggregated demand response and storage flexibility as the startup costs of these technologies are small, due to their inherent granularity, their ramp-up and ramp-down rates are high and the investment horizon is smaller allowing more agile business models.

1.5 Valuation of end-user flexibility

End-user flexibility in the electricity system can be realized using a number of incentives to the end-consumer. However, to make flexibility make a lasting resource, for most end-user electricity demand and supply technologies, the use of ICT for automation is indispensable. ICT is integrated or connected to user appliances for local optimization using local EMSs or for aggregation, to the metering and reconciliation processes and to operation of the power systems as a whole via aggregation in services as a part of ‘smart grids’.

In the Task 17 the picture in Figure 1-2 has been used to classify the topologies in which demand flexibility can be used. In the figure, the X-axis indicates the difference between unidirectional and bidirectional communication. The Y-axis indicates the decision making mechanism going from central coordination on the bottom to local coordination on the top. The scheme allows partitioning different types of user electric energy and power flexibility to be classified.

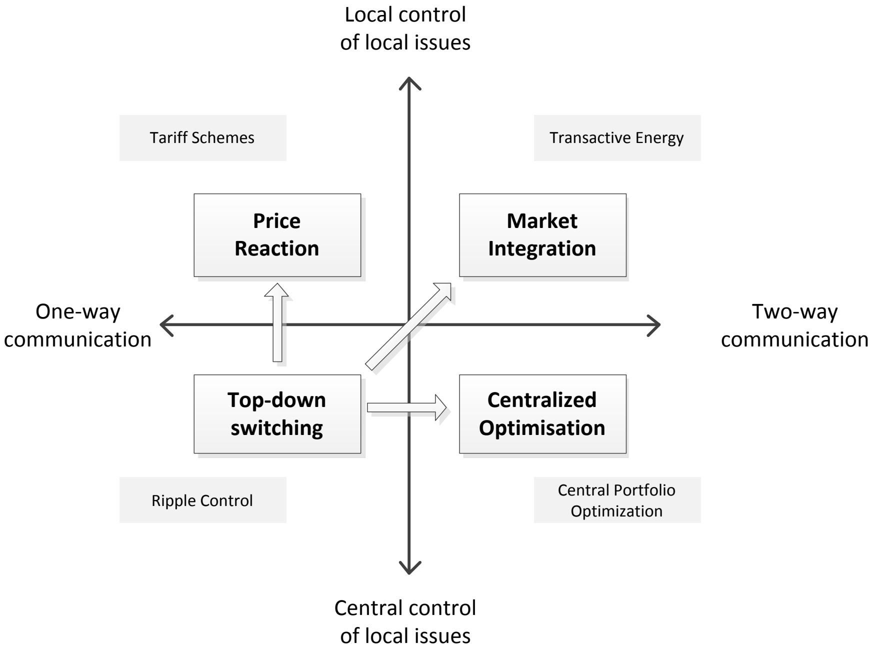


Figure 1-2: Demand Response evolution chart [7]

Power and energy flexibility characteristics of grid-connected devices depend on the type of device, the user preferences and external factors like the weather, time-of-year, day type and other factors. In the task, the concept of a theoretical, 'technical' flexibility can be derived along with a practically reachable one. The value of this flexibility depends on the real-time operational state of the grid regarding the instantaneous power and from the needs of supply and demand in commercial terms mostly regarding the energy in a timespan like a PTU. Additionally, accumulated cost and benefits of flexibility also may vary considerably on a by-country or by-state level due to resource mix, market design, and regulatory aspects.

1.6 The policy and regulatory context

Governments try to find a balance between minimizing the regulatory context and maximizing the stability of the power grid that is considered to be the most important infrastructure for economy. The policy context for increasing the uptake potential for DG-RES, DR and storage differs considerably in the countries studied. Extremes encountered are where the in-feed cost is defined by the bundled/vertically integrated utility up to countries, where net metering schemes and existing subsidies are giving a higher payback than the end-user electricity price. A complicating factor also is that taxes and subsidies are regularly changed which put end-customer and solution provider investments at considerable risk.

Because of the beneficial effect that electricity storage can have, in some countries, subsidies for infeed from or consumption of electricity from local storage, during high wind-production or local congestion, are comparable to subsidies for photovoltaics. A similar subsidy incentive to demand response was not found in the countries studied. On a test-basis, in certain countries, the scope of self-consumption/generation is currently extended to a certain geographic area to incentivize community self-consumption and balancing, relieving congestion in higher voltage levels of the grid. With the agreed Paris carbon dioxide reductions and grid-parity of DG-RES systems like PV in reach, the energy system transition in the next decades already now can be seen to be disruptive for the traditional players and actors in the industry unless they are able to increase the agility of their operational assets.

In countries with a moderate climate, substituting fossil fuels for transport and HVAC applications more than doubles the amount of electricity to be transported via the network and, due to increased simultaneity, even has a larger effect on the required peak capacity. The upgrade of network transmission and distribution network components requires additional investments that, in the future, might not be socialized to the extent of current electricity infrastructures.

2 Load and generation device flexibility

The device flexibility potential has a number of different attributes viz.:

- *Primary process constraints.* The primary electricity consuming process defines the operational power (kW)- and energy (kWh)- bandwidth for flexibility. User comfort, energy efficiency, safety, appliance lifetime and maintenance requirements define these constraints.
- Are there possibilities to *instantaneously* make *changes in the power* (kW)? Are there mechanisms to modulate and within which capability and what is the *response time* to a change request?
- *Energy (kWh) shifted.* Here the amount and the duration are important
- What is the ability to forecast a possible response on a certain time-ahead and what are the firmness requirements
- *Response interval* (PTU, daily, monthly, yearly)
- *Ease of interfacing* of the *primary process control systems*. The external DR coordination mechanism has to be coupled to the primary control algorithm. If this coupling is tight, lifetime cost can be expected to be higher than for a 'loosely' coupled mechanism.
- *Aggregation options* (homogenous, heterogeneous) and *coordination protocols* once aggregated.
- Suited for *power quality* related *services* (Voltage, frequency control)

.

A clear distinction between technical-theoretical and actual-realizable potential of demand response in different device primary process contexts has to be made. In this respect, DR automation reduces user's response fatigue and favors building a guaranteed response once configured by the end user. In the following, experiences with flexibility potentials per device type are further discussed in view of the work done in phase 3.

2.1 Thermostatically controlled loads (TCL)

Thermostatically controlled loads, due to their thermal inertia, already have been shown to have a considerable flexibility potential in end-user DR. With some heat storage, temperatures can be kept without impairing user comfort levels. Designers of TCL control systems try to find a compromise between keeping the number of start-stop cycles low, whilst remaining between the required temperature limits.

2.1.1 Water heaters and electrical heating devices

In a large number of electricity systems, these have been a flexibility resource for quite some time. Also today, they are used extensively to generate flexibility. Is has been shown that it is possible to control them via frequency pulse modulation that requires no information or communication infrastructure, but only a small frequency sensor unit. Increasing electricity tariffs and primary energy efficiency measures, however, have led to large substitution rates of these technologies by heat pump related systems integrating HVAC and tap water supply.

2.1.2 HVAC

The energy required for heating and cooling is the largest part of end-user demand. Modulation of the power of electricity system connected heating systems generally leads to an overall lower energy efficiency and, in case of Stirling or micro turbine µ-CHP, increased emissions. Newer technologies with variable speed drives and coolant loop variable valves have less of an efficiency impact. However, modulating the aggregated power of a collection of heat pumps (VPP) is to be preferred to modulating individual HVAC systems.

Compared to other devices, the volume of energy that can be shifted is considerable and, depending on the building thermal mass, the heat storage capabilities and the duration of the shift can be in the order of 1-6 hours. Typically heat storage, whilst cheaper than storage of electrical energy, comes at non-negligible investment costs. These investment costs must be returned by the benefits provided.

Improved meteorological models allow relatively precise forecasting of heat demands in homes and the degree of firmness depends on the building user comfort requirements and the interaction scheme.

Energy efficiency losses were found up to 10 % due to re-bounce effects and the amount of response and the response time in a certain domestic environment depends on the dedicated and inherent heat storage capabilities. Opposed to that a 20% efficiency increase is possible if operated in the optimal point of operation.

In case the HVAC is operated following the heat/cold demand, the flexibility can only be offered if there is a way for heat storage. Field tests have shown the potential of aggregated clusters of HVAC devices to exert commercial balancing using the capacity as spinning reserve and grid operation related functions like congestion management. Furthermore, energy community use cases using HVAC to consume local PV have been demonstrated.

Engaging utility and office buildings with automation and communication technology to improve energy and grid performance is difficult to cost justify, unless these are part of the deal for the users but also the investors in commercial buildings. In the recent past, special purpose communications and system integration that requires skilled labor is expensive compared to what financial payback may be available. Innovative, distributed control and coordination approaches that scale easily and address the complexity of interactions with multitudes of devices, hold promise for reducing integration and maintenance costs; however, their familiarity and maturity level need to increase before large-scale deployments will likely be realized. Greater transparency on the value of flexibility demand for multiple grid services is needed to provide adequate commercial signals for technology deployments. This includes the locational value of flexibility to address electricity infrastructure constraints. Managing the commitment of demand flexibility to address multiple grid services is a challenge that needs to be addressed to realize its full value.

Buildings automation uses a wide variety of standards that do not integrate easily with each other. The level of maturity of integration is at the protocol level with little progress on commonly supported information models of building equipment and no integration at the business process (application) level.

The lack of one or more consistent electricity market signals for demand flexibility in most electricity systems, does not encourage technology solution suppliers to invest in progressing standard interfaces. The level of HVAC installation automation is highest in large commercial buildings and industrial manufacturing facilities. Residential and small to medium commercial buildings have a lower budget to spend on automation technology; however current IoT directions hold the promise to drive connectivity costs down and innovative products are currently emerging. As said earlier, widespread use will require consistent flexibility signals that can mitigate differences between regions (service areas, states, and countries). In addition, the full value of flexibility from this equipment will not be exploited unless up/down regulation signals are available, and that is likely to lag energy and peak usage market signals. These signals since a number of years for example are available in the Netherlands system [8] and allow real-time responses of aggregators.

Heat pumps

Once installed and configured appropriately, heat pumps already have realized a large energy efficiency gain in replacing resistance heating systems and boilers. Heat pump manufacturers already started to equip devices with flexibility functions, like the Smart Grid Ready labeling for heat pumps. An external signal can be used to trigger or delay consumption. Optimization algorithms can use this flexibility to e.g., shift load for better self-consumption, or avoiding peaks.

CHPs

Medium size gas engines based CHP with several MW of capacity already are already used extensively. Downsizing to the end-user micro-level is currently underway. Problems here are of a technological and cost nature. Combined heat and power systems on the end-user level include Stirling engines, micro turbines and fuel cell based systems each with a different heat to power ratio. In some countries, ownership and operation of the micro CHP might be a barrier to market participation and ancillary service delivery. In the past years, micro-CHP systems have been funded by investment subsidies. Currently in many regulatory example environments, the CHP technology receives feed-in tariffs that incentivize a non-flexible operation around the optimal point of operation. From scratch, other types of CHPs like for instance fuel cells have less operational flexibility, and are designed to run all the time at their optimal point of operation as the fuel cells have to be heated to a certain temperature to before they are able to generate electricity.

Air conditioning

Air conditioning installations have an electricity consuming compressor operated cooling part and an air ventilation part. Both parts can be operated separately. This leads to different dynamics in terms of long term and short term opportunities for delivering of electricity demand flexibility. Due to the increase in computer and lighting energy efficiency, air conditioning load is a fast growing segment of energy usage in buildings globally, although the rate of growth in the US and Europe has dropped. So, harnessing the operational flexibility of this equipment will likely play an even greater role in balancing supply and demand over time.

Coincidence of solar irradiation and cooling need is a main factor for utilizing load shifting with a high share of variability. Due to thermal mass of building materials decreased electricity demand decreased electricity demand when clouded can be leveled out by decreased PV-generation.

2.1.3 Food storage

The temperature bandwidth and the thermal mass of the contents in freezers are larger than in for refrigerators. Electricity efficiency of compressors has increased considerably in the last decade bringing the yearly energy consumption of coolers and freezers in households back to 150 kWh per annum. So, due to the significant decrease in the overall volume, the DR-potential in terms of kWh and kW of cooling and freezing in a domestic setting is low. Domestic freezers and even more refrigerators offer a limited source of flexibility, so they have to be aggregated massively to make it possible to deliver services related to commercial and grid operations. Massively aggregated applications suggested are real-time frequency control modeling the compressors RPM or handling short-term high imbalance peaks by modulation. The flexibility to contribute to short periods of energy increase or decrease also make refrigeration a good resource to contribute to non-biased power regulation (i.e., addressing the random nature of regulation where energy use over time is near zero) [9].

Commercial industrial cooling and freezing systems have seen a considerable efficiency increase as well. In industrial freezing and cooling, market driven planning of defrost cycles provides an opportunity for providing demand response services. So, here the overall potential is higher. Compared to HVAC however, food storage offers more limited energy and capacity shift capabilities.

2.2 Wet appliances

Wet appliances' electricity consumption cycles generally are only movable as a whole, because of the subtle interaction of the detergents' enzymes with the laundry or the dishes during the washing process' energy efficiency and process quality requirements. Washing machines and dish washers thus can have a DR-role if they can be scheduled in advance to a certain temporal accuracy and from a change in choice of the total energy (kWh) spread and the resulting capacity (kW) used in a selectable, grid-friendly washing program. In the field tests studied in subtask 12 the cycle scheduling mechanism was used to attain substantial demand response effects.

Initially focusing on Monday, the required washing power co-incidence rate has diminished. There is a spread over the whole week including nights. Traditionally the electrically heated wash dryer had a considerable part of domestic electricity usage of up to 25 % in some cases. However in Europe resistance heating has been replaced by manufactures into heat-pump heating, so that dryers now have a much lower electricity use and demand response potential. Presently in the US, dryers are still either gas or resistive heated. As such, the resistive heating element can be modulated or turned off for periods while the clothes tumbling action is preserved or also modulated w/ little impact on the finished product

2.3 EV chargers

EV chargers electricity consumption profiles primarily are driven by car owner driving schedules and battery management requirements. Car owners are driven by range-anxiety striving to restore the EV's SOC (state-of-charge) to one soon after connecting to the charging point. From the car battery management system perspective, the electro-chemical processes at the cathode and anode of the battery require strictly following a charging profile constrained by the boundaries of the charging power at the current SOC. Today, a BMS neither allows frequent stopping or quickly reversing the charging current nor charging outside of the bordering constraints belonging to the current SOC. Currently level 2 fast chargers are installed in homes. The possibility of serving demand response flexibility during certain periods, conflicts with the user fast charging requirement.

EV charging poses both a challenge and an opportunity. The potential probability, that EV charging leads to exceeding electricity distribution capacity limits is increasing with higher penetrations of EV and schedules with fast charging. The latter also is found to lead to additional flexibility requirements at the higher MV-voltage levels. Also, the mobility of the EV means that their local impact can change throughout a day, week, or season. However, the potential for EV charging and discharging to be scheduled or otherwise modulated can make them a valuable flexibility resource. Where today's battery technology is limiting, if the need and value of flexibility becomes more transparent, scientific breakthroughs may allow EVs to have greater availability to participate in flexibility services.

Due to historic reasons, some network operators have general low price network tariffs for night times (e.g., Austria). These are considered to have impact on the network, once EV charging at the household level will start at the same time. Controlled charging needs to be introduced much earlier in these regions, compared to opportunity charging situations (charging when car arrives). In other countries like the Netherlands, where the distribution tariffs reflect the asset utilization, the market component in the tariffs is low and the network component is high during nighttime.

2.4 Energy storage

2.4.1 Electricity

At what level electricity storage provides a viable solution for grid applications depends on the power system topology, the demand and supply profiles of the connection points and the asset management strategy. The legislative setting defines the limits for quality of service and thus for profitability of storage. Where in-feed is expensive, self-consumption scenario's including electricity storage are becoming attractive; in the case of net metering over a year, positive electricity storage business models are non-existent. It also appears, that, in case of a low or negative infeed price, the tax components in the electricity prices and also the gross electricity prices are relatively low and in the latter category these are high. So, in both cases storage is difficult to account for financially. However, regional regulatory policy (such as California and NY in the US or Germany in Europe) are looking for ways to encourage more electric storage. A use case there is satisfying local needs, such as pairing storage with PV to mitigate potential distribution charges. Also storage can contribute to voltage regulation as mentioned before.

Storage can offer a large degree of flexibility which can be used for market purposes, storing energy in excess times and feeding it back into the grid in times when energy is scarce. Typically, market driven flexibility use cases are based on external price signals from the market. Storage also offers flexibility in order to provide system stability to the TSO, i.e. to provide primary, secondary and also tertiary control services. This is typically also a market use case. Storage can be used for network support, so as to avoid network expansion or mitigate transmission and distribution bottlenecks. If valorized properly, storage does not need any subsidies. A level playing field is necessary in order to allow a competition between the different flexibility resources. More transparency of the value of flexible supply and demand for multiple grid services is necessary to provide adequate commercial signals for storage deployments. This includes the locational value of flexibility to address electricity infrastructure constraints. On a multi-objective level, managing the commitment of storage flexibility to address a multiple of grid services is a challenge that needs to be addressed to realize its full value. Peak shaving is a use case more and more economical for energy storages. Often the maximum peak power is taken distribution/transmission tariff part for the monthly or yearly bill and as a basis for the network connection costs.

2.4.2 Hybrid multi-commodity

Hybrid energy storage solutions have attracted a lot of interest in the last few years. In countries with significant heat or cold demand, energy storage in the form of thermal storage is cheaper than electricity storage and connects the operational coordination of heat or cold production to electricity generating or consuming devices. Using inherent or dedicated heat/cold storage capacity allows uncoupling heat and electricity production. Dependent on the ratio between the gas and electricity price, it is one of the boosters of electrical flexibility in energy infrastructures especially in moderate climate zones, where the concept is wide-spread in horticultural, having high heat demands and low electricity prices during the night, and the utility buildings sector.

2.4.3 V2G

V2G is basically operating a VPP as a large distributed battery. In terms of flexibility, aggregated charging units of EVs might offer stability for the system at the local or at the control zone level. Since the flexibility is temporarily and spatially fluctuating, it is a challenge to apply algorithms that harvest the flexibility without endangering the network stability or introduce congestions. (Which will be similar to the algorithms currently used for route planning based on real-time GPS car position information.) It has one of the largest flexibility potentials in the grid, as more and more cars appear with rather large batteries. Additionally, second-life batteries might contribute to the flexibility sources of the network. The mobile nature of the battery DR-resource resource presents additional complexity as the value for flexible charging, and at some point the possibility of discharging, changes from place to place and throughout the day. While infrastructure constraints will follow EVs as they go from home to business and return, smart charging and discharging can contribute to reducing the impact of mass movements.

2.4.4 P2X

The borderline for grid parity of PV has reached the moderate climate regions of Western Europe. Currently, solutions are sought to prevent PV-curtailment by directly converting power to heat, to hydrogen or other chemicals (so to X), that can be stored and used later for electricity production. The low chemical process efficiency of these techniques and technological difficulties place a significant barrier for cost-effectiveness.

2.5 Pumps

Pump applications can be found with in warmer climate areas as applied in swimming pools but also for heat pumps with soil/water drills. In more moderate climates these are used by water management authorities for water-level control between different areas (e.g. polders). This type of load has been one of the first source of demand response for quite some time. The primary process is not very volume, capacity or time critical creating a large flexibility.

3 Automation of DR-systems

Demand flexibility is facilitated by automation. Automation of response prevent response fatigue which was found in some projects analyzed. In the projects assessed a range in degree of automation was found, from full automation to monitoring and advisory applications where end-users were in the driver seat. The ICT-architecture of DG-RES production and demand response optimization applications depends on the scope of the application chosen and coordination and interaction protocol topology as discussed in section 1.5. The implementation possibilities for automated DR applications have become larger at lower overall investment cost. Communication possibilities are there, but the semantics of the exchanged messages in the form of standards is still in an evolutionary phase.

3.1 Interfaces and architectures for end-node DR-systems

Currently, service applications like energy and DR management are shifting to thin-client architectures. This means, that the computer and memory footprint of local systems at the customer premises diminishes and the algorithms can be operated and maintained centrally. Cost savings also come from centralized system configuration management and software maintenance. The dedicated intelligence in the BEMS or HEMS is downgraded to a gateway functionality transmitting the local data to a computing cloud via cloud services. This architecture complies with using Web-services for user interaction as well as creation of apps for mobile devices leaving out a dedicated user interface device. Also from current IoT developments, device connection possibilities with tiny computational and memory footprints are proceeding from the hype phase to actual availability.

To facilitate the realization of energy management applications, a number of standards and protocols like PowerMatcher [10], openADR [11], OGEMA [12] and EF-Pi [13] - each serving a part of the aggregation puzzle - are available and further evolving at the moment. Within the IEC-61850 community, that traditionally models and connects distribution equipment to DSO SCADA-systems, efforts are currently underway to extend the standard to be used in the lower grid level segment and using it to uncover load flexibility. However, it has to be noticed, that it is a power industry standard and not a buildings standard. It is grid versus building focused. Examples of more facility directed standards emerging are:
ASHRAE FSGIM (Facility Smart Grid Information Model), that was approved by ANSI in 2016 [14]. The standard provides a way to model real building systems as a combination of four abstract components: loads, generators, meters and energy managers.
From the semantic IoT-domain, Project Haystack presents an open source initiative [15], set up by industry, to uncover smart devices' in the built environment flexibility and demand response potential.

In interfacing TCL HVAC systems at the end-consumer level mostly loosely-coupled systems are coming up. These intercept the current room and outside temperature reading and use these together with external information like user behavior and preferences to give an adapted, optimized thermostat set-point to the heating system. Examples are the Google NEST thermostat, the Apple HomeKit thermostat [16], Lowe's Iris ecosystem [17] Quby's Toon thermostat [18] and the NGenic [19] heat pump interface. The technologies do not need dedicated communication equipment, but use existing public communication infrastructures like TCP/IP via

WiFi to exchange messages. Technology providers of these products also using meta-data together with data-analytics methods for optimization and are able to act as aggregators.

Due to much larger complexity of the primary comfort management process - due to the larger number of actors and stakeholders with a diversity of interest - interfacing of utility building HVAC to uncover DR energy flexibility is more difficult. Interfacing of utility buildings based on a BMS sector model can be realized using BACNET. A more extensive view of the buildings standards interoperability landscape is given in [20].

Thermostatically controlled commercial food storage refrigeration equipment is becoming smarter with on-board intelligence and options for Internet connectivity enabling operation via apps for end-customers. Exploiting them for demand response in the commercial segment still requires special equipment from aggregators (utilities and third parties – e.g., EnerNOC [21]).

Interfacing wet appliances and laundry dryers mostly comes from delayed start options accessible via proprietary or standardized protocols.

In order to save on battery life, in the electric charging process only power schedules approved by the battery management system of the car are allowed. Interfaces from the EV battery management system to the EVSE (EV supply equipment) to secure this, are now defined in the IEC standard series (e.g. IEC-15118 describing the EVSE ←→ EV protocol). Furthermore SAE standards like J2836 (communication between EVs and stakeholders, [22, p. 28]), J2847 (DC charging; [23]) , J2931 (digital communications; [24]) are underway.

3.2 Inverters/converters

Inverters and converters are at the interface from DC to AC systems. They can be found for PV to generate the DC PV cell voltage (230V/110 V) and for AC-grid connected batteries. These devices are having analogous I/O ports with fast DSPs that sense the AC frequency signal and synchronize the infeed. Also they can be used to change the active/reactive power ratio and in this way control the voltage. Having this computation resources available has led to applications for remote maintenance and production/consumption control. PV-systems enabled as a DR-resource for reducing active power infeed, are connected to an information network and using existing standards. PV inverter boards mostly already have Webserver and WiFi connectivity to aid in operations and maintenance and collect operational information. The SunSpec Alliance [25] certifies DER system components and software applications for compliance to official and de facto communication standards.

3.3 Communication and aggregation

DSOs are currently digitizing their operations and company structures. During that process, they also adapt their domain models like eBix and communication protocols and information models as defined in IEC-61850 and IEC-61970 and 61968 to enable monitoring and controlling the systems between the primary substation level closer to the end-user domain. Aggregators of residential flexibility will require coordination with entities like a DSO to coordinate local residential storage and demand flexibility to offer DSO services; one of the important developments in this respect is the USEF-initiative [11], which offers a mechanism to divide tasks between stakeholders at different operational states of the grid. Analysis of field tests have shown the technical viability of intermediate storage systems to relieve congestion. HVAC systems connected to heat storage have the highest potential. Interfacing applications adapting the EV (fast) charging strategy with grid management can also be expected to contribute.

The value of flexibility of all these dispersed devices in the lowest grid segments increases with aggregation. Due to their size, aggregation allows selling or buying at electricity market segments, that otherwise are accessible to end-users, and also leads to an amount of power, which is continuously variable and can be planned and forecasted more accurately than when prepared for the individual units. It may also align objectives within a community of similar users [27]. Especially regarding the introduction of renewable energies, communities, regionally organized or virtually, are becoming more important. The DR markets in the US are acknowledged to be a stepping stone to the future because they do not include the distribution constraints that can impact large penetrations of DER from meeting a market agreement. VPPs in these settings have the same problem, if their resources are spread across the system, unless they do have multiple objectives for central commercial coordination and local grid operations. The trend in the US for community (local aggregation) generally falls under the micro-grid concept. In this case, local supply and demand is coordinated with full respect for distribution constraints to offer a combined flexible resource at some point of common coupling. This grid architecture featuring loosely coupled, grid connected micro-grids topples the traditional top-down grid architecture.

For automation meeting stakeholder or community objectives, aggregation (as sometimes operated as virtual power plants) are attributed a crucial role. During the last 10 years field tests demonstrating aggregation have been rolled out extensively in US, European and national research programs. The TRL-level of the solutions has increased and the hardware and communication footprint has decreased considerably.

A question than to be handled is: at what grid hierarchical level to aggregate preferentially and to aggregate the same type of devices or to aggregate into a heterogeneous portfolio. Other decisions to be made pertain to sub-aggregation at households, communities (concentrators) with a common objective or by DSO assets. The outcome of aligning these concentration levels to operational grid components for rural, urban and metropolitan configurations, in either vertically integrated or liberalized markets, then will determine the multi-objective target [28].

3.4 Security and dependability

The track record of applying ICT in existing power systems is questionable; system and maintenance cost are higher and long-term (> 10 yrs) software maintenance is difficult to contract. Business models of new actors in the energy management system sector, that now are becoming active, may rely on collecting online data and meta-data on the use of the system. These databases are used to improve the functionality and to offer the user tailored advices on the improving energy efficiency or lowering cost. An unconsented side-effect is possible infringement on privacy and loss of data-security. Applying security-by-design principles, minimizing aggregated information storage and in in this way keeping the data in the local scope here reduces the risks. Transactive energy algorithms and systems in this respect hold most promise.

4 Aggregation levels of energy (kWh) and power (kW) flexibility

Electricity flexibility always has played an important role in balancing and matching demand and supply in the high volume/high capacity customer segment. With the advent of the required increase of DG-RES embedding capacity, the technical possibility to be metered and rewarded for active demand and supply and the requirements from volume and capacity markets described above, demand flexibility for lower-volume/lower-capacity connection points in the grid now is increasing its value. A significant and changing role for end-users can be foreseen. Improved possibilities for low-cost aggregation and for automation here are the key reasons. In this chapter, use cases for different DR and DG-RES aggregation levels are discussed in terms of use cases ranging from the nano, micro, meso and macro level. The nano level pertains to individual households, the micro level to individual residential areas (possibly aggregated in a LV micro-grid), the meso level to typical operational areas of DSOs (MV-grids) and the macro level to the nationwide commercial market context and HV-grids like a EntsoE-control zone.

4.1 Macro-level use cases

4.1.1 Real-time portfolio optimization

In this use case, aggregation of demand and supply is well known. Electricity flexibility can be used to optimize the portfolio in the hands of the BRP, by shifting load and generation to times where the overall value to the portfolio is higher. Portfolio optimization services require a short time-frame response that might appear to be difficult to achieve for the possibly millions of dispersed DER-systems; on the other hand the response also may be considered statistically leading to at least the desired effect for a subset of the total aggregation. In field-tests, distributed control schemes have been shown to be able to coordinate resources to respond to price signals within the frame in the order of 2-4 seconds; however, it may also be worthwhile to revisit frequency regulation limits to understand if relaxing or restructuring the policy can better allow DER to compete on the value of these services. Real-time monitoring at least on per PTU basis and measuring and reconciliation of performance of installations are required to allow using aggregated response in this segment. Optimization may pertain to providing:

- *Ramp-up/ramp-down capacity* to improve the dispatch of large generators in the portfolio. Market trade is based on delivering rectangular blocks with a constant power over a certain period, while actual generators might need more than one PTU to come to that power or to switch to zero.
- *Provide passive intra-portfolio balancing services.* Flexibility of end user resources can be aggregated to adapt the current position, monitored in real-time, with respect to the program profile issued the day before. Portfolio imbalances, for instance, may result from shifts in a high-volume wind infeed energy profile. The volume of wind generation for the next day can be forecasted reasonably nowadays, but forecasting of the instantaneous power of wind on a per PTU basis still provides a challenge.
- *Provide extra-portfolio balancing services.* In this case, the current position regarding the program is known and the volume of additional flexibility that exists can be offered to the TSO. This type of ancillary services is the field for which flexibility, delivered from larger installations is predominantly used. However, the market volumes to be balanced are becoming smaller due to the improvement in the quality of load and generation forecasts

[29]. Also the liquidity has been seen to rise quickly when flexibility is more and more used. Apart from large CHPs with heat buffer, flexibility of load is typically used for these services but also larger batteries or other types of hybrid systems with heat storages can be used here.

- *Day-ahead and intra-day arbitrage.* If the cost of imbalance is low, possibly also the retailer may benefit from higher margins on the electricity sold to the end consumers. Having demand bids counter act bulk supply offers, changes what was a one-sided market to a more self-regulating two-sided market. The aggregator here is to ensure that DER are not overcommitted to multiple grid services.

4.1.2 System operation support

Flexibility can also be used in order to reduce the overall peak load in the system in contingency situations. This for instance happens, once the transmission system or distribution system operator, based on the programs issued by the BRPs, comes to the conclusion, that the programs cannot be accommodated for the next scheduling period. The operator in this case has to reduce the programs and the BRPs as a result of that have to create imbalance in their programs. Depending on the expected contingency, the generation or demand have to adapt their next day profile, leading to a reduction of peaking plants, load shedding schemes or wind curtailment. Demand flexibility can be used today in critical peak pricing and time of use rate programs to mitigate these system peaks. Other dynamic pricing schemes and transactive energy based systems currently are being tested in the field.

Ancillary services include frequency control via short-term balancing, and voltage control via reactive power compensation at higher voltage levels. Frequency control uses primary, secondary and tertiary reserves, which are paid for by contracted availability fees and actual use rates. The area of spinning reserves represent the field for which in most systems currently power flexibility is predominantly used. As noted before, business models are transient and investments in generation capacity thus are risky. Flexibility of load is typically used for these services but also larger batteries or other types of storages are used here. The growth of DER flexibility will likely diminish the need for spinning reserve and these resources can provide these services more cheaply if they are integrated with applications that serve other purposes. The issue is that an adequate amount of DER is attracted to the ancillary service market and the dependencies with energy markets are understood and managed.

4.2 Meso-level

This part pertains to the functional role DER-systems can have in the operation one level below the national level within the scope of a DSO. Electrification of transport mitigating NO_x, SO_2 and particle emissions in the local environment and globally reducing CO_2 emissions, HVAC applications in buildings with substitution of fossil fuels by electricity and end-user PV already have an increasing influence on day-to-day DSO operations. Massive rollout of these technologies is expected to be most disruptive on the lower HV/MV-level meso level of electricity distribution. An alternative to massive investments is congestion management by shedding loads and maintaining power quality in the form of voltage and reactive power management by curtailing generation. These are the main use cases for DG-RES flexibility. At the same ‘meso’-aggregation level, energy communities currently are growing.

4.2.1 Congestion mitigation services

On the HV-level competition for transport capacity takes place via regulated, market based procedures and pricing mechanisms. Congestion mitigation services at lower voltages can be provided by different sources of flexibility (load management, management of infeed or storage). Many flexibility options are available but, apart from technical implementation issues, it is hard to use these, as regulation regimes do not incentivize them. In this respect, transparent signals on the value of relieving congestion are being made apparent at the transmission level through mechanisms via LMPs. At the distribution level, given the socialization of the distribution infrastructure, regulators find it difficult to structure tariffs that impact customer bills differently in neighborhoods just because one area's distribution circuit or transformer reaches its capacity limit. Also, the expectation of almost having to double the electrical grid capacity to prepare for full substitution of fossil fuels driven by electric cars, raises the question on socialization of cost required for this application type [30]. High instantaneous power charging of electrical vehicles (Level 3 and Level 4 chargers) will massively affect the congestion dynamics on the MV level. There will be peaks of 120kW (and more) per car. Charging the electric vehicle from renewable electricity will have efficiency in terms of CO_2 and environmental impact. Battery and P2X storage of energy are considered to be potential components to relieve the impact of this technology. Also residential area energy storage can reduce load peaks or infeed peak. Investment in electricity storage could be reduced if multiple applications could be served. V2G and attributing a second life to EV batteries are candidates to fulfill this role. Home charging cycle dynamics constraints imposed by car battery management systems however do not support the required charging dynamics required by grid operation functions. Furthermore, for fast charging units of EVs the flexibility will be low. Hybrid energy systems also can be used to offer congestion flexibility services. Electrical heat pumps or µ-CHPs connected to heat storage or relying on the intrinsic heat storage capacity of buildings are examples.

4.2.2 Energy community balancing

Energy communities can be considered to be a collection of managed grid endpoints, behind which consumers/producer are coordinating to reach a certain objective. The simplest example of a community is an association of owners of an multi-storey apartment complex, with individual net metering points per apartment and common PV on the rooftop [31]. The objective here could be increase gross self-consumption. Community objectives also can be observed on islands like the Dutch island Texel [32] or the Danish isle of Bornholm [33].

The idea of aggregating energy demand and supply in energy communities are growing. Often, they try to balance their energy demand together with their distributed production. In terms of electricity, the concept of self-consumption is perpetuating the growing of energy communities as larger communities increase forecast accuracy and market power. Sometimes, it is allowed that several houses - mostly when they do not use the public infrastructure, i.e. the distribution network - are able to build large PV rooftop panels that supply a large part of the electricity or even heat demand of the community. Using economies of scale, the communities are saving in energy costs, especially by saving on network tariffs, and subsequently become greener. Though often not yet price competitive with wholesale market prices, the communities offer a large degree of independency, sustainability, and hence other incentives to participate. There is a competition for flexibility. Energy communities use a large share of their flexibility, as they take advantage of having a large degree of autarky and independence from the network. While these communities grow, the usage of flexibility inside grows as well, hence a learning curve will be developed on how using flexibility. A use case might be that surplus PV generation is stored in a community storage or “virtual” in the network and can be withdrawn later or simultaneous at another location. Direct trading of surplus between the energy communities is possible and only the clearing with the grid connection is paid.

4.2.3 Voltage regulation and RES curtailment mitigation

Voltage regulation is closely related to management of reactive power. Voltage inverters and converters have the capacity of steering the active/reactive power ratio. The value of keeping voltage levels at the LV and MV level within limits will compete with consumer’s energy needs. If smart inverters are able to provide voltage support more economically than deploying capacitor banks or tap changing transformers, then appropriate financial signals that allow these solutions to compete need to be made available. Smart inverters, used for charging of EVs are seen to need to fulfill this capability in order to meet voltage or thermal loading constraints. Flexibility offers a valuable asset to avoid the curtailment of RES. Often, the network cannot cope with all the fluctuating and high infeed of RES. A very simple solution besides expanding the conventional network, is to curtail the infeed. This is however disadvantageous, as infeed subsidies must be paid but the energy is lost. By using the flexibility of demand, that includes storage, the infeed of RES can be used, for example for heating purposes or other. The potential is at first harvested in self-consumption concepts. However, since flexibility is not always apparent to the same extent, it can be necessary to curtail RES infeed anyhow. Clearly, by using flexibility, the total amount of curtailment can substantially be reduced.

4.2.4 Asset investment deferral

The time schedule for a future high DG-RES electricity system with high-volume infeed from wind, serving increased levels of electricity due to electrification is unknown. Also, due to economic uncertainty, local lead times for developments of industrial and residential areas are also uncertain. Therefore deferral in grid investments by stakeholders enabled by demand response technologies is an attractive option.

4.3 Micro level

Micro-level aggregation and concerted operation of resources at the level of residential area connected to secondary substation is getting to the point of allocating energy resource needs locally. Main grid connected micro-grids already are part of the electricity infrastructure in topologies with islands connected with limited transport capacity. The service to the distribution operator and retailer should be less, if the electrical community self-balances and offers a “nicer” overall load shape. Also, a few housing developments in the US are taking this approach.

4.4 Nano-level

4.4.1 Self-consumption

Driven by subsidy schemes and lower prices of DG-RES, more and more end-customers (‘prosumers’) are investing in electricity production and storage assets. In-feed tariffs and subsidies are beginning to be coupled to optimized self-consumption stipulations (e.g. Germany).

Also the curtailment of the system are sometimes coupled to funding regimes, which fosters load shifting and storage to prevent curtailment of DG-RES. Large advantages in saving energy costs but also and predominantly network costs and taxes can be seen. These network costs might grow constantly in a distribution system that has to accommodate more and more DG-RES intermittent variability. This might lead to attributing different network costs between users with PV and without PV as already is the case in some countries in Southern Europe delivering a disincentive for renewable energy. The more flexibility is achievable, the more self-consumption can be attained. Also, the degree of autarky rises with the usage of flexibility.

Depending on the regulatory framework, self-consumption will continue to grow. A likely scenario in this case is, when feed-in tariffs or net metering schemes are gradually diminished and finally abolished. Hence the current but especially the future potential for flexibility here is large. A significant short-term flexibility source also is available in automated HVAC installations in buildings as seen in field demonstrations. Inverted rates, critical peak pricing, and time of use rates are becoming more common that incentivize DR.

Industrial facilities have a long history of flexing their demand to save money in their energy contracts. Large commercial buildings have automation in place to also offer flexibility; however, small to medium commercial buildings and homes are only beginning to see some incentives, because rental contracts are on /m^2 basis with location cost components far exceeding energy costs.

4.5 Lessons learned

Some dedicated applications utilizing aggregated demand flexibility already have been rolled-out at the commercial solution level nationwide with positive business models. The main use case here is aggregation to serve the secondary and tertiary control reserves market. Also in the extensive field tests, mentioned earlier, use cases for system operations support have been completed in several countries up to a level of 25-500 customers. Also here, technically, aggregation using ICT can be achieved and significant improvements can be seen. Incentivizing and rewarding customers within current transport and distribution tariff components in certain national contexts with capacity-based tariffs instead of dynamic tariffs is not possible. Customer acceptance of the concepts and behavioral adaptation to flexible device logics, generally speaking, is positive. Information technology aids in automating the response. Top-down tariff driven as well more bottom-up energy transactive driven applications were implemented.

In these field test settings in different participating countries (AU, NL, S, US), aggregation of end-user DER to provide electricity flexibility has been shown to lead to cost reduction and customer segment dependent peak shifts on a day-by-day basis from 5-15 % incidentally, if incentives are high enough, even up to 30 %. From the investment level, internal return rates are in the order of up to 13 %. In the experiments in different country settings, for all applications above, it was possible to build the required information systems that were also able to (partly) automate operations following user preferences. These systems could be built from mainstream ICT-technologies and were sometimes shown to operate for several years. The users united in user groups mainly reacted positive on the new interaction possibilities using energy dashboards and home gateways connected to their domestic energy infrastructure. Apart from cost benefits, which might sum to 100 Euro per household per year or a reduction of 5% in wholesale market costs, the users also showed improved awareness, which normally leads to more individual energy efficiency. Incidentally a small amount of household fatigue, based upon a rise in thermostat overrides, if the duration of a feeder capacity event was too long, were observed. Peak reductions ranging from 8-10 % with 30 % of customers connected via DR of up-to 48 % with full participation were shown for coordination of aggregated wet appliance loads.

Regarding the community use case, in the field test experiments assessed, use cases with a proof of principle on this level of aggregation have been in active operation. Also, in the Netherlands, on the side of the regulator, as a test, opportunities are created to extend net metering from the connection level to the community/residential area level. In this way, smart meter readings can be added to yield a reading for a virtual connection point.

Optimized self-consumption use cases are currently attracting interest in all countries participating in the task. Motives range from preventing curtailment to have self-sufficiency in distribution grids with a lower level of stability. As an example, concerted operation of washing loads and PV increased the level of self-consumption to 66% from a reference value of 55 %.

5 Valuation of electricity and energy flexibility

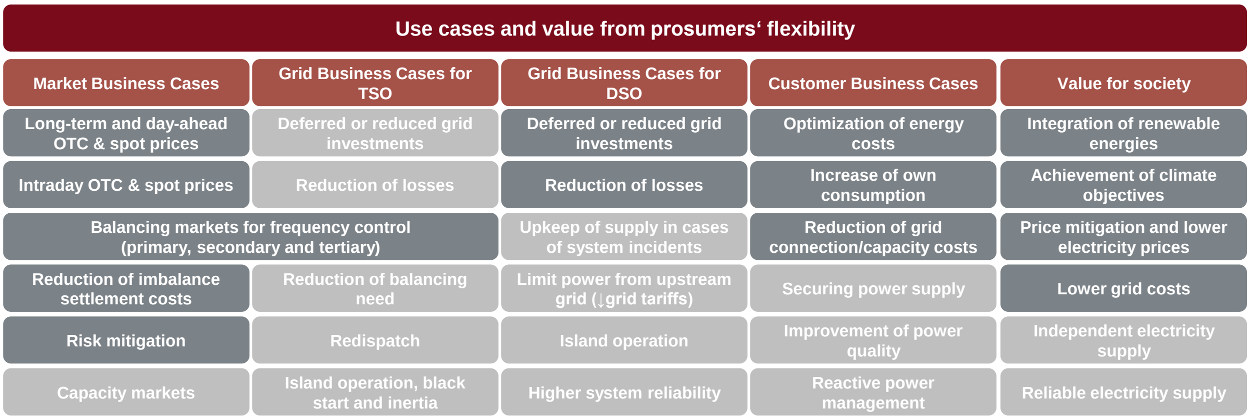
5.1 Use cases for flexibility

The value of DR and DG-RES applications in the current market and grid operational context is difficult to assess. The financial parameters and profitability of these technologies over time has to be taken into account while regarding an evolving electricity system. Bringing together existing actors in new roles and even introducing new actors, leads to changes in the value chain. Additionally, accounting operational and capital expenditures differently has an impact on the value chain. Main actors/roles, which the value of flexibility can be assigned to, have been presented in detail in IEA Task 17 Subtask 10 - Roles and Potentials of Flexible Consumers and Prosumers [4]. These actors/roles are shortly presented in Table 5-1.

Table 5-1: Actors and their associated roles. Roles in black are held by the respective actor, roles in grey are only held by the actor under certain conditions and may sometimes be conducted by an additional independent market party. For detailed information/definitions, see [4].

ACTOR	ASSOCIATED ROLE(S)
TSO	Data provider Grid operator Grid access provider System operator Market operator / Imbalance settlement responsible
DSO/DNO	Grid operator Grid access provider System operator Market operator / Imbalance settlement responsible Meter responsible
Independent aggregator	BSP Meter responsible Party connected to the grid
Supplier, retailer, traders	BRP Resource provider Party connected to the grid BSP Meter responsible Technology provider
Regulatory Authority	*Control function*
Society / Customer	Party connected to the grid

The value of flexibility can then generally be classified in the use cases presented in Figure 5-1, which have been presented in detail in IEA Task 17 Subtask 11 – Valuation Analysis of Residential Demand Side Flexibility.



Use cases and value from prosumers‘ flexibility

Market Business Cases	Grid Business Cases for TSO	Grid Business Cases for DSO	Customer Business Cases	Value for society
Long-term and day-ahead OTC & spot prices	Deferred or reduced grid investments	Deferred or reduced grid investments	Optimization of energy costs	Integration of renewable energies
Intraday OTC & spot prices	Reduction of losses	Reduction of losses	Increase of own consumption	Achievement of climate objectives
Balancing markets for frequency control (primary, secondary and tertiary)		Upkeep of supply in cases of system incidents	Reduction of grid connection/capacity costs	Price mitigation and lower electricity prices
Reduction of imbalance settlement costs	Reduction of balancing need	Limit power from upstream grid (↓grid tariffs)	Securing power supply	Lower grid costs
Risk mitigation	Redispatch	Island operation	Improvement of power quality	Independent electricity supply
Capacity markets	Island operation, black start and inertia	Higher system reliability	Reactive power management	Reliable electricity supply

Figure 5-1: Overview about use cases and the value from prosumer’s flexibility; dark grey are use cases that are already possible or that are possible in the near future [5]

Markets: The participation of flexibility aggregators on the markets can mainly enhance competition. Especially on markets and actions close to real time, flexibility gains importance. One example is imbalance settlement: The aggregator can either support the BRP to stick to its schedule (proactive system) or support the BRP/TSO to reduce the control error (reactive system).

TSO: As the operator of ancillary service markets, the TSO is responsible to keep balance between production and consumption with operations close to real-time. The costs and volume that needs to be balanced is dependent on the BRPs. If BRPs are able to use their customers’ flexibility to balance themselves, the TSO has less need to take action. Furthermore, aggregators of flexibility can participate in balancing markets under certain conditions in some countries and therefore enhance competition. The TSO may also use flexibility for congestion management by procuring it for redispatch from an aggregator. Finally, the TSO can profit through load-shifting by lower grid investments and more available capacity.

DSO: The distribution system operator can profit from the use of flexibility by deferred or reduced grid investments. They include on the one hand capital expenditures: These investments are highly dependent on the peak load on the grid. If flexibility is used to reduce this load, the DSO will have to make less investments in reinforcing the grid with expensive assets. On the other hand, also operational expenditures can be lowered as flexibility can be used to support security of supply during operation.
Additionally, DSOs can profit by reduced network losses. As these losses are again dependent on the peak load, the use flexibility for load shifting can help to lower the DSO’s costs.

Customer: New technologies like smart meters will have to be implemented to make use and measure electricity and energy flexibility. Due to these technologies, customers will get the chance to get a better overview and a better understanding of their electricity consumption and bill. They can therefore identify non-efficient devices with high consumption und use electricity in a more conscious way which can result in cost savings. Furthermore, prosumers can use their flexibility to increase their own consumption. Therefore, they can not only optimize their energy costs but also get less dependent on the grid (e.g. power cuts).

Society: The use of electricity and energy flexibility can help to achieve a country’s climate targets by enabling an easier integration of renewables to the grid and improving energy efficiency. Society may therefore profit from an enhanced quality of life due to lower greenhouse gas emission rates. Furthermore, society could profit from lower electricity prices and lower grid costs due to flexible tariffs. Savings of one actor may be handed to another one: If, for example, the DSO is able to reduce its overall costs due to the use of flexibility, society could profit from lower grid connection costs.

5.2 Valuation methods

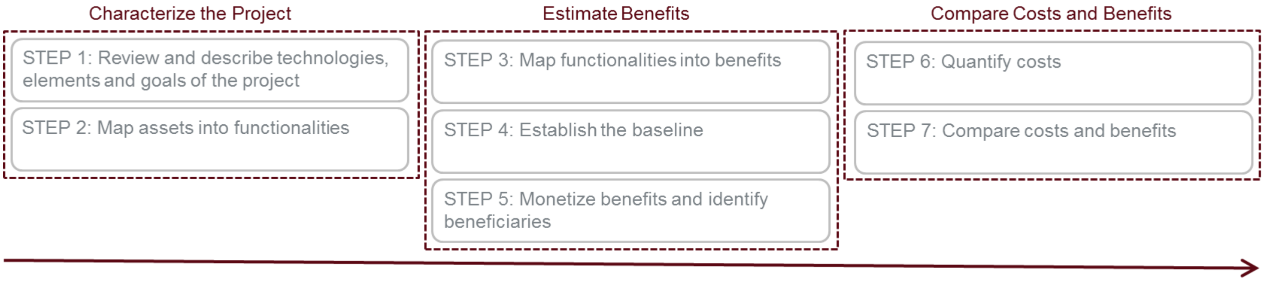
The common tool for establishing the value of a project is the cost-benefit-analysis (CBA). In a number of nationwide inventories, European initiatives and projects, CBA-models have been built. The method that is mostly known is the JRC method, which is again based on the CBA method of EPRI.

Method of EPRI

This valuation method [11] consists of three phases. In the first phase, a project overview is given. It contains basic information and framework parameters. The second phase is the research plan. It contains the identification and description of all technologies used for the project as well as the actual development of the research plan. Therefore, a comparison method for the comparison with a baseline scenario needs to be established and instructions for the use of the method (e.g. time intervals for measurements) need to be determined. In the last step, the actual CBA, measurements are used to estimate physical impacts that then again cause economic costs/benefits. Impacts categories can be helpful in this phase, some are proposed within the EPRI method (“customer”, “power quality”, …).

Method of JRC

The first phase of this valuation method [12] is to define boundary conditions (framework parameters, identification of data sources) of the project. The next phase is the CBA, which consists of 7 steps. These steps can be seen in Figure 5-2.



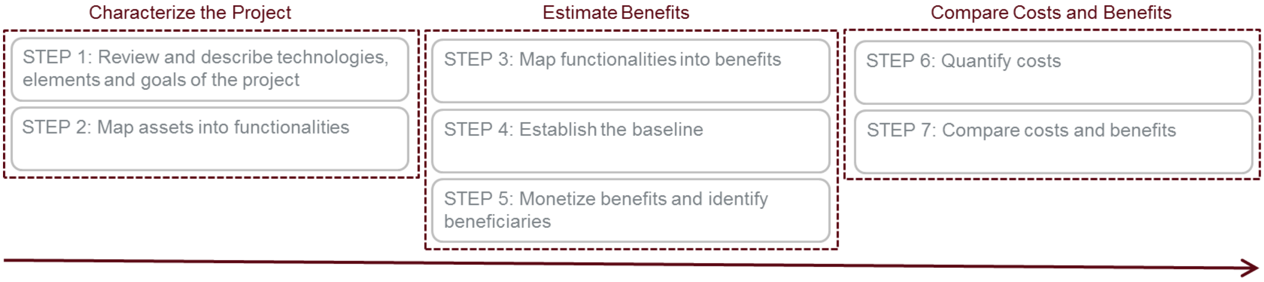


Figure 5-2: Steps of the CBA proposed by JRC (based on [12])

To complete the CBA, it is recommended to conduct a sensitivity analysis. In this analysis, main parameters (like the discount rate) are varied so that the influence on the outcome of the CBA can be seen. This phase is important as many parameters are depending on forecasts or estimations.

As a last phase of the valuation process, a qualitative impact analysis is recommended. In this analysis, all non-monetary benefits and the social impact of a project should be captured.

Although several valuation methods have been developed, overall valuation process remains difficult when it is applied on a specific project. This is because all proposed methods introduce high-level parameters that may not play an equally important role in each project as they have different focuses and approaches. Furthermore, the proposed valuation steps may not cover each important parameter of a project. Also mapping assets in functionalities as proposed within the JRC method is not always easily possible. Often the methods only introduce an abstract model of valuating a project but do not give details about the exact conduct of the analysis. As a result, the valuation methods are mostly adapted to the specific project or only partly used as a basis for the valuation process. This makes CBA results of different projects difficult to compare.
Therefore, general recommendations for valuation analyses are:

- Existing methods need to be generally refined and specified. The steps of the CBA that are so far only displayed in a very general way, need to be explained in their application.
- Therefore, CBA methods should contain at least one detailed example (project) where their framework is applied.
- One single CBA method can hardly cover each aspect of all different DR projects. Nevertheless, existing lists of parameters and their treatment in the analysis have to be continuously expanded to cover most aspects of different projects.
- Main parameters of most DR projects should be worked out. This set of parameters should be integrated in each CBA method.
- The further development of CBAs has to focus on combining quantitative and qualitative benefits in one single analysis. So far, qualitative benefits are often only treated as a “bonus”.

6 Recommendations

The impact of electricity end-user infeed and consumption on the electricity system market as well as the distribution system operation heavily depends on factors like the time-of-day, day of week, season and weather conditions. BRPs want to follow a commercially optimized profile and grid operators strive to a flat load curve to extend the lifetime of their assets and reduce the amount of money to be paid for energy losses on the market. These objectives have to be incentivized in the tariff structure offered to end-customers. For the commercial part it would mean reconciliation of market costs on realized profiles via smart meter allocation. This would also create market access still delegating the program responsibility per connection point, regulated in most electricity laws, to the BRP. For the transmission and distribution part it would mean dynamic tariffing. Design tariff structures which do not hinder the usage of flexibility but which are also reflecting properly the costs introduced by using the network. So the limit for automatic meter reading (AMR) and market access should be lowered and new pre-qualification criteria should be established.

Introducing smart meters and partitioning, processing and managing the data by the DSOs in several countries have been a major undertaking. Providing this infrastructure with extensions for control of aggregated flexibility service operation in a DSO governed setting is not likely because of intermixing grid and commercial management interests. Third party service providers are more likely to fulfill the aggregator role using easily available recent measured smart meter data. Automating is the preferred way of creating the best strategy in optimizing DR and DG-RES on the end-user level. Several aggregation levels are possible to do this. The optimal level to aggregate heavily depends on the demand-supply locations and the grid component topology taking into account distribution/transmission infrastructure costs and losses. The optimal aggregation level also might be varying in real-time at times promoting self- or community consumption to prevent PV-curtailment or lower congestion due to local EV-charging co-incidence. The regional status of electricity supply prioritizes demand flexibility in different ways. For instance avoiding daily blackouts might be a more important driver as opposed to cost savings in some part of the world. The global trend of increasing share of integration of renewables – also for remote communities and areas with weak network connections – needs cost effective solutions. Therefore smart aggregator services have to be established, that can be offered to BRPs, TSOs and DSOs. Additional to smart meter rollouts, which focus on collecting metered energy data, functionality in the form of gateways collecting data for energy management and connecting for aggregation is necessary for use in coordinated energy service applications.

The new role of the DSO in a regulated environment is only emerging in select areas of the world. The concepts related to the DSO are important to establish to support DR resources to compete with other system resources for grid services. Legislative and regulatory policies are needed for the successful formation of organizations to fulfill the designed role of a DSO.

In particular recommendations are:

- Use tariffs with clearer mapping of impact of supply and demand on the grid.
- Connection capacity fees to real-time power distribution tariffs.
- From a regulatory perspective, allow for market driven usage of flexibility, i.e. load and supply, by setting clear nondiscriminatory rules for using the network.
- Design rules on how and when to intervene into markets.
- Avoid creating barriers for using flexibility freely.

- Set simple rules for optimizing self-consumption and use the flexibility given there for efficient network planning and expansion, i.e. use self-consumption together with control techniques to avoid network expansion.
- Allow actors to make the transition into their new roles. This requires involvement of power transport constraints to be reflected in the aggregators' bidding and operational decisions.
- Social media and ICT in smartphones, PCs and tablets allow the design of attractive energy dashboard products for consumers and producers. Use Internet marketing logics to have consumers to take active part in pilot and demonstration projects in order to gain experiences and show that it works and show the benefits.

In the new high DG-RES perspective, end-users are not only paying tax on the energy (kWh) used or earn money on the energy (kWh) produced. Also, having the capability of flexibility can create value, without producing or consuming. So, not an amount of energy or delivery of power can be accounted for or taxed. From the regulatory perspective, the ownership of flexibility (not-used energy) should be formalized and the individual responsibilities of each actor should be defined by new electricity legislation.

Detailed cost-benefit-analyses are crucial for defining the added value of business models. However, there exists no general valuation method that can be easily applied to projects yet. Research needs to focus on new methods and especially specify the process of applying the framework of the method. Only then, comparable results of different projects can be gained. Analyses that have been conducted so far have shown that financial advantages for consumers are quite low. Thus, aggregators respectively companies, who offer aggregation services, need to concentrate on key messages on a broader level in order to attract consumers [37].

Many studies came to the conclusion that automated demand response has a higher success and acceptance can be achieved if certain requirements are met [16], [33], [29], [51]. 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.

It can be concluded that automated DR mechanism need to find resources and areas of operation where the primary processes and comfort are not interfered. Operating (thermal as well as electric) energy storages within certain increased operation limits can be considered as a potential DR resource.

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