Demand Side Management

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Learning Objectives

- Be able to describe the main motivation and technical options for demand side management (DSM)
- Be able to understand the potentials and future perspectives of DSM
- Be able to classify and describe price- and incentive-based demand response (DR) programs
- Be able to understand demand flexibility markets
- Be able to describe the emerging new business actors, their aims and roles, and (new) opportunities related to DSM

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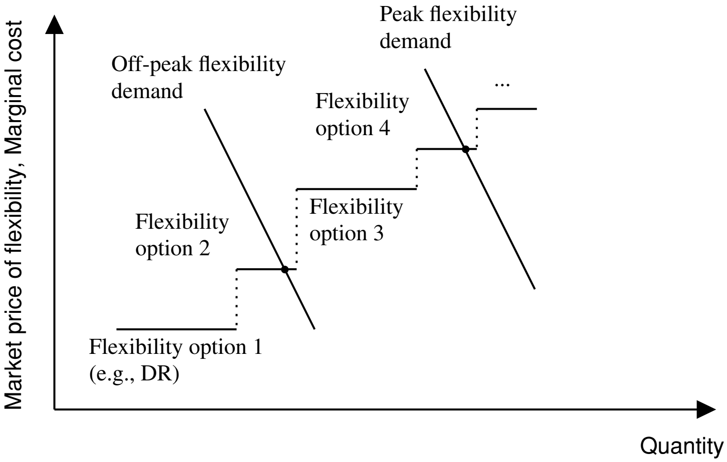

Fig. 1 Merit order of flexibility options in a smart grid (viewed as a market for flexibility with supply and demand)

1 Economic Considerations

To respond to the variability of supply that characterizes power generation from renewable energy sources (RES) a range of potentially competing options exists, including DR, grid expansion, energy storage, enhanced flexibility of power generation, and improved operational practices. For a better understanding, the set of alternatives that can provide responsive energy over various timescales can be grouped into supply side, demand side, and grid-related ones (Denholm and et al. 2010; IRENA 2018). While supply-side flexibility is closely related to the performance of the technologies comprising the generation units of a power system, demand-side flexibility refers to specific types of demand-side management where the demand pattern could be shifted to better match electricity supply (IRENA 2018).

Although the objective of this chapter is far from an in-depth explanation of the technical characteristics of each option, it is relevant to point out that each alternative option to enhance the flexibility of the energy system comes at different potentials, spatial and temporal availability, and costs, and thus fits better (or worse) for the different timescales and challenges related to the integration of growing shares of variable renewables. Figure 1 illustrates the "merit order of flexibility" in a stylized manner. Obviously, the costs of some of these options can be expected to come down over time due to learning and economies of scale effects.

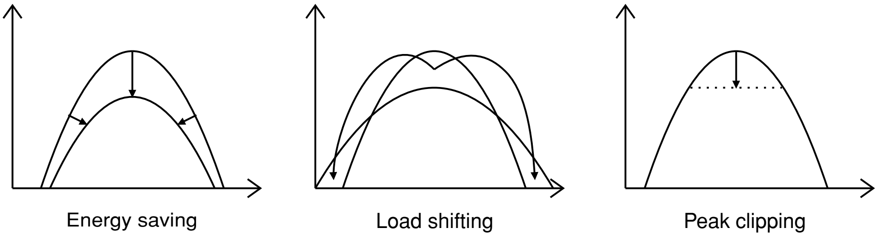

Fig. 2 Demand response and form of load curve obtained based on (Batalla-Bejerano et al. 2020, p. 4)

2 Demand Response Potential and Future Perspectives

With the aim of improving efficiency, reliability, and safety of the power system, intelligent technologies are being incorporated across the entire system, from power generation, transmission, and distribution networks, to electricity consumption at the premises of consumers. Within the context of the energy transition, one of the key objectives of smart technologies is an energy-efficient power grid to better manage volatile renewables and demand. DSM includes all the activities that target the modification of the consumer demand profile, in time or in shape, to make it better match the supply (Alizadeh et al. 2012).

Through different mechanisms, demand response allows consumers to play a role in the operation of the grid by adjusting their electricity consumption subject to price signals or long-term direct-control agreements with different objectives. Demand response programs can be introduced in the following ways (Fig. 2):

- **Peak Clipping.** To reduce consumption at times of peak demand. The hourly demand for electricity fluctuates throughout the day, with peaks normally around noon and in the early evening. During these periods, it is necessary to employ generation technologies with higher costs in order to meet demand. Because of this, one of the objectives of any energy policy is to reduce the relevance of these peaks in demand given their implications in economic and environmental terms and where the introduction of smart meters with their associated new functionalities offer the possibility of managing electricity demand, allowing greater efficiency in the markets in the years to come.
- **Load Shifting.** To move electricity consumption from one time period to another—normally with less expensive generation costs, such as advancing or deferring the use of an appliance to another time. The idea behind this strategy is that, by shifting the load to another period, the returns generated through energy cost savings or DR participation are greater than the potential well-being loss from the behavioral change. Unlike other energy cost-saving strategies, the issue tackled by the load shifting is the when rather than the how much. Hence, with load shifting, the overall energy consumption is the same but the moment when it is consumed changes.

- **Strategic Energy Saving.** To reduce energy consumption at all times. All efforts that imply reductions in the load curve entail multiple benefits in terms of competitiveness, security of supply—especially for those countries or regions strongly dependent on external energy resources—and environmental sustainability. Measures such as improved energy efficiency in buildings or in devices that consume energy at home (i.e., heating, cooling or appliances) are included in this area. As for the DR for the residential sector, the conservation strategy is to encourage households to modify their patterns of behavior in response to an indication of consumption and/or prices, leading to a reduction in consumption. Unlike peak clipping and load shifting, consumption reduction is not necessarily put into effect during a specific intraday period, such as times of peak demand, nor is consumption shifted to other periods.

Among these technical options, DR can be used in combination with energy storage to further reduce curtailment of variable renewable generation and independently of the strategy, the aim behind all of the options is to benefit from the huge potential that is inherent in DR programs.

According to the European Commission (2016), the theoretical potential of demand response, understood as a change in electricity consumption patterns in response to a signal, in 2016 adds up to about 100 GW and is expected to reach 160 GW in 2030. The highest share of DR potential lies in the residential sector that accounts for 23% of total energy consumption worldwide, placing it third after industry at 37% and transportation at 28% (IEA 2019).

However, some barriers need to be overcome before we can expect to see the wide-scale uptake of demand response solutions. Regulatory and market barriers seem to be the main obstacles. Regulatory support is key to the success of DR, given that if regulators do not succeed in structuring the market so that energy savings benefit the consumers in terms of final cost reductions, consumers have no compelling reason to implement DR programs. At the same time, removal of market barriers to demand side participation on the wholesale markets is crucial and the figure of the aggregator and its future role could help in the provision of new services and products that foster demand response.

Another challenge to be overcome is gaining consumer trust and encouraging consumer participation in this kind of DR initiatives. While the business sector is largely driven by economic reasoning, households are not necessarily so. Factors such as education, social norms, age, and culture are prevalent (e.g., Darby 2010; Hargreaves et al. 2010; Vine et al. 2013). Nevertheless, in a context where energy prices are continuously rising, the public's engagement with demand response will increase, as consumers are attracted by the financial and efficiency benefits that DR solutions can offer.

Consumer empowerment to participate and well-functioning flexibility markets are the two key components needed for a successful DSM. The first part of this section is devoted to exploring the measures to empower electricity consumer participation. The DR emerges as one of the main activities within the DSM, characterized by including changes in the consumption pattern in response to certain signals. Energy storage systems and RES self-production are also considered to be relevant

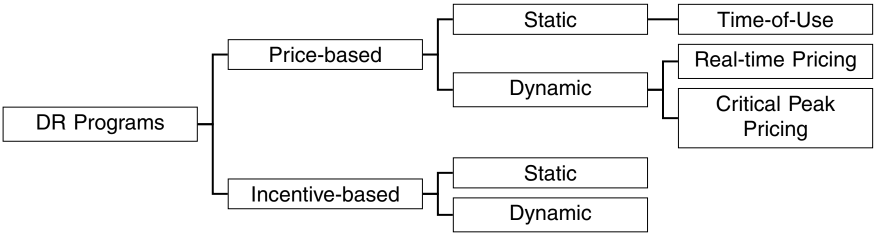

Fig. 3 Demand response programs

elements facilitating electricity consumer participation. The installation and use of interconnected home appliances are essential to the successful functioning of DSM, alongside with the production of the equipment needed and the setting of specific technical requirements to be fulfilled. An additional element influencing consumer empowerment is the energy service company (ESCO), acting as an intermediary in charge of facilitating the finance of energy-saving programs. Finally, given its prominent role in creating the necessary space for supply and demand interaction to achieve efficiency gains, in the second part of the section, a detailed description of flexibility market designs and functioning is provided, including both ancillary and balancing markets.

2.1 Consumer Participation in Demand Side Management

Demand response is usually defined as a change in the consumption patterns of electricity consumers in response to time-varying tariff structures or incentive payments in order to operate the electricity system in a more efficient and reliable manner (see also Chap. 2 on the elasticity of demand in light of enhanced flexibility). Hence, the principal DR activities include tariffs or programs designed to motivate the electricity use by end-user consumers, in response to changes in the price of electricity over time, or to give incentive payments designed to induce lower electricity use at times of high electricity demand or when facing reliability issues.

Depending on the offered motivation to shape consumer behavior, DR programs are typically classified in two main categories (Albadi and El-Saadany 2007): price-based programs and incentive-based programs (Fig. 3). While the price-based programs offer customers time-varying prices that are defined based on the cost of electricity in different time periods (Aghaei and Alizadeh 2013), incentive-based ones consist of programs that offer fixed or time-varying incentives (payments) to customers that reduce their electricity usage during periods of system stress (Mohagheghi et al. 2010).

With the aim of shifting consumption from periods where costs are high to periods where costs are low, in the price-based programs, the actual cost of electricity generation, transport, and supply is reflected in time-varying tariff structures. The price-based programs can be classified into static and dynamic time-varying pricing. The basic difference between these two types of price-based programs is that in the static pricing scheme, time-varying retail prices are present for pre-determined hours and days, while dynamic prices are allowed to change on short notice.

Within the price-based programs, the static time-varying prices (usually referred to as time of use (ToU)) is the application of flat pricing to different time periods. Under the ToU pricing scheme, prices are retained fixed within different pricing periods, which can be different hours during a day or different days during the week. For instance, within the day, ToU typically include two or three different price increasing periods: off-peak, (mid-peak), and peak. The dynamic pricing programs are typically represented in two basic types: real-time pricing (RTP) and critical peak pricing (CPP). While in RTP, the price changes every hour following exactly the changing market conditions, the CPP allows for the retailer to occasionally declare an unusually high retail price for a limited number of hours and to charge those prices to consumers. Dynamic pricing can be more complex than static pricing, but it has been shown that it can capture a far larger share of the variation in wholesale prices (Borenstein et al. 2002).

In the incentive-based programs, consumers obtain (fixed or time-varying) payments for participating and for reducing their load when required. Consumer enrollment and response are voluntary, although depending on the terms of the contracts a financial punishment might exist in the case of failing (no participation) when events are declared. The incentive-based DR programs can be categorized into classical, with consumers receiving a participation payment (usually in the form of bill credits or discount rates), and market-based, where participants are rewarded with money for their performance in terms of the amount of electricity reduced during critical conditions.

The most widely used incentive-based programs are the interruptible Load (IL) schemes, where pre-defined incentives are provided to participating consumers. An IL program considers curtailment options like, for instance, curtailing a specific part of the electric load or curtail the total consumption to reach a predetermined level. While partial load interruption is more often used in the context of domestic consumption, the total curtailment is mostly used in the case of industrial consumers. In addition, these DR programs can provide a rate of discount or bill credit in exchange to reduce the load during system's emergency, and consumers that do not respond to these options receive a number of penalties as defined in the agreed terms of conditions (Albadi and El-Saadany 2008; Faria and Vale 2011). Salah et al. (2017) provide an alternative angle on the subject matter by developing a morphological taxonomy of different rate design features which jointly span the design space for all different energy pricing schemes.

The savings on the energy bill achievable by consumers through the participation in DR programs during peak hours are among the most often emphasized benefits of these programs. And from the consumer point of view, these benefits constitute the main element stimulating consumer participation in DSM programs. In addition, because expensive peak plants have to be ramped up with a lower frequency, as a result of DR a market-wide price reduction can be expected. And with respect to grids, with DR investment in infrastructure can be deferred and the management of grid congestion issues can be dealt with a number of different tools.

RES self-generation is considered an important facilitator of electricity consumer participation in the context of DSM. Consumer awareness and choice relative to energy management and self-generation options is growing. Consumers have multiple choices at their fingertips to explore, including rooftop solar PV, smart appliances, electric vehicle (EV) charging options, heating, ventilation, and air conditioning (HVAC), water heating, and solar PV plus storage. All aspects of homes connected to the grid can accommodate customer preferences and comfort. Because these behind-the-meter elements can be read in near real-time, they can be used to generate lower or more predictable energy bills for consumers. Usage insights can also be used to help drive additional products and services to improve the customer experience and ultimately incentivize their participation in DSM programs.

Another relevant element facilitating electricity consumer participation in DSM are energy storage systems. Multiple storage technologies can be used in both households and industrial facilities to alter the electricity load from times with surplus energy to be released for later use, i.e., load shifting. Particularly in the context of RES self-production, it has been demonstrated that the combination of small-scale storage with DSM significantly improves the local use of photovoltaics (PV), thus increasing the PV value for the user. It is foreseen that this combination will play an important role in the future smart grids (Castillo-Cagigal et al. 2010). Considering distributed energy resources (DER), by storing electricity when local production exceeds consumption, future needs can be satisfied with electricity coming from this local source. From the grid point of view, this corresponds to anticipating a part of the consumption, for instance during midday sunny hours instead of during the evening load peak. As a result, it can create value for the grid, part of it being shared with end-users by reducing their consumption costs without modifying their electricity demand patterns.

2.2 *The Role of Smart Grids and Smart Devices*

Currently, DSM is increasingly viable by means of highly efficient electrical appliances that can be remotely controlled (Hinnells 2008). Many of these devices can also benefit the grid when collectively managed, by minimizing, shifting or optimizing energy use within the home. In addition to premise-level optimization technologies, distributed energy resource management systems are being piloted and deployed by suppliers and third-party aggregators to control fleets of customer assets that meet a variety of grid needs. It is apparent that the installation and use of interconnected home appliances are essential to the successful functioning of DSM, this under the pre-existent condition of having some guarantee that the production of the equipment (sensors, smart meters, and control systems, among others) and the setting of specific technical requirements are fulfilled.

Combined with cost-reflective price signals, such as dynamic pricing, DSM systems can provide a way for consumer empowerment and facilitate better coordination of energy usage in ways that reduce the cost of delivering electricity, which supports a more affordable, reliable, and sustainable grid over time. Thanks to smart device technology, consumers can now understand how consumption patterns impact their energy bill, comfort level, and supply security. Consumers can see how energy usage during peak times is more expensive and shift their use during less expensive times of the day. In addition, data from smart meters allows suppliers to observe consumption patterns and load shapes, which can be used to improve blackout management and the overall flexibility of the grid.

2.3 The Role of Energy Service Companies

An additional element influencing consumer empowerment are ESCOs, acting as intermediaries in charge of facilitating the finance of energy saving programs. The leverage that comes from the evolution of smart grids is described in more detail below, in particular, the multiple roles of conventional ESCOs are summarized. These financing arrangements differentiate ESCOs from the traditional energy consultants or equipment suppliers. ESCOs have the know-how required to provide key services and solutions for achieving significant cost reductions while dealing with various market-related barriers remaining. Some of the most common functions of ESCOs include handling projects, managing or mobilizing financial and non-financial resources, as well as undertaking installation and maintenance work.

ESCOs typically carry out their economic activity under two main contracting mechanisms: energy performance contracting (EPC) and energy supply contracting (ESC). By linking their benefit to the performance of their implemented projects, ESCOs assume performance risks under EPC. With this risk acceptance, ESCOs ultimately incentivize themselves to deliver savings-oriented solutions for consumers and for society, with the consequent overall welfare gains. Under the ESC concept, the ESCO is only remunerated for the useful energy output, that is, it supplies useful energy (such as electricity, heat, or steam) under a long-term contract to a building owner or building user. It is, therefore, in the interest of the ESCO to reduce the final energy demand, aligning once again the incentives of both, energy consumer and service provider.

3 Business Opportunities and New Market Actors

In the context of demand side management, new services emerged and traditional actors, like retailers, are becoming more active while facing challenges from new actors competing for customer service provision, namely, the aggregators and the ESCOs. In this section, we explain the roles and the interplay of these actors, along with the roles equipment and appliance manufacturers have in providing the required elements for advanced services.

Power aggregation can significantly speed up the integration of renewable power generation from intermittent sources, improve demand flexibility, and decrease the dependence on renewable energy support policies. However, single individual, commercial or domestic consumers would only have a limited impact towards the achievement of more aggregation and market integration. The use of distributed generation, demand side response, and different forms of storage can only be effective through the coordinated actions of massive amounts of diverse consumers and producers interacting in the markets.

Aggregators

Aggregators are formally defined as legal entities with the aim of optimizing, technically or economically, the production and consumption of an electricity system. The aggregation can involve generators and consumers, operating in one or multiple electricity markets. In other words, they are facilitators between the supply and demand sides of electricity markets, and under a design including the appropriate incentives, the wholesale electricity markets might benefit from aggregation. On the downstream side of the market, aggregators act on behalf of consumers through the use of technological solutions and information and communication technology (ICT) for optimization. In this business line, aggregators provide energy services for industrial, commercial or domestic consumers who own generation and storage units or can offer demand response. On the upstream side of the market, energy aggregators offer value to multiple market players to optimize their portfolios and for balancing and congestion management. In this business stream, the aggregator's services are provided to balance responsible partys (BRPs), distribution system operators (DSOs), transmission system operators (TSOs), and energy suppliers.

ESCO

One last option for the aggregator is to offer value to some downstream and upstream entity—this is the case of ESCOs. Demand response programs are opening up new opportunities for ESCOs to play a significant role in the operation and optimization of energy grids. After all, ESCOs have a unique competitive advantage: they can combine their energy management expertise with granular customer insights to help reduce or shift their clients' energy usage during peak periods in response to time-based tariffs or other incentives.

A context with an increasing demand side management will also offer a great way for ESCOs to extend energy services beyond raising energy efficiency—by contributing to grid stability, safety, and environmental sustainability—while reaping additional cost savings and opening up new revenue streams for their customers. This does not mean that ESCOs will necessarily enter into competition with other new market players, e.g., "aggregators". ESCOs can take advantage of upcoming energy monitoring platforms which enable their clients to participate in demand response programs without having to take an aggregator role. Consequently, an ESCO will only have to install the necessary equipment for demand response as it usually does for other purposes such as sub-metering.

Energy Supplier 2.0

The “Energy Supplier 2.0”, already mentioned in Chap. 2, is a conceptual business model for energy suppliers aggregating flexible distributed assets introduced by Specht and Madlener (2019). The focus of new business models in the electricity supply market (and actually also other end-user energy supply markets) has to focus much more on the customer needs and potentials. The conceptual business model of the Energy Supplier 2.0 (that is based on the Business Model Canvas approach by Osterwalder and Pigneur (2010, cf. Chap. 8) sketches out a dedicated aggregator of flexible capacities on the household level. It reveals how a specific new energy business model can tap the potential of distributed flexible energy assets (including DR), and is thus also very relevant for new demand side management services offered by an ES2.0.

Virtual power plant operators

Virtual power plants (VPPs), as an orchestration of a collection of DER, have been proposed to reduce upstream power generation and transmission capacity needs, but also as a new business model enabled by smart grid technology. VPPs may include demand response aggregators and/or such aggregating battery capacity, both focusing on flexible loads. The concept where a VPP is formed through peer-to-peer transactions between self-organizing prosumers has been referred to as “federated power plant” (Morstyn et al. 2018). A VPP is a cloud-based distributed power plant that aggregates the capacities of heterogeneous DER for the purposes of enhancing power generation, as well as trading or selling power on the electricity market. Under a VPP, all the elements of the grid (sources, storage, building, district, transformers, etc.) are integrated and all communicate together, using standard TSO/DSO communication protocol, to choose the best management solution to provide energy services.

Prosumers

Prosumers can be autonomous from the grid or not. Those households that can make themselves independent from the grid throughout the year need to install sufficient renewable energy capacity and energy storage, as well as some smart home/home automation technologies for energy management including DR. Those prosumers who remain connected to the grid may be passive or active agents from the grid perspective, i.e., either providing some energy and/or ancillary services to the grid or not. Efficient demand management is paramount for maximizing the level of autarky that can be achieved at a reasonable cost.

Citizen energy communities

On the meso level between an individual household and the entire supply region of an energy provider, there are local, more or less self-sufficient, energy communities. With a multitude of potential legal arrangements (e.g., cooperative societies, public limited companies, or some small-medium size enterprise), energy communities integrates, aggregates, and coordinates distributed energy services for users and providers at the neighborhood level, facilitating the active involvement of citizens in the configuration and operation of the energy system, and its flexibility. Besides, energy communities can team up with other market players and jointly invest in energy assets, enabling the interactions in such a way that the full potential from DR is gathered for the shared benefit of the community and the rest of the energy system.

Data centers

Data centers use different ICT devices to provide the services associated with the process of storing and communicating the data behind the myriad of information services we rely upon every day. All these services are powered by electricity used by the information technology (IT) devices. On average, servers and cooling systems account for the greatest shares of electricity consumption in data centers, followed by storage drives and network devices (Shehabi et al. 2016). Given that data centers demand very large loads for the grid and are well suited for demand response programs thanks to their level of automation, there is a potential for data center participation in demand response programs (Ghatikar et al. 2012; Koronen et al. 2020).

(Smart Home) Equipment Suppliers

In-home premise equipment and appliances play an essential role in the future of demand side management. Consequently, the manufacturers of technical solutions implemented to accommodate demand response programs, also represent an important type of market actor. Some of the most interesting business opportunities for manufacturers are related to the provision of smart metering and submetering equipment, but also sensors and solutions safeguarding data and data privacy, where needed. These are required components for monitoring energy consumption at high frequency intervals to be used for information capturing and communication with, potentially multiple, services providers including retailers, aggregators, and ESCOs. Appliances for domestic, commercial, and industrial consumers increase the potential gains from their participation in demand response programs; the provision of this component (including those linked to ESCOs and/or aggregators) is also a potential vein of business for manufactures.

Distributed generation contribution to balancing services

When optimizing system operations, the need for balancing resources is strongly influenced by fluctuations in power generation and is expected to increase in future power systems due to the increased penetration of renewable power generation. Concretely, renewable energy, and especially newly installed wind power, have prompted additional demand for reserve and response operations. This demand arose predominantly from the uncertainty of day-ahead forecasts for renewable feed-ins. To appropriately respond to increased uncertainty, decentralized energy systems arise as a new player. A decentralized energy system is a relatively new approach in the power industry in most countries. Traditionally, the power industry has focused on developing large, central power stations and transmitting generation loads across long transmission and distribution lines to consumers in the region. Decentralized energy

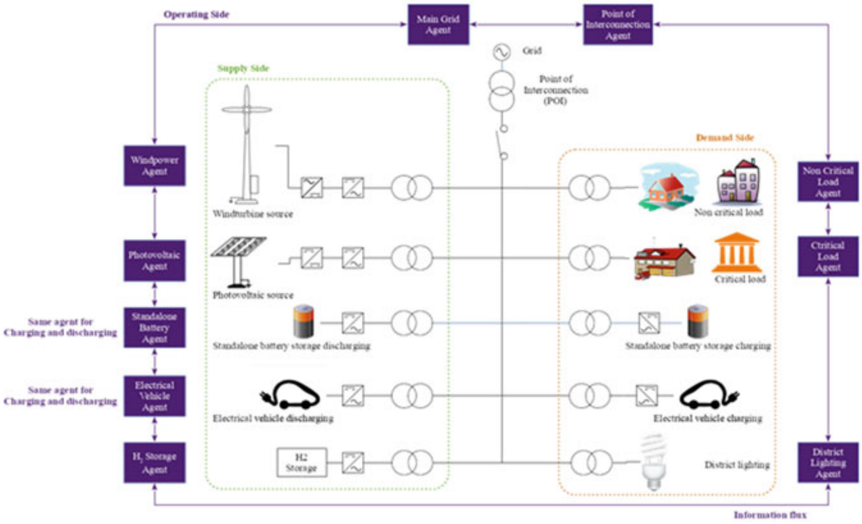

Fig. 4 Simple example (PV, wind, battery, H_2 storage, districts, lighting and POI) of interconnection and potential agents

systems seek to put power sources closer to the end user, enabling to provide power balancing services (Fig. 4).

Moving from a centralized system to a decentralized one implies that the agents work at different frequencies:

- Microseconds (for energy producers) for those who are connected to power electronics;
- Milliseconds (for energy producers) for agents managing power electronics control loops, breaker switching, voltage a frequency control, machine dynamics and transient stability, protection;
- Seconds (for energy producers), if they control batteries, super-capacitors, or mechanical system;
- Minutes (for energy producers, TSO/DSO and local system managers), for tie line regulation, global electricity load (a district for example) and hydropower plants;
- More than minutes (for energy producers, TSO/DSO, local system managers, and in general end users), for all the systems like heat storage, building inertia, heat concentrated solar power plants, and biomass-fired power plants.

Each agent has its local behavior resulting from its status, its knowledge, and its sharing of information with all the other agents of the local grid and one can also add to the agent a classical controller (model predictive control for example). Then, the agent can switch from one, the other, or both controllers depending on the following constraints of grid/market and/or characteristics given summarized below:

- Power flow control between each element of the net;
- Real-time monitoring and control;
- Effective information visualization;

- Dynamical optimization of the performance and robustness of the system;
- Quickly react to disturbances in such a way as to minimize impact;
- Effectively restore the system to a stable operating region following a disturbance;
- Fast isolation & sectionalization if a defect appears somewhere in the grid;
- Adaptive islanding;
- Anticipation of disruptive events which will lead to a blackout;
- Electricity price (spot market, etc.);
- A competitive solution compared with solutions combining variable output renewables with electrochemical storage.

4 Change in User Behavior by Smart Meter Feedback

There are two ways in which user behavior (and thus energy demand) can be affected by Smart Meter feedback, namely direct and indirect feedback (Darby 2006). *Direct feedback* can be provided via a display on the power meter itself or on a separate display. The design of the display can have a significant impact on the response—e.g., in terms of the type of information provided (qualitative or quantitative, analog or digital, etc.), the time coverage (historical, actual, expected future), the level of disaggregation, and benchmark comparisons, e.g., against previous consumption or that of some neighbors/peers (cf. Anderson and White 2009). *Indirect feedback* refers to rehashed data (e.g., consumption trends) or comparison against recommendations/target settings. Research along these lines has found that persistence of the behavioral change is higher for extended periods of information provision (greater than three months) and more detailed information (e.g., Henryson et al. 2000), and that intrinsic motivation seems more important than extrinsic one.

Demand can be influenced in various ways, e.g., by the shut-off of the energy-using device, less frequent or intensive usage, more sensible usage, or by performance (energy efficiency) improvement of the device (which often implies replacement with a more energy-efficient, state-of-the-art device) (see Table 1). Figure 5 shows different types of feedback that can be thought of by smart meter intervention (Watson et al. 2006).

5 Deep Reinforcement Learning and Building Optimization: Towards Smart Demand Response with Big Data

With the diffusion of advanced metering infrastructure, large data volumes are becoming available which can be used for the online optimization of schedules for building management systems (Mocanu et al. 2019).

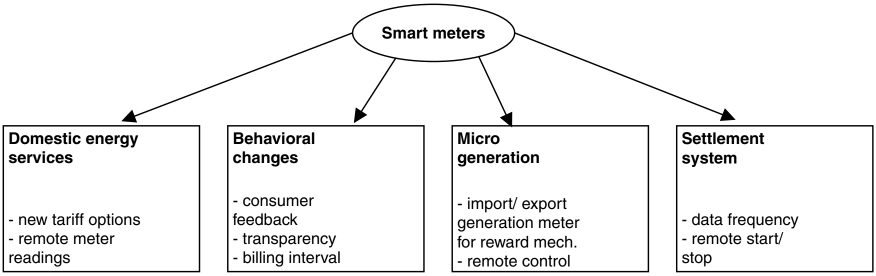

Fig. 5 Types of impact of smart metering on user behavior

Big data enables a deeper analysis and understanding of individual consumption behavior, by automatically extracting, controlling, and optimizing demand patterns, and thus bears the potential to enhance energy efficiency and optimize energy consumption in buildings (Mocanu et al. 2019).

Still, due to the curse of dimensionality, reinforcement learning algorithms/ approaches often fail in tackling large-scale problems but can be combined with others (e.g., combining deep learning with reinforcement learning). Overall, this trend has been referred to as Smart Home Energy Management Systems (in contrast to conventional HEMS).

Table 1 Five main categories of energy feedback (Darby 2006)

Type of feedback	Process	Examples
Direct	Available on demand	• Self-meter reading
		• Direct displays
		• Interactive Feedback
		• Pay-as you go meters
		• Ambient devices
		• Cost plugs on appliances
Indirect	Data processed by utility and sent to the customer	• More frequent billing
		• Comparative or historical feedback
Inadvertent	Learning by association	• Micro-generation
		• Community projects
Utility-controlled	Learning about the customers	• Smart meters
Energy audits	Learning about the energy capital of a building	• Undertaken by a surveyor engaged by the client
		• Undertaken as part of a survey
		• Carried out on an informal basis

Such hybrid machine learning (ML) approaches enable to optimize energy consumption at both the individual building and the aggregated level (with only a single agent). In combination with dynamic pricing such approaches can be used, e.g., to either pursue cost minimization or flattening the net energy demand/load profile.

6 Business Models for Smart Demand Side Management

Among the new business models for smart DSM are platform-based models involving some of the new market players described above (and in more detail in Chap. 2). Platform-based business models for DR are likely multi-lateral, i.e., involving different types of actors. A major challenge is that the notion of the customer is blurred and that there is a need to orchestrate multiple value propositions.

7 Policy and Regulatory Aspects Related to DR

Regulatory and policy aspects (e.g., tax and subsidy programs) also have an influence on the DR potentials that can be exploited.

Full exploitation of the (growing) DSM potentials due to the smart grids evolution also necessitates continuous adjustments to the legal framework and supporting policies. Smart Energy Demand Coalition (2015) has performed a review of the incentive-based DR developments in Europe. Specifically, they use the following four criteria: (1) consumer access to DR aggregators or service providers; (2) adaptation of balancing market requirements to allow for DR participation; (3) existence of standards for measurement and verification; and (4) establishment of appropriate DR remuneration schemes and penalties for non-performance, including standards for transparency and reporting (Fig. 6).

8 New Perspectives for Demand Response

Demand response becomes more valuable in light of the increasing demand for flexibility by renewable power generation. At the same time, DR, also for small consumers, becomes more accessible through ICT. Furthermore, electricity will be more and more used for heating and transportation, entailing flexibility by thermal storage units and vehicle batteries (Madlener and Ruhnau 2021).

ICT enables bi-directional communication between the grid operator/s and the end-users and thus greatly facilitates dynamic pricing, requests/offers for load flexibility, load scheduling, and availability of DER (e.g., for reducing peak demand or providing ancillary services). Smart grid enhanced DSM, on the one hand, can thus greatly help to stabilize the system, but on the other hand cause extra costs and

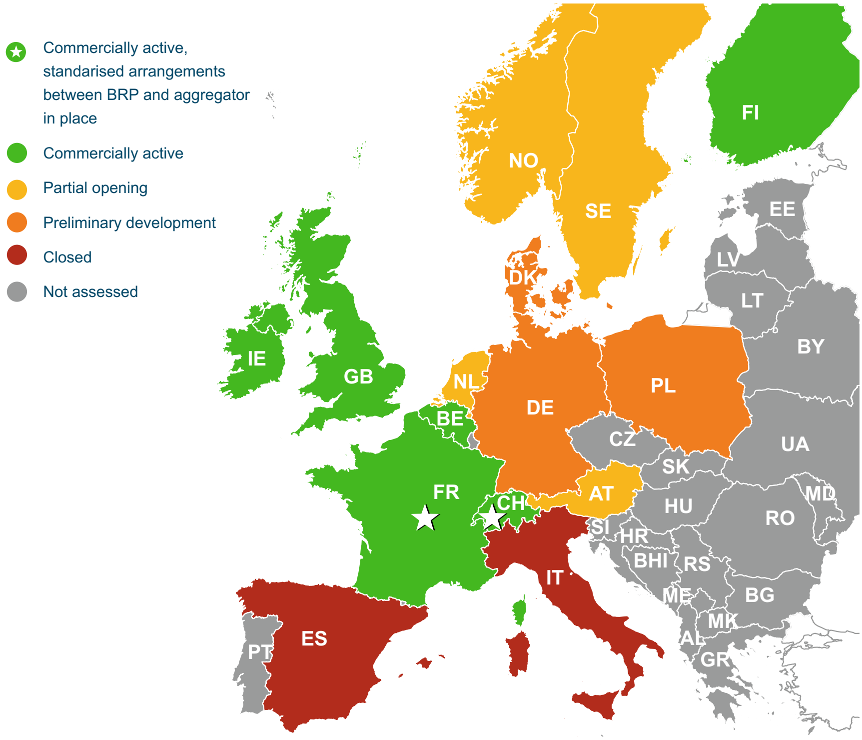

Fig. 6 Map of explicit demand response development in Europe (Smart Energy Demand Coalition 2015, p. 10)

hazards due to the impacts of bidirectional energy flows for which the system was originally not designed (Fig. 7).

In principle, two strategies can be distinguished for using DR in combination with DA and intra-day market trading: (1) activation of DA market (valued at the DA price) and (2) activation of intra-day market (valued at the intra-day price). A mix of these two strategies is also conceivable, i.e., trading DR capacity in both markets. Likewise, DR could be traded multiple times during the continuous intraday trading period (Madlener and Ruhnau 2021). DR benefits from market price volatility, which, in turn, is driven by the intermittency of renewables as well as their forecast errors.

Figure 3 shows the results from a stylized example for Germany. The assumption is that 1 kWh of electricity demand is shifted every day from the time of the day with the highest price to that of the lowest price. It is assumed that DR is available throughout but can only be activated once a day. Perfect price foresight on the energy markets is also assumed. The results show that the market value of DR is driven substantially by price volatility and that it is twice as high for quarter-hourly products than for hourly ones. With decreasing lead times it increases modestly. Note that for the case

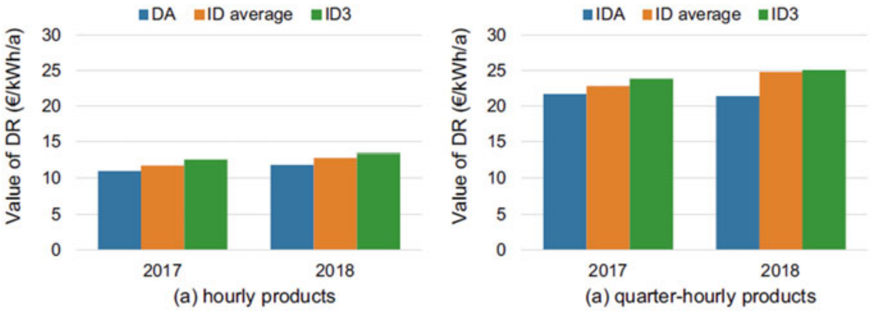

Fig. 7 The value of DR in the German electricity spot market 2017–2018. DR activation strategies are compared for hourly **a** and quarter-hourly **b** products in the DA and intra-day auction as well as in continuous intra-day trading, using the volume-weighted average intra-day price over the entire trading period (intra-day average) and over the last 3 h of trading (Madlener and Ruhnau 2021)

of capturing the (higher) price volatility of quarter-hour products, it is necessary that the DR application must be able to adjust demand by 4 kW, rather than by 1 kW only for the hourly products (Madlener and Ruhnau 2021).

The role of DR being integrated into a portfolio of renewable power generation assets, jointly optimized by trading in the intraday and day-ahead markets, has been studied by (Garnier and Madlener 2016). They show that the day-ahead activation of DR can increase the sales revenues of renewables, and thus the day-ahead market value, whereas the intra-day activation of DR can help to reduce the balancing costs of renewables.

9 Conclusions and Final Remarks

In this section, we have first provided a short overview of the various flexibility options to accommodate growing shares of variable renewables, including DR, followed by a discussion of the major forms of DR programs and the various challenges involved. The issues brought up are generally relevant for residential, commercial, and industrial end-users alike, although the practical specifics might be quite different from each other.

Second, the role of dynamic pricing and tariffs is discussed as an important lever for activating and enhancing consumer participation in DSM, alongside the various DR schemes available. The special role of ESCOs in this context is emphasized (here primarily in a conventional energy system setting).

In the third part, the different new market actors and emerging business opportunities are covered, especially ESCOs (now in the context of the evolution of smart grids). In particular, the role of aggregators, ESCOs, smart appliance equipment providers, and "Energy Suppliers 2.0" were addressed, as well as the importance of (reducing) transaction costs.

Finally, we addressed the need for policy action and regulatory change to support cost-effective demand response.

Overall, we pointed out that while DSM/DR has been used for decades, the evolution of the smart grid and the emergence of new actors bear an enormous potential for better exploiting the DSM potentials for balancing energy supply from increasing shares of variable energy resources (VER) with the rapidly changing needs (and thus load profiles) of both consumer and prosumer households. DSM is one of several options for flexibility. It needs to be seen how the "merit order of flexibility options" evolves over time.

10 Case Study 1: Demand Side Management Experiences

The ongoing power sector transformation is being accelerated by the combination of electrification, decentralization, and digitalization. The application of digital monitoring and control technologies in the power generation and transmission network has been an important trend for several decades, and has recently started penetrating deeper into power systems. Wider usage of smart meters and sensors, the application of the Internet of things (IoT) and the use of large amounts of data with artifical intelligence (AI) have created opportunities to provide new services to the system and the emergence of new business models.

There are multiple examples of new business models associated with this transformation process. More specifically, in this case study, some illustrative examples of system flexibility provision, will be discussed. Through ICT and digital technologies, all industrial and residential consumers can provide flexibility services.

This trend, driven by the increasing deployment of smart grids, smart meters and other software platforms that capture data on energy use, is expected to rapidly gain ground in the coming years and become a more mainstream way for businesses to reduce energy consumption and costs.

According to research on the future of the DSM market published by Navigant Research,[1] emerging DSM technologies are starting to offer energy users better ways to reduce energy costs by increasing their focus on behavioral measures and data analytics. This is a promising future, where according to this report, DSM and new business models are expected to lead to an estimated US$63.6 billion in worldwide spending in 2028.

In order to benefit from this increasing market, a range of solutions providing the new energy services are being developed based on automation and market signals. In the case of the domestic and small and medium enterprises segment, these solutions can be grouped in the following fields:

Heating, Ventilation and Air-Conditioning

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[1] https://guidehouseinsights.com/reports/demand-side-management-overview.

Since HVAC systems represent a significant portion of domestic energy consumption, its potential participation in DSR mechanisms has gained attention in recent years. This highlights the importance of developing building energy control and operation strategies, which would help to increase the energy efficiency and indoor comfort in the buildings. For this purpose, energy-modeling tools have been developed, with the aim of minimizing the energy cost while respecting the customer comfort.

When providing these DSR solutions, independent aggregators have been active in offering technology to residential consumers in order to connect appliances so as to aggregate their flexibilities. For instance, one European aggregator uses a wireless transmitter and electricity modulator provided to consumers, installed and operated without charges, to connect appliances such as electrical heaters, air conditioners, heat pumps and water boilers in homes, commercial buildings and offices. The aggregated flexibilities are sold to the grid operator for balancing and safety purposes, and on a daily basis to all players through wholesale markets. The cooperation with manufacturers of heating devices to directly include control technology into the devices, enables consumers to participate in DR offers without further investments costs for the consumer or the aggregator. This enables the current heating system to operate efficiently and helps save up to 15% of heating expenses (Eurelectric 2017).

Home Battery Automation

Increasing adoption of EVs fosters the development of new business models associated with home battery automation. These Energy as a Sevice (EaaS) models could provide storage systems for customers to store energy during periods of low demand and to draw from that stored energy during periods of peak demand.

In some European countries, home battery automation has been advanced and commercially developed by electricity suppliers or energy services companies. In exchange for a discounted home-battery, the consumer agrees to let them use a percentage of the battery capacity. The aggregated capacity is then used to spread over its consumer portfolio to create a virtual power plant providing balancing services to the grid.

Transactive energy management solutions

The market for energy management solutions has also been developing on pace. Under this business model, an aggregator accumulates transactive loads such as electric thermal storage heaters, hot water heaters, ice-based air conditioning, compressed air energy storage, and electric vehicles into a grid asset (Virtual Power Plant), to deliver ancillary services to grid operators. They also monitor real time price variation and purchase electricity when it is cheapest. Through the combination of savings from arbitrage with profits from ancillary services, they provide low-cost ancillary services to grid operators and reduce the cost of heating for consumers.

The provision of this demand side flexibility, defined as the ability of a customer to deviate from the normal electricity consumption in response to economic signals, could be monetized through the active participation of the customer in the power system operation and its associated markets (Table 2) providing services to the TSO, the DSO or the actors participating in these markets and with the BRP.

Table 2 Different roles of demand side flexibility

	Service provided to the power system	Potential client		
		DSO	TSO	BRP
Constraint management	Voltage control	X	X	
	Grid capacity management	X	X	
	Congestion management		X	
Adequacy	Capacity payment		X	X
	Strategic reserve		X	X
	Hedging		X	X
Wholesale market	Day ahead optimization		X	X
	Intraday markets		X	X
	Generation optimization	X	X	
Balancing markets	Frequency containment	X	X	
	Automatic and manual frequency restoration	X	X	
	Replacement reserve		X	X

11 Case Study 2: Market Design for Greater System Flexibility

The increasing share of RES deployment required to reach the sustainability targets stated by the European Union will have increasing impacts on the functioning of electricity markets. When replacing conventional power plants with renewables such as wind turbines and solar PV, the ability to provide power balancing services in the classical sense disappears. As the intermittent electricity generation from fluctuating renewables increases, the need for balancing services will consequently also increase. Furthermore, conventional fossil fuel power plant generators are synchronous with the grid, and therefore, provide rotating inertia that supports the system frequency against changes.

It is, therefore, evident that the transition towards a decarbonized power system will lead to challenges of balancing the electricity supply and demand. Alternative sources of balancing services must therefore be established as the conventional power plants are pushed out. One of the approaches to obtaining alternative balancing services is the smart grid concept, where flexible consumption takes part in the balancing effort. Demand side response could be the main contributor to more effective markets and to system security with a high penetration of fluctuating generation.

Historically, generators, such as gas-fired power plants and pumped hydropower plants, have mainly supplied flexibility. Nevertheless, in an increasing renewable generation scenario, this could not be enough. Demand-side resources can provide

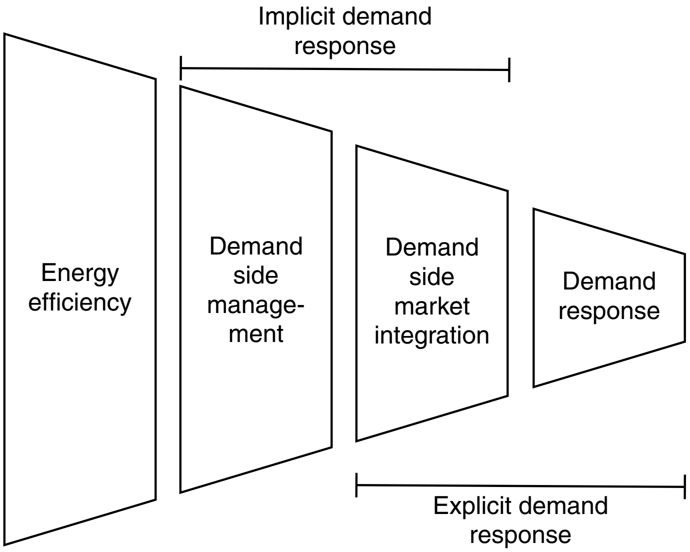

Fig. 8 Demand side engagement (ACER 2017)

flexibility through demand response. Industrial consumers are already offering flexibility this way to the system operator, by agreeing to reduce or increase consumption as needed, in return for compensation. Residential or small commercial consumers can also provide demand response, but the relatively small scale of the flexible loads of these consumers requires new approaches to provide these flexibility requirements through new energy actors such as aggregators.

Different kinds of demand side activities have been considered worldwide for demand side participation. Focusing on explicit (industrial and residential consumers adapting their consumption patterns to price without explicitly participation in the market) and implicit demand response services (demand response is explicitly sold by consumers to the market or to grid operators), the market design has to be adapted accordingly for enabling both types of DR (Fig. 8).

The envisaged transformation is likely to require numerous regulatory adjustments and the implementation of new market design elements to efficiently respond to the expected changes coming both from the supply and the demand side. That requires common rules and standards for the operation of power grids with different approaches.

European Experience

The recently approved Clean Energy Package includes a set of measures to push forward the energy transition with the consumers at the center of this process. Integration of demand side flexibility has been identified as an important component of the European Union’s transition towards a low carbon economy. This case study will provide some insights on the most relevant aspects that provide new business opportunities.

The development of such rules has been initiated by the Agency for the Cooperation of Energy Regulators (ACER), establishing guidelines to which these common rules and standards need to comply with. Based on these guidelines, the European Network of Transmission System Operators for Electricity (ENTSO-E) drafted eight network codes with the aim to enable the implementation of the EU internal electricity market. These network codes have the legal status of directives. The network codes on Capacity Allocation and Congestion Management (CACM) and Electricity Balancing (EB) concern the design and operation of short-term electricity markets across EU Member States and thus provide a framework under which potential developments of these markets can be materialized. Demand side response is considered a key component of future power system operation where residential consumers offer potential for load balancing as well as economic savings.

US experience

In the United States, according to North American Electric Reliability Corporation (NERC), higher penetration of variable generation resources has created a growing need for flexible resources, such as demand response, in order to balance electricity supply and demand, ensure resource adequacy, and meet ramping needs. Planners and operators could face challenges when integrating variable generation resources and other emerging technologies as inputs, potentially requiring revisions to operational practices, enhancement of reliability standards, and changes in market designs.

The rise of renewables is expected to continue, at least for the next few years. In this regard, some electricity markets, such as the California Independent System Operator (CAISO) has started to recognize, to varying degrees, flexible and resilient electric resources. Likewise, policy makers at the Federal Energy Regulatory Commission (FERC) and the PJM Interconnection are shifting focus, in the United States at least, to the role that battery energy storage and flexible resources like distributed resource aggregators (DRA) could play as electricity markets evolve.

In the field of DER, they have made their contribution; (smart grid supported) DER is an emerging resource category too often overlooked, with aggregation pilots focused on monitoring and offering services to the grid.

Asia-Pacific experience

Asia-Pacific's liberalized electricity sector is attracting active participation from private companies and customers in the DR market. Countries such as Japan and Singapore have already developed DR regulations and are in the process of testing DR to assess its viability and arrive at the right mix of incentives to encourage private participation.

As a large industrial nation with a forecasted peak load of more than one Terawatt by 2025, China is a potentially large market for demand response management systems. The country has experienced shortages in power availability because of rapid economic growth, a situation that has been solved in recent years. Nevertheless, to manage this mismatch between electricity demand and supply, large industrial customers are one of the most relevant players in these DR programs focused on reducing peak demand.

Overall, demand side response is considered a key component of future power system operation where residential consumers offer potential for load balancing as well as economic savings.

Review Questions

- Can you identify and describe the five main flexibility options for accommodating increasing/high shares of renewables?
- Are you able to list five main barriers for the wider uptake of demand response options?
- Can you name and explain three different types of DR programs, and the most important differences between them?
- Are you able to explain the role of aggregators in managing distributed energy resources?
- Can you describe the main criteria for (demand-side) flexibility market design?
- Why are energy monitoring platforms attractive for ESCOs?
- Sketch the demand side engagement funnel. Can you explain its main elements?

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