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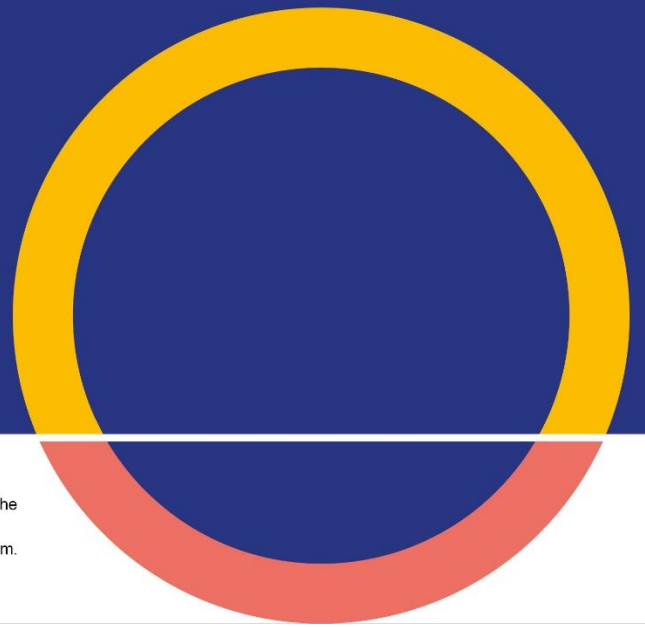


EXECUTIVE SUMMARY



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Executive Summary

The availability of sufficient resources of operational flexibility in the power grid is the key factor in order to integrate large-scale stochastic renewable energy sources and to massively electrify transportation and heating sectors. Thus, flexibility is needed at all levels and in all parts of the network, in order to enable the power grid operator in both transmission and distribution levels to adjust any imbalances caused by wrong forecasts and fluctuations of renewable power generation or demand, and to safely operate the power grid by relieving line congestion and voltage issues. The flexibility in the supply side is inherently limited, where gas fired generators are heavily capital-intensive investments, and it becomes even scarcer by phasing out conventional generators. An efficient solution can be harnessing flexibility from Distributed Energy Resources (DERs) including flexible loads. Flexible power consumption is often referred to as demand-side flexibility, which implies the capability of electric power demands to directly or indirectly adjust their consumption level according to an external signal provided by the power grid operator.

Demand response has shown great promise in many studies, and it is widely believed to be a vital part of the solution to the energy challenges for flexibility. The DR-RISE project will look into the benefits of DR in the residential sector and demonstrate innovative technologies to optimise not only the end-consumers' side but the overall energy system and the actors involved. The DR-RISE will further develop a holistic set of tools and services with will increase energy efficiency via optimal management and demonstrate DR schemes technical and socioeconomic benefits.

To begin with, the task 1.1 first briefly reviewed the demand response mechanism and its current position in the energy markets. The several markets of different time frames (forward, day-ahead, intraday, balancing) are more or less apparent across Europe with some differentiations appearing, so there is still room for further harmonisation especially regarding DR. Depending on the minimum bid size and the digitalisation capabilities of the grid infrastructure, the end consumers have more opportunities to participate and provide their flexibility. The harmonisation guidelines for demand response are elaborated in the upcoming network code for demand response, which will clarify several issues regarding balancing, congestion management and voltage control. The stakeholders' role and the data exchange guidelines are presented providing a basis for the development of demand response markets, as well as important information for the developments of technologies, use cases and demonstrations of DR-RISE project.

The task 1.1 activities provided a brief review of the energy landscape in several countries and presented the existing products, services and incentives for demand response of industrial, tertiary and residential sectors. The countries under analysis were mainly the ones participating in the project either as demo sites or partners, i.e., Spain, France, Germany, Italy, Greece, Bulgaria, Belgium, Ireland, as well as other countries with mature demand response markets such as UK, Netherlands and the US. In this analysis, several approaches for demand response participation schemes have been presented, that can be grouped in mature markets (e.g., UK or France), where there is a variety of products for residential and industrial/tertiary sectors, and in early markets (e.g., Spain or Greece) where there is still a need to establish

the market mechanisms for wide scale use of demand response. In general, smart meters penetration is in pace with the maturity of the demand response market, i.e., countries with high penetration of smart meters and relative communication technology are having more mature demand response markets. Thus, the development of smart metering infrastructure is considered vital for the wide applicability of demand response mechanisms in order to be able to support the implementation of the market mechanisms.

Several EU funded projects have been also looking into the demand response mechanisms involving residential, tertiary and industrial sectors as well as several market stakeholders, i.e., TSOs, DSOs, market operators, aggregators, suppliers and others. Many projects are developing AI-based smart grid tools that facilitate the operation and control of distribution network and flexibility resources management. Consumer engagement strategies are also playing a key role in the research development, including dedicated activities to engage the end users' participation in the demonstration campaigns of the developed demand response technologies. Data exchange platforms and interoperability are also in the spotlight and several IT architectures are being developed and tested during these projects, especially related with the 'TSO-DSO-consumer' coordination challenge and the provision of active system management for balancing and congestion management services.

Furthermore, the technology challenges and enablers for demand response have been examined, regarding the information tools that can monitor the consumers' energy performance, leverage the big data produced by their flexible edge devices. AI-based technologies and data analytics can support energy stakeholders forecasts of system peaks and congestion bottlenecks, and manage their reserves proactively to mitigate several critical issues. The IoT technology, edge devices and smart meters should be interoperable to leverage the data streams and provide fast and accurate control mechanisms. Additionally, the construction value chain of building management systems and smart building technologies should be trained and enriched with competent trained personnel. They can really promote public acceptance of smart building technology, facilitate the wide public to familiarise with edge intelligence and thus participate in demand response market mechanisms.

Regarding the socioeconomic challenges and enablers for demand response, there is a need to incentivise and/or fund a portion of the upfront cost of consumers' infrastructure upgrade that enables the delivery of demand response services. Furthermore, there is a challenge to present the energy system information in an attractive way to the consumers, in order to engage them in the energy system operation daily and let them indications of the grid issues resulting from the electricity flows. There is also great ambiguity regarding the prediction of consumers' demand profile, while among aggregated loads demand types behave differently and the characteristics of individual households and appliances would not be known by the power system operator. Furthermore, the consumers can be characterised with 'inertia', prohibiting them from changing their energy habits, thus limiting their participation in demand response.

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1 Introduction

Electricity cannot be stored on the grid. Therefore, it is necessary to constantly balance electricity production and consumption. Whenever even a very small imbalance (well below 1%) appears, it must be urgently compensated, in order to avoid power outages or even blackouts. To maintain balance when it is threatened, various adjustment measures are currently implemented, including:

- Requesting additional energy or up/down ramping of carbon-fueled generation units, which are both expensive to operate and contributors to greenhouse gas emissions.
- Reducing the consumption of industrial sites (industrial curtailment), which also has disadvantages as such adjustments may disrupt factory operations, leading to economic, ecological, and even social consequences.

However, these measures only partially meet the needs of system operators due to their significant environmental impact, lack of flexibility, and response. It is also challenging to scale them up as quickly as energy demands change. The development of intermittent and unpredictable renewable energy sources (wind and solar) and the emergence of new uses (electric vehicle charging, IoT, smart homes, etc.) make the balance of the electricity grid even more precarious, requiring faster adjustment measures that can be mobilised within minutes or even seconds.

Demand Response (DR) can be considered as a 'reliability' tool that helps reduce stress on the electricity grid during periods of high stress and risk. During these periods, energy demand can support the frequency restoration and can be adjusted to match the capacity of the grid. By reducing the demand on the grid during in peak periods of time, demand response ensures that these carbon-based peaking power plants do not need to run. The direct benefit is the measurable emissions reduction by not running those carbon-based peaking power plants during these peak periods of time. Because demand response lowers energy usage during these peak periods and effectively flattens out the demand, demand response often ensures that these additional power plants do not need to be built, thus represents major savings for the system.

As more and more renewable energy resources are being built and added to electricity grids throughout the world, the need for flexibility resources (not carbon-based preferably) is increased. Demand response, and the foundational approach of shifting demand to meet supply will continue to play an important role in ensuring grid stability. The dynamics of demand response will play a significant role as the grid becomes more complex and dynamic, and this is enhanced by the integration of smart metering and communication technology in the network.

To be more specific to the majority of end consumers, residential demand response should be designed to influence customer behaviour as well as to shave the peak, working to ensure additional CAPEX-intensive infrastructure costs (i.e., new lines, transformers, substations) are delayed as long as possible driving down costs for the system. Typically, residential customers participate in demand response programs through automated demand response, where the deployment and curtailment of customers is all planned and executed automatically. Many customers also participate with thermostats, where setpoints are raised as well as with hot

water heater controls. DERs can come in many forms, and encompass a wide range of technologies, but are defined by their proximity on the grid to their point of use. All these will be further elaborated during the DR-RISE project providing specific solutions to foster their wide-scale application.

To sum up, demand response is a very efficient tool alongside the energy transition and they have to be integrated into the existing markets framework in harmonised way across Europe to achieve optimum results.

Electricity Market Directives

In 2019, the European Union issued the Clean Energy Package to prepare the way for an integrated and competitive EU electricity market, starting from today's fragmented national and local electricity markets. Four pieces of regulation are worth mentioning setting the rules for this new future united market of electricity:

- Regulation (EU) 2019/941 of 5 June 2019 on risk-preparedness in the electricity sector and repealing Directive 2005/89/EC (Risk-Preparedness Regulation)
- Regulation (EU) 2019/942 of 5 June 2019 establishing a European Union Agency for the Cooperation of Energy Regulators (ACER Regulation)
- Regulation (EU) 2019/943 of 5 June 2019 on the internal market for electricity (recast) (Electricity Regulation)
- Directive (EU) 2019/944 of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU (Electricity Directive)

This set of directives aims to facilitate the transition towards a decarbonised and decentralised European electricity system, transforming the current market rules supported by higher RES uptake, energy storage, electrification (mainly of transport sector, but also building HVAC) and flexible demand. The focus of this directive is to allow consumers and energy communities to take an active role in electricity markets, adjusting consumption according to price signals and becoming service providers by accessing the markets to trade their demand flexibility and self-generated energy.

The key role of the Directive 2019/944 for Demand Response aggregators

Concerning DR-RISE ambitions, this Directive entitles customers to operate in demand response markets directly or through an aggregator, and actively participate in flexibility schemes and energy efficiency schemes, either directly or through third party energy management companies in charge of the installation, operation and maintenance. Aggregated demand response flexibility should be allowed to participate, together with producers, in all electricity markets, including the wholesale day-ahead market.

Participation in all electricity markets for aggregated Demand Response is naturally essential for aggregators to be sustainable in the long term, and in turn contribute to innovative business models.

This is especially true of the wholesale day-ahead market. Indeed, while balancing and ancillary services are usually the first markets to be open to Demand Response aggregation, they are by nature smaller than the day-ahead market and are not enough to justify significant investment in Demand Response capacities.

Another interesting novelty in this Directive is that all individual consumers and producers, whether individually or by means of energy communities, are made financially responsible for the imbalances they cause in the electricity system. This renders demand flexibility a suitable and cost-effective way to provide local balancing and avoid imbalance position costs. Finally, interoperability of energy services should be ensured to promote retail market competition and avoid excessive data handling costs.

The Electricity Directive should have been transposed at national level legislation before the end of 2020. However, delays were expected in some countries. Results of the Directive implementation are expected to be reviewed in 5 years by the European Parliament and the Council.

2 Energy landscape for Demand Response in Europe and US

2.1 Demand Response overview and positioning in the electricity markets

As being defined in the Electricity Directive [1], Demand Response (DR) can be considered as *“the change of electricity load by final customers from their normal or current consumption patterns in response to market signals, including in response to time-variable electricity prices or incentive payments, or in response to the acceptance of the final customer's bid to sell demand reduction or increase at a price in an organised market, as defined in point (4) of Article 2 of Commission Implementing Regulation (EU) No 1348/2014, whether alone or through aggregation”*. In this sense, DR has great technical and economic potential while promoting the interaction and responsiveness of the customers. Demand Response can be considered as a flexibility service characterised by direction, size, time and location. However, DR is, across the EU, still in the development phase, with different levels of maturity. National regulations framing DR and market opportunities across the Member States significantly differ across the EU.

Currently, the consumers' usage of electricity can be characterised as inelastic in short time frames, since the consumers do not pay for the real price of energy production, because in that case they would choose to change some of their electricity use according to prices following the fluctuations of the real prices.

The relation of price and electricity produced by generation units are dispatched in order, starting first with generators with the lowest marginal cost (lowest variable cost of production) until the instantaneous electricity demand is covered. In most power systems, the wholesale price of electricity represents the marginal cost of the highest cost generator that is injecting energy.

In the following Figure 1, the DR effect on the electricity demand elasticity is depicted in order to highlight the importance it can have in the rationalisation of the electricity price. In this figure, the inelastic demand of electricity is illustrated by the curve D1, while the supply curve S is based on the marginal cost, where the cheaper generations produce first. The price P1 (high) is associated with the inelastic demand D1, and it is extrapolated off the point of intersection of the supply curve S and the demand curve D1. When the DR measures are introduced and adopted by the end consumer, the demand becomes more elastic, represented with the curve D2 in figure 1. The new equilibrium point given by the same supply curve S and the more elastic demand curve D2 gives a much lower price P2, given the slope of the supply curve.

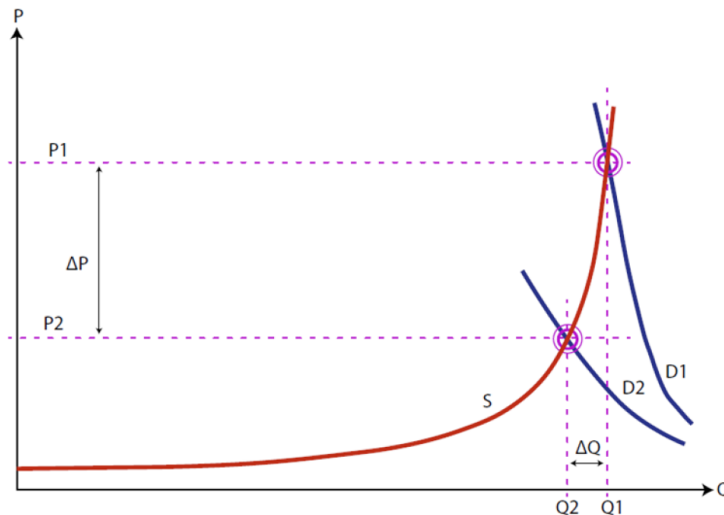


Figure 1: Impact of Demand Response elasticity on the electricity price for the end consumer.²

Thus, based on the rules of the current electricity markets organisation, a reduction in demand during peak hours will result in a big reduction in general cost and, in turn, a reduction in electricity price. The DR can significantly impact the electricity markets: on the one side, economic benefits are triggered for both the grid and the energy consumers DR application has some disadvantages such as the amount of adaptation needed, the coordination of all stakeholders including the establishment of roles. Barriers will be further discussed in detail in this deliverable.

The electricity systems are dynamic and highly complex, especially in the transportation of energy because of rapid and unexpected changes due to transmission and distribution line outages, volatile generation sources (renewables) and sudden load changes. Maintaining a reliable and secure operation is essential, i.e., achieving a perfect balance between supply and demand in real time, ensuring a dynamic equilibrium with the fixed values of frequency, voltage, and currents.

Electric power systems around the world have similar structure and configuration. In most countries, wholesale electricity market design has evolved towards the use of short-term marginal costs as the optimal economic signal for energy trading. In liberalised markets, retailers and producers can also set up bilateral contracts for electricity supply, where only a small part of the electricity demand is traded in real-time. Capacity markets, not used in all electricity markets, are also utilised for long term procurement of electricity provision by all market parties.

Markets for power have been developed over the years due to the liberalisation of power industries. Most of electricity markets are divided into three categories: product market, control reserve exchange and balancing energy [2]. Across Europe, the target model has been adopted including successive electricity markets with different time scales (forward, day-ahead, intraday, and balancing markets) have their own rules for transactions between generation and load parties [3].

The EU has put forward the target model for electricity markets as a basis for the development of a Single Electricity Market across Europe [4]. As part of the EU's third energy package, which aims to resolve structural problems of the internal energy market, the target model is a blueprint for what the electricity market should look like across Europe. The target model is based on two main principles:

- ✓ A “flow-based method” that calculates the capacity of electricity at certain points and allocates the energy as directly as possible to where it's needed. Ideally, all the

electricity markets between member countries are interconnected in one grid allowing for market coupling.

- ✓ Regional wholesale markets are established on a zonal basis that can account for constraints in the system in different places, since the generation and allocation of electricity is not uniform across European member countries. Thus, this occurs in zonal pricing to reflect these differences.

The structure that has been established in most countries includes the following markets.

Forward Market

On the forward and futures market, electricity is traded between four years and one month before delivery. Forward market products are financial products, which are settled against spot market prices of future delivery periods. Forward market is important for many large producers, large consumers, suppliers, Balance Responsible Parties (BRPs) or traders who trade power bilaterally to hedge electricity prices for a certain period. Hedging prices gives these parties financial certainty that they will be able to purchase or sell a certain volume for a pre-agreed price. If two parties want to conclude a deal across borders, they also need to acquire long-term cross-zonal transmission rights that are auctioned on the JAO platform.

Day-Ahead Market

The day-ahead electricity market (DAM) operates a day in advance of the physical delivery of power and comprises the most important in terms of trading volume of energy. In the DAM, the deadline for bids is one day in advance from the delivery of power, which is organised for each hour of the day. After that, a two-sided auction, producing (selling) and consuming (buying) the bids of price and quantity are submitted and accordingly results in the generation decisions for the next day. On the day-ahead market, participants can sell and buy electricity for the 24h of the next day in (hourly) blocks. The day-ahead market is cleared at 12:00 o'clock noon each day of the year. At this time, the intersection of demand and quantity offered determines the electricity price and volume for each hour. This price is then either paid or received by all market participants who were successful in the auction. Because the day-ahead market is organised shortly before delivery and has a single clearing price (per hour), it best reflects the value of electricity during different hours. The clearing price of the day-ahead market is therefore often referred to as “the electricity price”. The price is determined per bidding zone, which in Europe mostly corresponds to the borders of a country.

Intraday market

Following the closure of the day-ahead market, the intraday market opens. Through the intraday market, buyers and sellers can adjust their order volumes in line with better demand or renewable feed-in forecasts or unexpected power plant outages. On the intraday market it is possible to trade power continuously in quarter-hourly, one hour or even longer intervals. As soon as a buy bid matches a sell bid, a trade is concluded. The platform for day-ahead and intraday trade is the spot market. There are multiple different spot exchanges for electricity in Europe, such as EPEX or NordPool.

Balancing market:

After trading in the intraday market closes, the balancing mechanism is in place to ensure that supply equals demand in real-time. Each TSO is responsible for the real-time balance in its control area. To do so, each TSO organises balancing markets where it procures the resources needed to balance the system. Balancing markets consist of balancing capacity markets and balancing energy markets. In balancing capacity markets, contracted Balancing Service Providers (BSPs) are paid an availability payment. Contracting is done one year ahead up to one day ahead of delivery in order to make sure that there will always be enough balancing energy available in real-time. The BSPs contracted in the balancing capacity market

(as well as other BSPs without contracted balancing capacity) then offer their balancing energy in the balancing energy markets. The volume of activated energy depends on real-time imbalances. The balancing market design at the European level is prescribed in the Network Code on Electricity Balancing [5].

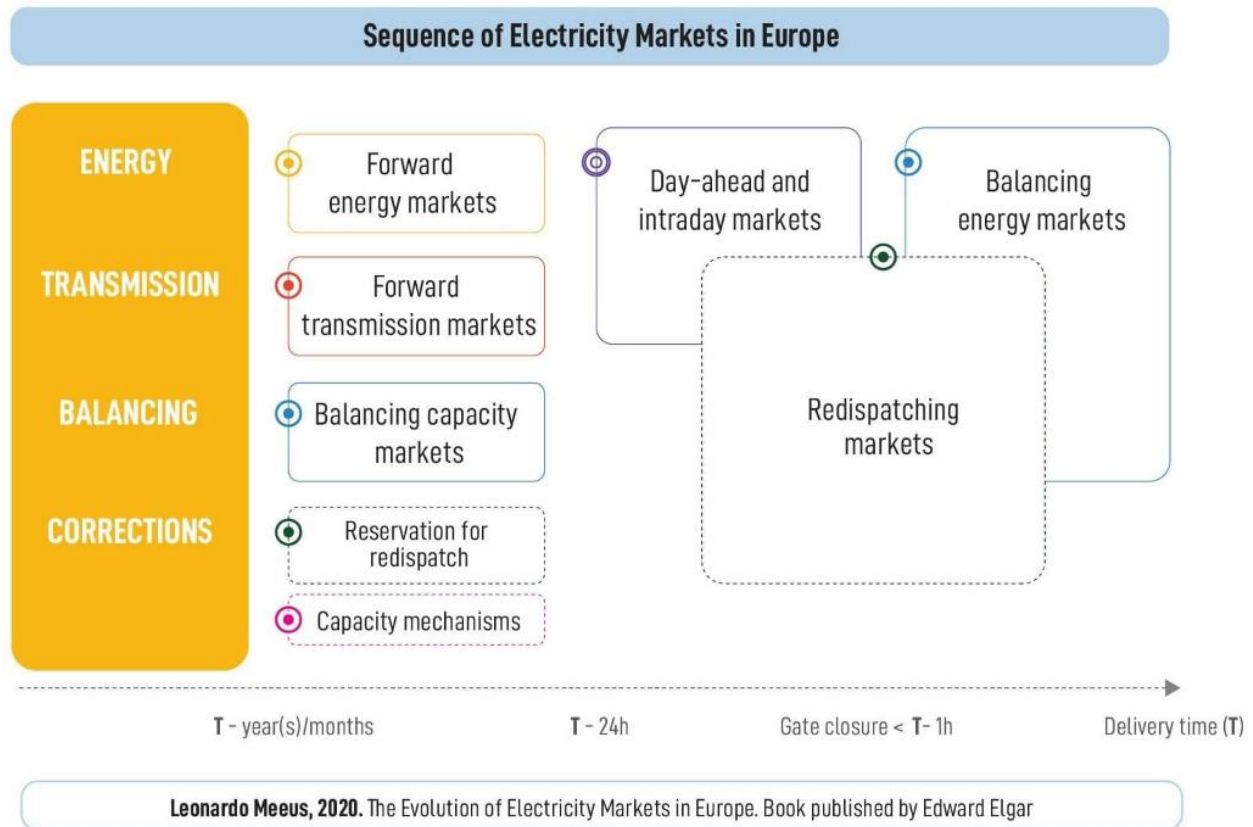


Figure 2. The sequence of Electricity Markets in Europe. [6]

The Transmission System Operator manages network constraints and, following the DAM, it operates the balancing market, announcing the balancing bids to activate at Gate Closure (end of bid submission), solving the imbalances from Gate Closure to Real Time, taking under consideration these balancing bids and other pre-contracted ancillary services (i.e., fast reserves). In electricity markets, the Transmission System Operators (TSO) are the entities responsible of assuring system's security and providing an adequate quality of supply by managing the ancillary services which include active and reactive power reserves for balancing power, frequency and voltage control.

Ancillary Services (AS) are services associated with the production, transmission, and distribution of electric power and are necessary to guarantee the quality, security, and efficiency of supply. They can be categorised as frequency and non-frequency ancillary services, allow system control and dispatch, reactive and voltage support, regulation and frequency response, energy imbalance. The frequency related ancillary services in Europe are being defined and harmonised as follows:

- ✓ Primary reserve (Frequency Containment Reserves, FCR): automatic balance between generation and demand, using rapid response (maximum activation within 30 seconds)
- ✓ Secondary reserve (Automatic frequency restoration reserve, aFRR): centralised and automatic function whose objective is to regulate generation output in a control area, to exchange energy with other control areas at the programmed levels, and return the

frequency to its set value in case of a (major) deviation, thus restoring primary control reserve. Activation time is considered between 30 seconds and 15 minutes.

- ✓ Tertiary reserve (Manually Frequency Restoration Reserve, mFRR): automatic or manual change of the generator operating point (mainly by rescheduling) to restore an adequate level of secondary control reserves. The maximum activation time are 15 minutes.

The frequency ancillary services are implemented during the balancing process, practically the situation in which a TSO acts to ensure that demand is equal to supply, in and near real time. The efficient balancing markets ensure the security of supply at the least cost and can deliver environmental benefits by reducing the need for back-up generation, if it uses the potential of DR.

Balancing service providers (BSPs) can offer balancing services (capacity and/or energy) to the TSOs, who in turn use these services to balance the system. As far as non-frequency ancillary services are considered these are the steady-state voltage control, congestion management, the fast reactive current injections, the inertia for local grid stability, the short-circuit current, the black start capability, and the island operation capability. All these services are currently not delivered through market mechanisms, they are procured through bilateral agreements with system operators or generators. These providers could be generators, demand response aggregators and storage operators. Balance responsible parties (BRPs) shall keep their individual sum of the energy volume physically injected or withdrawn from the system in balance or help the system to be balanced, as they are financially responsible for the imbalances of their portfolios. This could be electricity producers, consumers and retailers.

Electricity markets organisation and operation described above will help to understand what demand response is, how it works, its impacts and some changes needed in electricity markets for its deployment.

Currently in Europe, the majority of balancing markets (procurement, settlement and real-time operation), in relation both with power and reserves, are local in scope and mainly managed independently by each TSO. However, in line with the Guideline on Electricity Balancing (GLEB) regulation, some initiatives are done to balance energy among neighbouring TSOs with a set of harmonisation rules elaborated in network codes [7]. There are certain platforms that have been developed to realise the EBGL:

- i. TERRE, MARI and PICASSO, three platforms on which balancing energy and system services are to be auctioned, cleared, monitored, and remunerated within the Energy Union. PICASSO deals with pan-European trading for aFRR, MARI aims to do the same for mFRR. TERRE is meant to establish a trans-European exchange for Replacement Reserves (RR)
- ii. FCR Cooperation, where 9 TSOs from six European countries including Germany, Belgium, and the Netherlands already procuring FCR power from market participants on a common platform called “Regelleistung”. Primary reserve power from several countries is already auctioned together; the increased competition has led to lower costs for the TSO.

Demand response regulatory aspects for network code development

Recently in Europe, a network code for demand response has been formulated by the European associations of TSOs, ENTSO-E, and DSOs, EU DSO Entity, and set for public consultation [8]. Based on the draft document set for public consultation, this regulation “establishes a network code which lays down the requirements in relation to demand response, including rules on aggregation, energy storage, and demand curtailment rules, to contribute to market integration, non-discrimination, effective competition and the efficient functioning of the market pursuant to Article 59(1) of Regulation (EU) 2019/943”.

In this same new Electricity (Recast) Directive 2019/944 the Article 17 addresses Demand Response through aggregation: “*Member States shall allow and foster participation of **demand response through aggregation**. Member States shall allow final customers, including those offering demand response through aggregation, to participate alongside producers in a non-discriminatory manner in all electricity markets.*”.

Further, the new entity of independent aggregator is recognised: “(a) *Member States shall ensure that their relevant regulatory framework contains the right for each market participant engaged in aggregation, **including independent aggregators**, to enter electricity markets **without the consent of other market participants.***”

Implicit Demand Response is considered when customers react to price signals by shifting their consumption patterns to minimise their bills. Adapting the use of household appliances to day/night tariffs is a popular basic way of participating in implicit DR. Implicit DR can be offered by suppliers but cannot be addressed by aggregators [9].

Engagement of small end-consumers in implicit DR programs can drive (or be driven by) the adoption of smart meters and can enable consumers towards a conscious energy consumption behaviour. Energy consumption consciousness can indirectly enable the adoption of explicit DR. however, this can also have a lock-in effect for customers: as retailers are the only entity that can offer implicit DR, who would not take the further step towards explicit DR.

Explicit demand response is delivered through electricity markets as dispatchable flexibility resource. When enabled to engage in explicit DR, consumers can aggregate their loads, but also generators and storage. Depending on their configuration and on whether they are behind-the-meter, the aggregated assets can result in a variety of entities ranging from aggregated loads alone to VPPs, distributed storage, V2G options, power-to-X. The aggregators of assets can engage in value stacking, wherever this is permitted by the regulation.

These options are evaluated in the demand response network code, which “*lays down the obligations for ensuring that the systems operators have access to energy resources of all the electricity markets in accordance with the principles regarding the operation of electricity markets pursuant to Article 3 of Regulation (EU) 2019/943, and allow the use of energy resources by the systems operators for the operation and planning of the Union electricity network.*”

In D1.3 of DR-RISE, an in-depth presentation of The Network Code for Demand Response will be presented. The network code for demand response provides a very good basis of guidelines to support the developments in DR-RISE and provide significant exploitation pathways for the technologies to be developed.

2.2 Status of demand response in the European countries

This section is mainly focusing on the countries of the consortium and presents a concise overall picture of what is the demand response situation in respect with the national energy system.

2.2.1 Spain

Spain tops the list of countries with high potential in terms of flexibility markets [10]. As a result, demand response strategy is arising as one of the potential solutions to current energy challenges. However, several factors must be considered when implementing this strategy in the country:

- **Market tariffs:** Tariffs should allow end-users to adjust their consumption to the DR incentives. This would economically reward those adopting a DR strategy.
- **Energy grid maturity:** A more advanced energy grid is required, with more sophisticated equipments than currently available. These encompass new consumption smart meters, automation load mechanisms and other equipment destined to implement DR without hindering the end-user's comfort. Although smart meters are available nowadays for all residential citizens (CNMC, 2020) [11], the rest of the equipment above is only present in specific pilot plants in Spain.
- **Data availability:** There is a noticeable lack of public data available from TSO (Red Eléctrica de España, REE) concerning market flexibility. Without up-to-date, reliable information, stakeholders may hesitate to invest in such policies.
- **Regulatory:** A lack of independent aggregator status in the Spanish regulatory framework hamper the development of explicit DR.

Data from 2016 indicates that DR in Spain has potential benefits for both generation and distribution companies, as well as for end-users [12]. This is particularly relevant for price-based DR, considering the existing time-variable prices in Spain. However, another conclusion from the same study stated that the benefits for households might not be sufficiently compensated for the additional equipment costs required for automated compensation.

Regulatory and policy challenges

Although the DR landscape has seen improvements since the year of the aforementioned study (e.g., new dynamic tariffs, higher price of electricity, regulation of self-consumption), significant regulatory barriers remain. As of 2021, existing energy policies and regulations in Spain are not yet fully aligned with integrating DR strategies into the energy market. The regulatory framework needs to be conducive to this transition and address critical areas such

as data privacy, interoperability, and the role of different stakeholders (*Spanish Decarbonised Electricity Tax Proposal Eurelectric Statement, 2021*)[1]

The European Commission (2021) has emphasised that regulatory adjustments should remove barriers to entry for new market players, facilitating DR and encouraging their participation. The greatest barrier for the development of explicit DR is considered to be the lack of independent aggregators status. While independent aggregators are recognised in the primary legislation (Real Decreto Ley 23/2020), a lack of clear regulatory framework in the secondary legislation hampers their development.

Technological infrastructure and tariffs challenges

Spain's technological infrastructure, comprising advanced smart grids and metering systems, can support DR. However, large-scale deployment of equipment allowing automation, as well as fully defined market agent's roles (e.g., aggregators, energy communities, etc.), are essential for harnessing DR's full benefits. Additionally, enhancing consumer awareness and participation is essential for successfully implementing DR strategies. According to data from 2021, Spain plans to install 60 GW of renewable capacity from 2021 to 2030, increase storage capacity by 6 GW, and promote DR through demand aggregators. (Energy Policy Review Spain 2021, IE [13]).

An analysis of the market tariffs concerning the implementation of DR reveals certain challenges. High network tariffs, especially for consumers in the residential sector, limit the financial incentive for participating in DR programs. Reducing the fixed costs of these tariffs, in addition to the already introduced dynamic pricing, could help enhance consumer participation and enable the market to respond more efficiently to price signals (ACER/CEER, 2021) [14].

Nevertheless, in recent years, Spain has witnessed a notable shift in its electricity tariff structure, evolving to the 2.0TD tariff, whose structure has significant implications for the evolving landscape of DR in the country. The 2.0TD tariff, characterised by its time-differentiated pricing, has introduced a more dynamic and responsive approach to electricity pricing. Under this new framework, consumers are exposed to varying rates depending on the time of day and market conditions. Such a shift encourages end-consumers to adopt a more conscious and flexible approach to their energy usage.

According to a study carried out by the KEI (Knowledge Engineering Institute) comparing demand from 2018-2019 with 2021-2022 in Spain, the national demand curve has flattened up to 10% thanks to the inclusion of this new tariff.

The load shifting due to the dynamic pricing of this specific tariff can be considered a form of implicit DR for all intents and purposes. Despite the potential of this tariff, some challenges are still unsolved to achieve the full potential of this strategy. For instance, the high fixed costs associated with the 2.0 tariff can adversely impact the economically favourable outlook for end-users. While this tariff introduces price flexibility and potential savings during low-demand periods, the fixed costs represent a significant portion of consumers' bills regardless of their actual consumption.

Moreover, capacity remuneration mechanisms to incentivise power plants for their available capacity rather than actual energy generated could also stimulate DR. However, the development of a CRM is still under negotiation in Spain. Such policy measures could help manage peak demand and ensure grid reliability. Regarding the current states of the balancing market in Spain:

- FCR is a mandatory service for power plant (and not remunerated);¹
- aFRR is open only to BSP with a minimum portfolio of 200 MW;
- There is no availability payment for mFRR which limits DR business case .

These BSP are defined as “zonas de regulación”, composed of as many Programming Units (“Unidades de Programación” or “UP” in Spain) as needed. These UPs need a minimum of 1 MW to be part of a “zona de regulación”, which might be an open door for an aggregator to be part of this market. However, it is still not defined whether an aggregator can be defined as a UP or not [15].

In conclusion, while Spain has shown progress in the adoption of DR, there are several areas which require attention: policy and regulatory adjustments, technological integration, and tariff reforms. However, given Spain's commitment to renewable energy and carbon reduction targets. DR could have promising future in the country's energy market if these issues are addressed.

2.2.2 France

Wholesale and domestic Retail electricity markets

The French wholesale market is divided between the future energy markets and the spot markets. The future market lets market players negotiate electricity contracts bilaterally for delivery in the future: weeks, months, quarters and even years. Those future products are standardised to facilitate their exchange on the market. The prices allow market players to hedge in advance the revenue from their power production or the cost from their power consumption.

The spot market encompasses the day-ahead and the intraday markets and are managed by the company Epex Spot. Nordpool is also present for the IntraDay. The Day-ahead market prices, which are the reference price for the electricity market, result from a matching of selling bids and purchasing orders for the next day and is done every day. The Intraday market on the other side is a continuous market where orders are traded until 5 minutes before the delivery period. On the intraday market, a trade is executed as soon as a sales order matches a purchase order.

The below Figure 3 shows how the global demand response is handled in France and why different markets are integrated in this global balancing.

¹ P.O. 7.1 Servicio complementario de regulación primaria, REE.

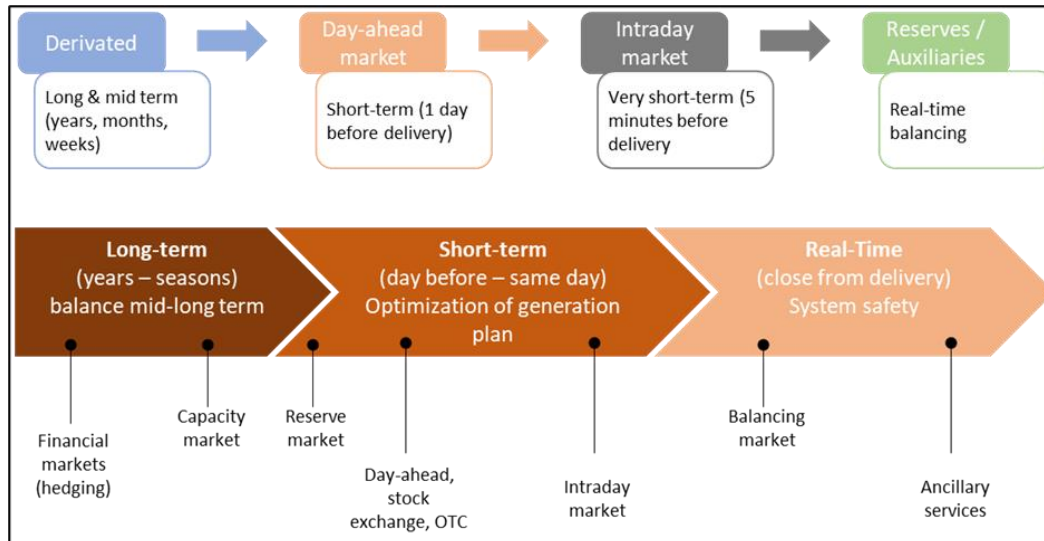


Figure 3. Global demand response mechanisms in France's electricity market.

Capacity Market

This market exists since 2016 in order to allow the different players to valorise their different power capacities towards electricity providers that are obliged to be balanced. These players obliged to be balanced are called “Acteurs Obligés”. They therefore need to buy Capacity Guarantee (GC) equivalent to the level of consumption of their customers during national peak demands. The GCs can then be exchanged through regular bids or directly Over-the-Counter between players. This mechanism has replaced public tenders in place before that to nationally push for more capacities to support the Grid during the peak hours.

Due notably to the high penetration of electric heating, the French market accounts for half of the thermosensitive in Europe: if the temperature is colder by 1°C, it is estimated that the peak consumption will be increased by 2.4 GW nation-wide. The demand peaks are defined by signals called PP1 and PP2 defining Grid stress times that may occur from 10 to 25 days per year.

This mechanism is only operating during the Winter period, from October 1st to March 31st, from 7:00 to 15:00 and from 18:00 to 20:00 (10 hours per day).

Retail markets for residential customers

The French Energy Regulatory Commission (CRE, Commission de Régulation de l'Énergie) defines residential power consumers as consumers whose yearly consumption is below 10 MWh and whose subscribed power is less than 36 kVA, they account for 86,7% of the consumers and 36% of the total consumption.

The market is fully contestable, and consumers have access to regulated tariffs (tarifs réglementés de vente, TRV) offered by classic retailers only and market offers that can be offered by classic and new retailers. Even though up to 29 retailers are active in the residential segment, 73% of consumers are still supplied by classic retailers.

Demand response Market

As of today, French market is one of the most-advanced market in Europe in terms of Demand-Response. Demand-Response Aggregators (OE for Opérateurs d’Effacement) are allowed to participate both in Energy and in Capacity markets, here are the ones fully opened (Figure 4):

DIFFERENT DEMAND RESPONSE MARETS			
ENERGY	ENERGY	CAPACITY	CAPACITY
Balancing market (MA)	Wholesale market (NEBEF)	Capacity mechanism (MECAPA)	Service Systems (SSy)
Participation through bids on day-ahead. Paid as bid system	Only for Demand-Response operators. Possibility to access the wholesale market for any activation of demand-response	Since 2016. Allow to valorize the capacities to suppliers that need to balance themselves. Take over former public tenders	Through contractualisation of capacities – needs to be very flexible and reactive as activation is done on a very fast basis (seconds)

Figure 4. Different demand response markets available in France.

All in all, demand response (and demand response operators) can access most electricity markets in France: balancing and ancillary services (primary and tertiary reserves), the capacity markets and most notably the wholesale day-ahead market where aggregators can offer their flexible capacities that compete with power production units.

The ability to sell demand response volumes on the wholesale day-ahead market is essential as the balancing market is by nature smaller and very competitive as new technologies such as EVs and storage are allowed to participate.

However, even though demand response can participate in the wholesale day-ahead market, it is not on an equal footing with power production and faces significant entry barriers. Such barriers for participation would have the long-term consequence of preventing aggregators to build profitable business models and, therefore, preventing any flexible capacity to be offered to the power system. It is also important to note that such participation will be removed with the implementation of the European Directive 2019/944 [1]. Indeed, according to the article 17, paragraph 4 of this directive, such financial participation can’t prevent from entering the market for aggregators and develop themselves.

Zoom on the participation in the wholesale market

A series of rules published by the French TSO (NEBEF rules) detail the participation of Demand response aggregation in the spot day-ahead market. The rules specify a number of key points for the participation of demand response to the wholesale market:

- The possibility for demand response and demand response aggregation to bid on the market alongside power producers.
- The ability for aggregators to use the data that they gather through their own metering devices for settlement purposes, such data can be audited by the TSO afterward.
- Rules to establish a consumption baseline, actual consumption is compared against the baseline to establish the actual amount of curtailed power.

However, demand response aggregators also have to compensate retailers for the curtailed power. Because of this, demand response cannot compete economically with production and this barrier to entry could in effect prevent DR to participate in the market and provide its

flexibility to the power system. Directive 2019/944 [1] guarantees that such barrier to entry should be removed, if it is implemented correctly by the Member States.

2.2.3 Germany

The establishment of a demand response system in Germany depends on different factors. In particular, the current system in Germany must be made more flexible. Based on data from 2022 (Murley/Mazzaferro 2023) [10], the following statements can be made regarding the flexibilisation of the German system.

- In terms of progress in regulating flexibility on the demand side, Germany can be seen as an emerging market. The development towards more flexibility has already been initiated and will be fully pursued in the future.
- In terms of the potential size of the flexibility market, Germany can be described as a maturing market. Nevertheless, barriers still exist.
- When it comes to the flexibility of the distribution system, Germany can at best be seen as an early market. Further measures are necessary here. The same applies to the development of local energy systems.
- Flexibilisation will be further promoted in the future. Germany can already be seen as an emerging market here. The need for further flexibilisation is a major topic in the discussion on flexibilisation, especially due to increasing shortages of fossil energy sources.

Data from 2015 also shows, that “a significant portion of demand-side flexibility in Germany remains untapped” (SEDC 2015, p. 77). There are a whole series of barriers in the German energy system (ibid.). Particularly noteworthy are network charges and certain metering requirements.

The discussion about Demand Response (resp. Demand Side Management) in Germany is mainly focused on companies (industry, tertiary sector, cross-cutting technologies). Despite promising prospects, Demand Side Management is still unknown in large parts of the target groups. dena (German Energy Agency) wants to change this by supporting interested parties and users with expertise.

Compared with knowledge on Energy Efficiency (EE), DR is much less known or common and the share of companies familiar with DR is low (4% of the companies have conducted DR compared to 48% in case of EE; Wohlfarth et al. 2020). For DR, more persuasion is needed, as DR is not yet as well established as EE and the gains for the energy system are rated lower by the companies than gains from EE (ibid).

Current research on dissemination of DR in Germany, enlightens the role of aggregators as service provider between energy supplier and energy consumers. The central role of the aggregators is to first raise awareness in the industrial companies for the potentials of load flexibilisation and to support the key players in the companies with the implementation (Stede et al., 2020).

However, dena recognises demand response potential not only for companies but also for residential households. The current situation in Germany is that Distribution System Operators

(DSOs) offer a so-called “Peak-Tariff (PT)” (Hochtarif, HT) which is used during the day and a so-called “Off-Peak Tariff (OPT)” (Niedertarif, NT) which is used during the night hours. With increasing shares of renewable energy and distributed generation on the system, this simple distinction between day and night is out-dated and no longer covers on - and off-peak times (Bertoldi, et al., 2016).

Demand response is understood as a short-term, deliberate change in consumer load in response to price signals in the market, dynamic electricity tariffs of DSOs are needed to provide these price signals, or the creation of local flexibility markets for congestion management that Germany stopped due to their concern of gaming. However, such dynamic tariffs were not very widespread in Germany, so the legislator obliged the DSOs to offer them. The largest DSOs had to introduce dynamic tariffs as early as 2021, the smaller ones by 2026 at the latest. For a dynamic tariff, a definition according to § 3 EnWG (law on electricity and gas supply) is to be applied here, according to which a dynamic tariff must reflect price fluctuations on the exchange.

The reason for the low penetration of these tariffs is that they require the installation of smart metering systems. As by now, meter operator are only obliged to install smart meters if households consume more than 6.000 kwh per annum. All other consumers are to be equipped with smart meters by 2032. Consequently, the roll-out of smart meters is at between 2% and 15% [16] in German household, so that they cannot react on price signals and cannot participate in implicit Demand Response.

Due to the long delays and the multi-year wait for approved, certified smart meters, the topic of dynamic tariffs has never experienced a development push, and this despite the fact that the topic has already been legally legitimised since 2016 with the resolution of the Metering Point Operation Act (MsbG). As a consequence, more and more DSOs offer dynamic tariffs, but only for those end-consumers who are already equipped with smart meters.

However, even if Demand Response is applicable in households, it is usually not economically attractive to get engaged in DR. The DSOs in Germany agree that the demand for dynamic tariffs is very low, especially with the current price development of electricity (risk of high prices at the stock exchange compared with lower prices of flat rates for electricity).

Due to the numerous barriers and the data available so far, the market for demand response in Germany is still very small. Above all, market regulation (SEDC 2015) has so far prevented further dissemination. Other elements are hampering the development of DR. Contrary to European law, an end-consumer still needs the approval of its electricity supplier before being able to engage in DR schemes.

2.2.4 Italy

Italy has been working on demand response programs for some time and has a national plan to achieve a target of 55% of electricity consumption by using renewable resources by 2030. This has implemented demand response management programs in various mechanisms to actively enhance the efficiency and security of supply. In Europe, Italy has implemented the highest number of smart meter installation programs, equipping 98% of consumers with smart

meters that read energy consumption data every hour. This enables a better understanding of energy consumption patterns.

Terna developed a pilot project for testing the possibility of demand response: the UVAM (Mixed Enabled Virtual Units) project which, since November 2018, has enabled consumption units (tertiary and domestic sectors), production units and storage systems in the same aggregations for the services market. Virtually Aggregated Mixed Units (UVAMs) are now enabled to provide services such as congestion resolution, balancing and secondary and tertiary reserves.

The economic regulation of UVAMs differs from large plants because it involves not only ordinary remuneration linked to energy activated (€/MWh), but also remuneration for resource availability (fixed fee, €/MW). The decision to adopt availability remuneration is motivated by the fact that the participating resources on the consumer side for demand response are mainly represented by industrial production plants, which are prepared to reduce their own energy withdrawals. The provision of flexibility by these parties must bear fixed investment costs for the installation and calibration of the equipment required to develop the service, as well as annual operational management costs (e.g., establishment of energy management rooms).

2.2.5 Greece

The ongoing process of decarbonizing Greece's energy system is progressing, with the revised National Energy Climate Plan targeting at further enhancement.

The final energy consumption stands at 15.65 ktoe, with expectations to reduce to 15.4 ktoe by 2030 and 11.5 ktoe by 2050. Renewable energy sources (RES) share in gross final energy consumption is 22%, with a target of reaching 44% by 2030. When focusing on final electricity consumption, RES presently make up 36%, and projections suggest an increase to 79% by 2030. In terms of greenhouse gas (GHG) emissions, the current level is 71.3 tCO_{2eq}, a notable improvement from the 115 tCO_{2eq} recorded in 1990. The target for 2030 is to further reduce emissions to 49.5 tCO_{2eq}, and to achieve a significant reduction to 8.5 tCO_{2eq} by 2050.

Final energy consumption by fuel, ktoe

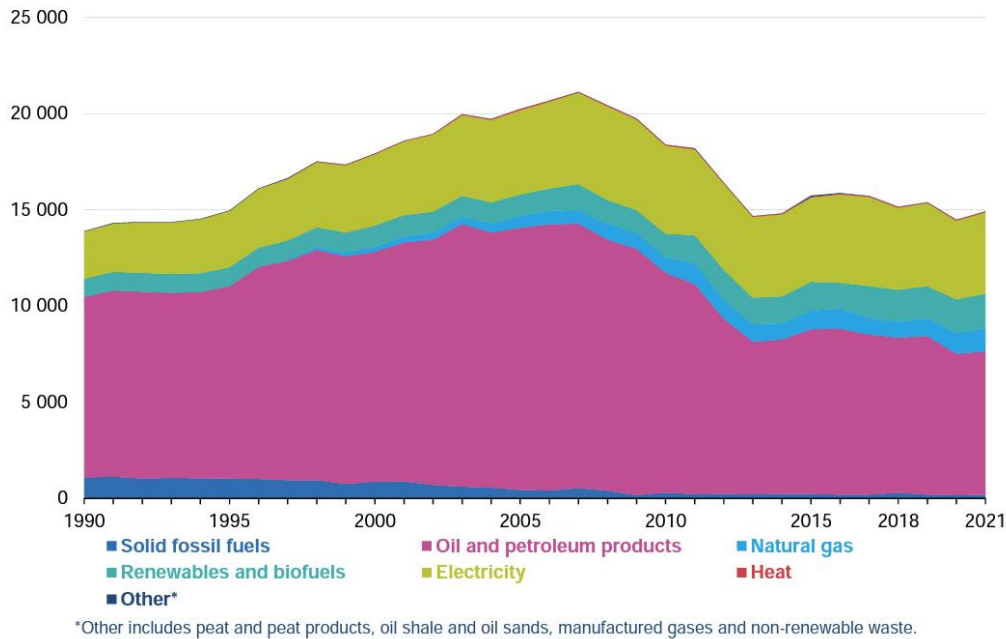


Figure 5. Energy consumption profile in Greece [Source: Ministry of energy and environment, 2022]

Gross electricity production by fuel, GWh

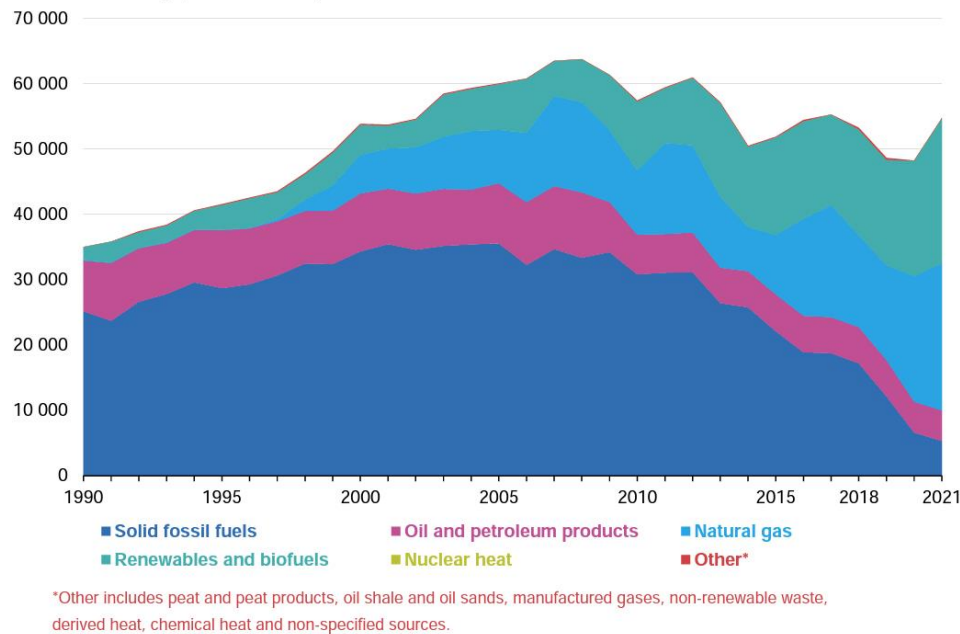


Figure 6. Electricity production in Greece [Source: Ministry of energy and environment, 2022]

The national Demand-response and demand-side flexibility context

While the liberalisation of the Greek electricity market commenced nearly simultaneously with that of numerous other EU member states, the harmonisation of the Greek legal framework was slow, consequently impacting the deployment of demand response.

In 2011, Law 4001 incorporated the Third Energy Package into the Greek legal framework, allowing for access to both demand response and storage within the capacity mechanism of

the Greek Electricity Market, referred to as the Transitional Flexibility Remuneration Mechanism.

In 2015, Law 4343 transposed the Energy Efficiency Directive 2012/27/EU, encompassing all relevant provisions concerning demand response and aggregation.

In 2016, Law 4425 specified the reform measures within the Greek electricity market, aligning with the requirements of legislation aimed at establishing the single European electricity market. It specifically addressed provisions outlined in several EC Regulations related to network access for cross-border trading, forward capacity allocation, capacity allocation and congestion management, as well as the establishment of forward, day-ahead, intra-day, and balancing markets. It also introduced the concept of an aggregator.

In 2018, guidelines published by the Regulatory Authority clarified specific market design choices. These included aspects such as the central dispatch method, unit-based generation bidding, portfolio bidding by aggregators, the requirement for aggregators to submit separate injection and offtake orders, and the designation of a 1-hour Imbalance Settlement Period.

In 2022, Law 4986 was introduced, establishing the regulatory framework for the participation of Demand Response in the Balancing Market. This framework leverages automation and dynamic adjustment of electricity demand. Key provisions within the law include Article 48B, which introduces '*demand-response service contracts*', Article 48D concerning demand response aggregators, and Article 59A, which addresses smart metering, data security, consumer protection, and transparency issues. Up to now, demand-response was procured as capacity by the Greek Transmission System Operator (TSO) through interruptible load contracts. The new law envisions increased activations and shorter planning times, particularly in the Intraday and Balancing Markets.

Demand-side flexibility assets and enabling systems

By now, Demand Response applications primarily concentrate on the energy-intensive industrial sector. Nevertheless, it is anticipated that new opportunities, novel business cases, and increased involvement of a broader spectrum of consumers and market participants will emerge.

The residential sector is expected to see gradual penetration, particularly as grid digitalisation and electrification continue. The proliferation of electric vehicles and the electrification of home heating and cooling will further increase the potential of demand flexibility, while building insulation will enhance this flexibility by enabling the shifting of heating loads. Moreover, the flexibility of residential consumption will be enhanced by the ongoing rollout of rooftop solar panels and collective self-consumption schemes through energy communities, as well as behind-the-meter batteries. The widespread adoption of smart meters is a crucial condition for the swift and successful deployment of demand response, as it will facilitate communication between consumers and the energy market.

Demand response is expected to create new business cases for demand-response aggregators, energy providers, and energy communities, fostering synergies among these stakeholders.

Smart meters

Due to legal complaint for the tendering process, there has been over 10 year delay in the installation of smart meters. As per DSO's plan the installation of 7.3 million smart meters is expected to be completed by 2030 as follows: 1.6 million by the end of 2024; 2 million by 2026; 1.8 million by 2028; and 1.9 million by 2030.

Self-consumption and collective self-consumption

Despite limited grid access and challenging permitting procedures, self-consumption and collective self-consumption in Greece are making steady progress. Self-consumption is primarily facilitated through net-metering schemes. According to the latest data from the DSO, as of August 2023, the total licensed and installed capacity has reached 604 MW. Net-metering serves as a promising case of demand-side flexibility as the optimisation of self-consumption enhances the economic benefits.

Collective self-consumption is primarily implemented through the virtual net-metering model, available to energy communities. The total licensed and installed capacity across 98 projects is 44 MW (August 2023). Currently, the use of virtual net-metering does not offer incentives for flexible demand management. However, in 2023, the net-billing model was introduced with the aim of gradually replacing virtual net-metering. Net-billing design incentivises consumers to enhance their economic benefits by optimizing self-consumption.

Storage

The current storage capacity is approximately 0.7 GW, and is projected to reach 5.3 GW by 2030, with a primary reliance on pumped hydro storage and battery systems

Table 1. Total and battery storage overview in short and long-term plans in Greece.

	2021	2025	2030	2040	2050
Total storage capacity (GW)	0,7	3,3	5,3	11	24,8
Battery systems (GW)	0	1,4	3,1	8,8	22,6

Source: Ministry of Energy and Environment. Draft revised National Energy and Climate Plan, 2023

Housing energy upgrades, renovation and retrofitting

Energy upgrading of buildings is of paramount importance and will continue to be supported through dedicated financing programs. Furthermore, targeted programs for the adoption of heat pumps, appliance replacements, smart energy management systems and improved lighting efficiency will continue in the coming years. Focusing on heat pumps, currently, 8% of residential buildings are equipped with them, with the goal of increasing this to 19% by 2030. The following Table 2 offers an overview of the current status and the short- and long-term plans for housing upgrades and heat pump adoption.

Table 2. Housing energy upgrades and heat pump adoption short and long-term plans in Grece.

	2021	2025	2030	2040	2050
Average annual rate of housing energy upgrades	0,8%	1%	1,4%	1,5%	1,7%
Energy savings due to energy upgrades	34%	49%	76%	61%	37%

Energy upgraded building stock	7%	12%	19%	31%	43%
Households equipped with heat pumps	8%	12%	17%	53%	91%
Average energy consumption (kWh/m ²)	135	128	112	98	90
% of electricity in the energy consumption	36%	38%	47%	56%	61%
<i>Source: Ministry of Energy and Environment. Draft revised National Energy and Climate Plan, 2023</i>					

Electromobility

According to the Association of Motor Vehicle Importers Representatives (AMVIR) electric and hybrid vehicles reached 7,9% of the total sales in 2022, compared to 6,9% in 2021, 2,6% in 2020 and 0,5% to 2019. Pivotal to that was a dedicated financing programme. The advancement of electric mobility is expected to continue its growth, hand in hand with the development of the charging infrastructure, which has experienced substantial expansion - the number of charging points increased sixfold to 1,344 in 2021.

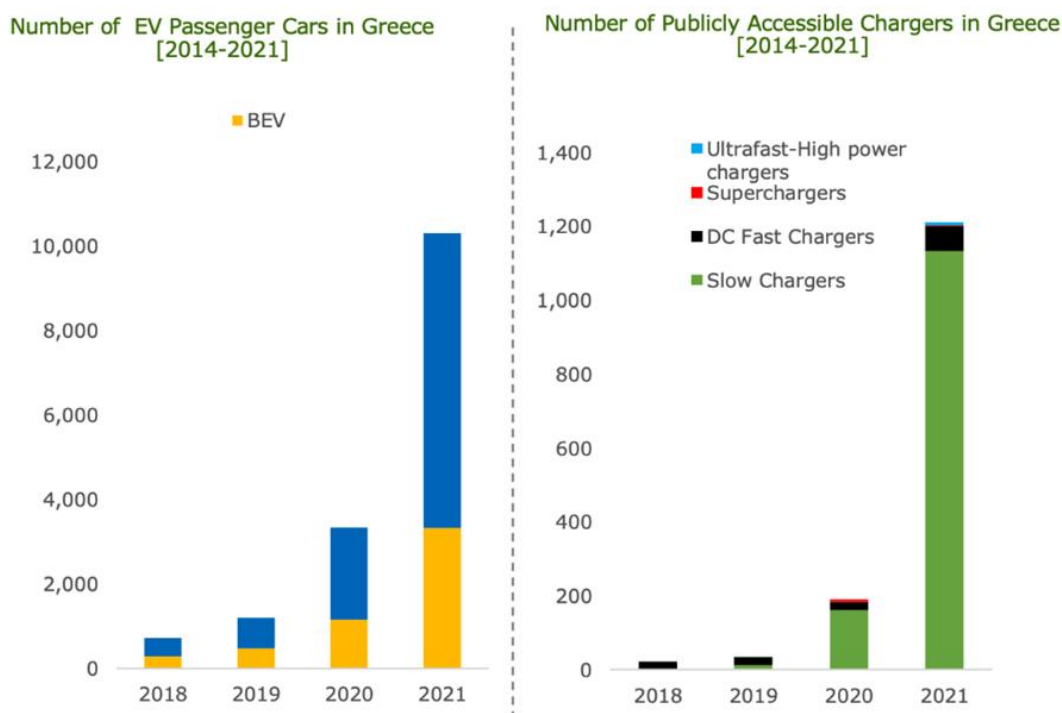


Figure 7. EV cars and chargers in Greece [Source: HAEE]

Barriers and next steps

While Greece currently lags behind other EU member states in the deployment of demand-response, the recent reforms represent a promising step toward unlocking its potential. Nevertheless, several barriers must be addressed, and further interventions will be required. Focusing on the residential sector, the most significant barrier is the absence of smart-metering infrastructure.

Other issues that may hinder the widespread adoption of demand response in the residential sector include split incentives for deploying energy management systems, heat pumps, EV chargers, as well as PV and solar thermal systems. There is also lack of a wider range of demand-response and flexibility services, such as explicit demand-response services provided by energy communities, flexibility services procured by the DSO, and widespread

solutions aiming at the optimisation of self-consumption and collective self-consumption. The introduction of a diverse set of services would facilitate engagement from a broader spectrum of consumer groups and catalyze the emergence of demand-side flexibility as a dominant trend.

Furthermore, suitable business models for effective collaboration between energy communities, demand-response aggregators, and energy providers are yet to be explored – ensuring no contradictory roles and incentives, as in other business cases. Issues of interoperability of equipment and DSM systems will need to be addressed, and a significant amount of work is needed to showcase good practices and run dedicated capacity-building and awareness-raising actions.

2.2.6 Bulgaria

Looking at the Bulgarian energy system in 2022, the coal energy was the main source of electricity production in Bulgaria in 2022. That year, this energy source accounted for over 42 percent of total electricity generation. Nuclear ranked second, making up 32.5 percent of total production.

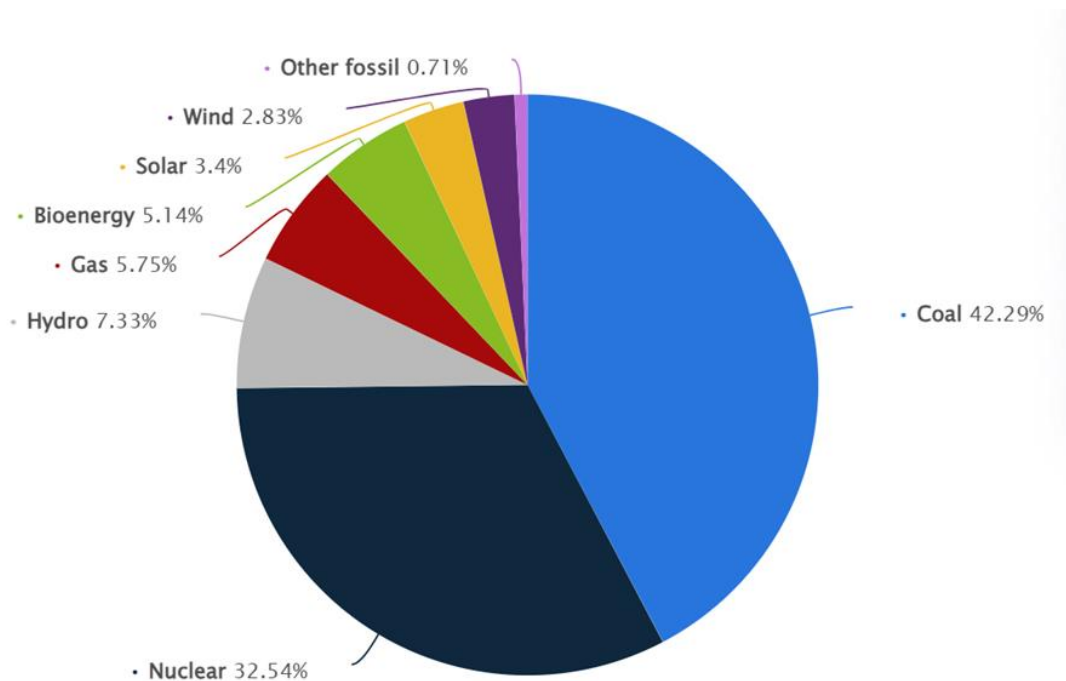


Figure 8. The electricity production in Bulgaria during 2022.

Regarding the EV charging infrastructure, currently there are over 1400 AC and DC chargers across the country. The Bulgaria's grid operator, Electricity System Operator (ESO), is planning to install 10,000 charging points for electric vehicles (EVs) over the next five years. There will be both slow and fast EV charging points, which would serve electric cars as well as electric buses and other heavy-duty vehicles. The number of electric cars is expected to reach 200,000 by the end of the decade. It means 600 GWh of electricity per year would be required for the fleet, which is seen growing to 3.5 million by 2050. The electric vehicle fleet in Bulgaria is expected to grow to 3.5 million by 2050. ESO forecasts that annual energy

consumption of all road vehicles in Bulgaria, currently at 45 TWh, would become three times lower by mid-century due to massive deployment of electric models. The new EV charging installations will exchange information on the state of the infrastructure, need for locations and capacity, decision by national and municipal authorities and the financial estimates.

The Bulgarian Ministry of Energy has announced a big rebate scheme (BGN 240 million, i.e., \$134 million) for applications from residential buildings for the installation of solar water heating systems and rooftop PV arrays, ideally coupled with battery storage systems. The residential users can apply for financing of solar water heating systems, as well as rooftop PV systems of up to 10 kWp, which by the coordination with batteries to provide demand response services. The PV systems no larger than 10 kWp will be financed up to 70% with the maximum sum of BGN 15,000. The criteria for funding will be that the installations will take place at the applicant's permanent residence, which currently uses an inefficient heating source, such as wood or coal-burning stoves, boilers, or a fireplaces. In this way, the residential flexible and energy efficient technologies will benefit and increase the flexible resources at the edge of the grid that will be capable to provide flexibility resources.

Regarding demand response, in Bulgaria all types of demand-side response are eligible to participate in the wholesale electricity markets (including day-ahead and intraday), as individual players or via aggregators. Any demand side response provider who can provide at least 5 MW of demand response is eligible to participate in providing certain balancing services (replacement reserves) and can participate in Frequency Containment Reserves (FCR) and Frequency Restoration Reserves (FRR) services as introduced from December 2020. Some large industrial consumers do currently participate in providing Replacement Reserves (RR). However, there are currently no demand side response aggregators active in Bulgaria, and neither is there a licensing regime for such players.

In Bulgaria, the 100% of industrial users, the 53% of business customers in the free market and almost 0% of customers in the regulated market are provided with smart meters. Smart meters are capable of metering and transmitting at least hourly metering values and data management systems enable suppliers to settle customers based on at least hourly metering values. In order to fill this gap, in the installation of smart meters, Bulgaria has recently approved amendments to the national regulation (Bulgarian Energy Act), which now requires electricity distribution companies to install smart meters for clients if requested.

In order to increase the competition, Bulgaria is advised by the Commission [17] to develop and/or review as appropriate legal, regulatory and technical market rules to enable participation of aggregators (of demand side response and of smaller generation) in the wholesale market and in the balancing market tenders for reserve services. In the same opinion document, the minimum bid size of 5MW is too high to allow smaller installations' participation in providing replacement reserve services. And it is recommended to decrease such minimum size to 1MW as applied in many other Member States (e.g. France, Germany for FRR, Italy, Greece, Spain, Slovenia) or even 500 kW. This will facilitate greatly the greater participation of end users in demand response.

2.2.7 Belgium

Belgium has committed to reach a 32% share of renewable energy of the total energy by 2030, as part of the European Clean Energy Package. In 2018, the share of renewables of the total consumption was merely 9% [18]. This ambitious target is set out to be accomplished mostly by using solar and wind generation. As this will increase the need for flexibility of the grid, demand response will play an important role.

Demand response has been established by TSO Elia in 2013 [19][20] and has been progressively embraced as a source of flexibility in its primary and tertiary reserves portfolio. Thus, the DR resources can participate in the Primary (FCR) and Tertiary Reserves (mFRR), as well as in the Interruptible Contracts program, classified under the Tertiary Reserve. The Secondary Reserve (aFRR) is also open to Demand Response, and payment is based both on availability and energy. The reserves that are currently open for demand response services have strict requirements that need to be met by organisations placing bids. Elia allows two reserved ancillary services: FCR and mFRR.

For FCR there is an automatic, continuous and decentralised response to frequency deviations. The volume must be deployed in full within 30 seconds with a minimum contracted capacity of 1MW. The TSO offers different types of FCR products that can be bid on: symmetrical or asymmetrical (Both increase or decrease of load) with DR resources to adjust their consumption for deviations above 100 MHz (or 200 MHz), which has reduced impact on the industrial processes [21].

The mFRR is manually activated product, energised at Elia's request, whose volume must be deployed in full within 15 minutes, i.e. the target capacity must be reached within 15 minutes. Participants in mFRR services can be consumers and holders of decentralised generation capacity connected to the transmission system, the distribution system or any aggregators who can react within 15 minutes and for a period of 2 or 8 hours, depending on the product chosen, and that have a minimum of 1MW of DR resources. This 1MW can be aggregated across multiple sites. During the time of the contract, availability must be guaranteed.

The Belgian electricity market has different types of tariff structures, ie. flat rate, dual rate and night rate only. The dual rate splits the day into blocks of peak and off-peak periods [22]. The night rate is only accessible for heating systems, Various other DR mechanisms, such as real time pricing, local energy trading between buildings or between households in the same building are not allowed in Belgium while some derogations as living labs have been given for innovative projects, e.g., Energyville.

2.2.8 Ireland

Demand response (DR) regulations in Ireland have undergone significant developments in recent years, aligning with the European Union's energy and climate goals. In Ireland, demand response is a crucial element of the country's commitment to enhancing energy efficiency and integrating renewable energy sources into its grid. Currently, Ireland allows the partial participation of consumers (principally large industrial and commercial) in balancing the market and limited wholesale [23][24].

Electricity consumers in Ireland and Northern Ireland currently have the opportunity to engage in Demand Side Management (DSM) through tariff-based programs, encouraging them to shift their electricity usage to more affordable off-peak hours. Examples of such programs include "Economy 7" in Northern Ireland and "NightSaver" in Ireland. Additionally, EirGrid, the system operator in Ireland, administers two DSM schemes, namely "Short Term Active Response (STAR)" and "Powersave," primarily designed for large electricity consumers.

Moreover, medium to large electricity consumers have the option to participate in a "Demand Side Unit (DSU)" or an "Aggregated Generating Unit (AGU)." A DSU comprises one or more demand sites capable of reducing their electricity consumption as per EirGrid or SONI's instructions. These reductions must be sustained for at least two hours, with a one-hour window for implementing the reduction.

A DSU, which stands for Demand Side Unit, refers to a single demand site or a group of demand sites capable of decreasing their electricity consumption when directed by the National Control Centre (NCC). DSUs allow parties to bid their demand reductions into the all-island wholesale Single Electricity Market (SEM), much like a generator bidding to supply electricity. DSUs offer flexibility as the system operator can instantly see their availability and request the units to provide the previously bid demand reductions.

DSUs have been part of the SEM since 2007, but their adoption was limited until the summer of 2012. Regulators in both Ireland and Northern Ireland recognised the potential of demand side management to deliver economic and environmental benefits, as outlined in the "Demand Side Vision for 2020" published in May 2011. DSUs are seen as a crucial element in implementing a market-based approach to demand side management. Currently, there are two operational DSUs in Ireland, providing up to 70 MW of demand reduction, with four more in various stages of the application process. These DSUs are aggregated by third-party companies specializing in demand side participation.

In contrast to DSUs, there was a demand side scheme called the Winter Peak Demand Reduction Scheme (WPDRS) in operation in Ireland for over a decade. This scheme rewarded demand sites for reducing their electricity consumption during winter weekday evenings between 17:00 and 19:00. The main advantage of DSUs over WPDRS is their flexibility in aiding power system operation in a dynamic supply and demand landscape. DSUs can be called upon when needed, based on real-time demand reduction availability. WPDRS, in contrast, only determined the reduction after the fact during settlement.

The "Short Term Active Response (STAR)" scheme involves electricity consumers being contracted to make their load available for short-term interruptions, providing reserves to the system in the event of a large generating unit loss. This scheme has been in operation for over 20 years, with interruptions lasting around 5 minutes each. There is no prior notice given for interruptions, and participating customers cover the cost of installing metering, communications, and control equipment. In return, they receive payments based on the energy made available for interruption. Customers participating in STAR can also engage in Powersave or be part of a DSU but not both.

The objective of the "Powersave" scheme is to encourage large and medium-sized customers to reduce their electricity demand on days when total system demand is close to available

supply. Participating customers are compensated based on the reductions in kWh achieved during a Powersave Event, which can be called on any business day at any time. Participants are notified via email and text messages about Powersave Events. Customers involved in Powersave can also participate in STAR but cannot be part of a DSU.

2.2.9 Other countries

United Kingdom

The Electricity Transmission network in UK which spans across Great Britain comprises a mixture of overhead cables, underground cabling and subsea cables – the size of these assets varies from of 400kV, 275kV and 132kV assets. These are all linked together via substations across the country that then connect separately owned generator, interconnectors, large demands, and distribution systems. During last September 2023, according to National Grid ESO, the electricity produced originated from gas by 33%, wind by 24,9%, Nuclear by 17,4 %, Biomass by 4,3%, Coal by 1,4%, Solar by 5,8%,Hydro by 1.5%, Storage by 1.1% and imports by 10.6%. that is to say 49% of the electricity came from zero carbon sources [25].

Demand Side Response simply involves businesses increasing, decreasing, or shifting their electricity use – in response to a signal – to help balance Britain’s electricity system. In return they receive sufficient financial incentives, lower their bills, reduce their carbon footprint and play an important role in the transition to a low carbon energy system. Participating in DSR makes perfect sense for any business that is serious about being environmentally responsible.

According to National Grid ESO, the DSR and other forms of flexible technology, such as storage, can help to provide the capacity and flexibility needed to operate the electricity system in tomorrow’s world. This new reality of smart grid and low carbon emissions create challenges in operating the grid, it presents exciting opportunities for energy users. Power Responsive DSR program has been introduced in the UK and aims to make sure there is a level playing field for both supply side and demand side solutions in Britain’s energy markets while helping businesses take full advantage of these opportunities.

DSR is considered in the UK as an important tool to help ensure a secure, sustainable and affordable electricity system. It can help us soften peaks in demand and fill in the troughs, especially at times when power is more abundant, affordable and clean. For business and consumers, DSR is a smart way to save on total energy costs and reduce their carbon footprint. By encouraging greater and wider participation, collectively we can turn an industry problem into a customer opportunity. Demand side providers can deliver services by either reducing their demand or taking advantage of onsite generation. Consumers can participate either as (i) large industrial and commercial customer; (ii) small to medium enterprise; or (iii) aggregator.

DSR can help to reduce peak demand by redistributing end-users’ electricity demand to other times of the day (Figure 9. Effects of DSR on Typical UK Demand ProfileFigure 9-a). This lowers the need for supply capacity designated for use at times of peak demand. DSR can also provide the flexibility to match supply and demand every second when unpredicted fluctuations occur (Figure 9-b). Finally, DSR can be used to keep the amount of electricity demand within the limitations of the national and local power grids.

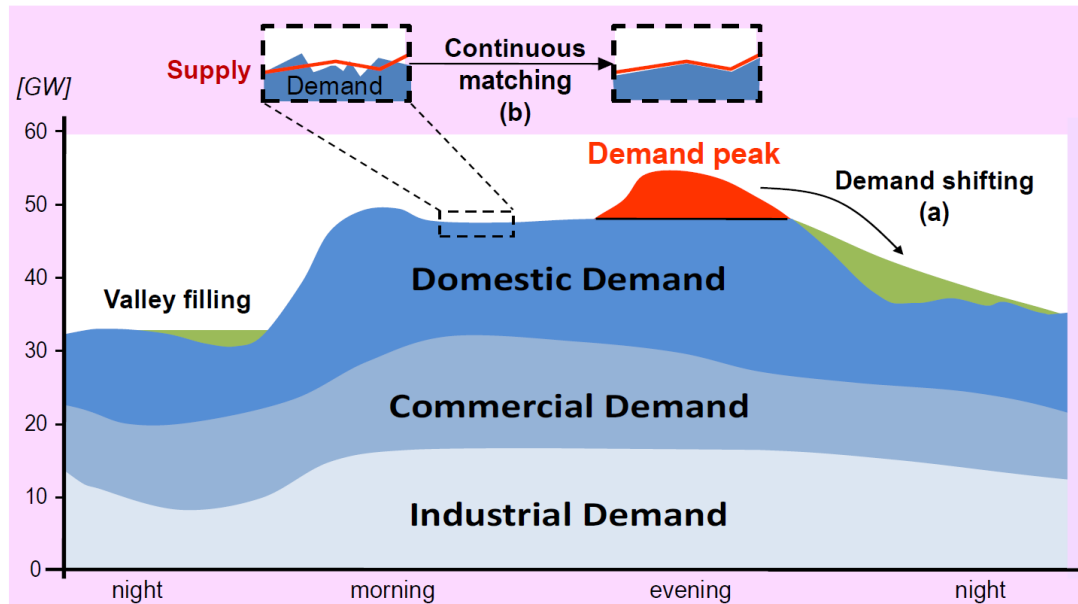


Figure 9. Effects of DSR on Typical UK Demand Profile. [26]

The role of DSR in the Electricity System is important, as it helps to redistribute predicted electricity demand to different times of the day, manage unpredicted changes in supply and demand, and manage constraints of the electricity transmission network.

a) **Redistributing Predicted Demand:** Shifting demand to off-peak times allows plants to be run at full capacity, which is more efficient as it reduces stopping and starting and spreads fixed costs across more of the electricity output. Currently most DSR used to shift predicted demand comes from three main approaches:

- ✓ Incentives are offered to 117,000 large electricity end-users (which make up 50% of UK electricity use) to change their patterns of electricity use.
- ✓ Certain tariffs encourage 2 million household customers to shift electricity use to the night, moving 20% of annual household demand from the day.⁴
- ✓ Network charges encourage industry, suppliers and aggregators to decrease demand during the winter peaks, as the size of annual peak demand determines the network charges. This leads to a reduction of annual peak demand by 2% (1GW).

b) **Responding to Unpredicted Supply and Demand Changes:** To maintain the stability of the electricity system, the total electricity supply must match demand for electricity continuously, second by second. However, constant fluctuations in demand and sudden changes in supply (for example, when a power plant breaks down) cause mismatches. To resolve these mismatches the TSO in UK responds by adjusting supply and demand. Currently DSR used to balance unpredicted changes in supply and demand comes from two main sources:

- ✓ Industry and commerce, which contribute 1.1 GW, with most provided by on-site (usually diesel) generation.
- ✓ Households, which contribute 0.25 GW through storage heaters that automatically turn on at night.⁴

c) **Managing National or Local Network Constraints:** DSR can be used to keep the amount of electricity demand within the limitations of the national and local power grids. If the amount of electricity flowing through the grid is too high it may lead to damage or failures. Transmission and Distribution Network Operators can use DSR's temporary demand reductions to prevent these high local electricity flows. Also, if an unexpected failure occurs, DSR can be used to reduce electricity flow in the remaining network capacity to prevent further

damage. In the extreme case of a black-out, it can help to restart the system by assisting a synchronised start-up of supply and demand.

Netherlands

By 2030, the Netherlands has set a target of 27% share of renewables, mainly built on the transition means from coal power plants to wind and solar generation. The Netherlands has an increasing need for flexibility in their power system, with decarbonisation as a driver for electrification of gas-based services and an increasing share of DER. An increase in electricity demand in combination with less inertia and control of the power generation, pushes for an increase in flexibility resources.

In order to cover these requirements, the Dutch flexibility market has been opening up to Demand Response and lowering the restriction to participate. This opens the door to smaller DR resources such as residential DR. TSO TenneT has kicked off the flexibility market for FCR, aFRR and mFRR services. For FCR, there is a minimum threshold of 1MW for bids, this 1MW can be aggregated from multiple smaller units. The FCR service needs to be able to be activated within 30s to its full volume, with more requirements on frequency measurement accuracy, insensitivity range and frequency deviation levels. FCR bids can be both upwards and downwards.

The aFRR product also has a minimum threshold of 1MW, but here aggregation is not allowed. The product is available for upwards and downwards directions. The BSP is only allowed to offer three bids below 4MW in the same auction and the product is required to be observed within 30s of the event notifications. The stricter requirements make aFRR less or inaccessible for participants with smaller resources and aggregators. Bids are made in monthly and weekly auctions and the remuneration covers the entire rewarded period, similar to FCR.

Manual FRR acts as an extra reserve flexibility on top of the aFRR product. In the Netherlands mFRR is split into two products: mFRRda (directly activated) and mFRRsa (scheduled activated). mFRRsa has a 20MW threshold and is thus only accessible for large flexibility resources. It also works both directions and the contracted power must be available within 15min of activation. mFRRsa has a different structure than the previously mentioned ancillary services. Since it is a non-reserved product, it does not work with contracts. Bids are placed and can be activated when needed. Similar to aFRR, it has a minimum threshold of 1MW and a maximum of three bids below 4MW. Remuneration is only offered when the bid is activated.

In the Netherlands, the retailers can offer two types of contracts: fixed or variable. A fixed contract will offer a fixed rate for the entire duration of the contract. Variable contracts will change the tariff twice a year, 1st of January and 1st of July. Within these contracts, there is a possibility of having peak and off-peak tariffs, depending on the installed meter. The daily structure depends on the region, the largest part of the Netherlands works with peak hours between 7am and 11pm. Residents of apartment buildings are already allowed to share electricity generated by solar panels, but energy trading between buildings is not allowed.

2.3 Status of demand response in the US

The US has a diverse landscape regarding the functioning of electricity markets. The country is divided between different control zones. Some regions managed by an Independent System Operator (ISO) like in California, Texas or New England liberalised their electricity sector. The deployment of DR is rather linked to the challenges faced by ISO in their control area. California developed products to cope with a large share of renewable energy and adequacy issues during summer peak; while New England developed DR as an answer to the decommissioning of aging and polluting power plants.

Overall, they have more ease to develop DR products as power companies are more integrated locally. One company can produce electricity, own the transmission and distribution grid (but not operate) and act as local retailer. It eases significantly the coordination issues that we are facing in Europe. The power systems are organised in successive electricity markets with different time scales and with their own rules for transactions. These differences mean that for DR participation, different requirements are apparent to take part in the markets are necessary according to the rules and the time-ahead to the delivery of the service (i.e., as in the USA the long-term contracts, day ahead markets, intraday markets, balancing markets and reserve markets). In the following Figure 10 it can be seen which the demand response participates in the electricity market, The ancillary services are contracted in advance, but the dispatching is done on the day-ahead economic dispatching and the operation according to the time of operation of ancillary services. As closer to the delivery of energy to the load, the power or balancing services that could be provided are more valuable, which is also applicable for DR services.

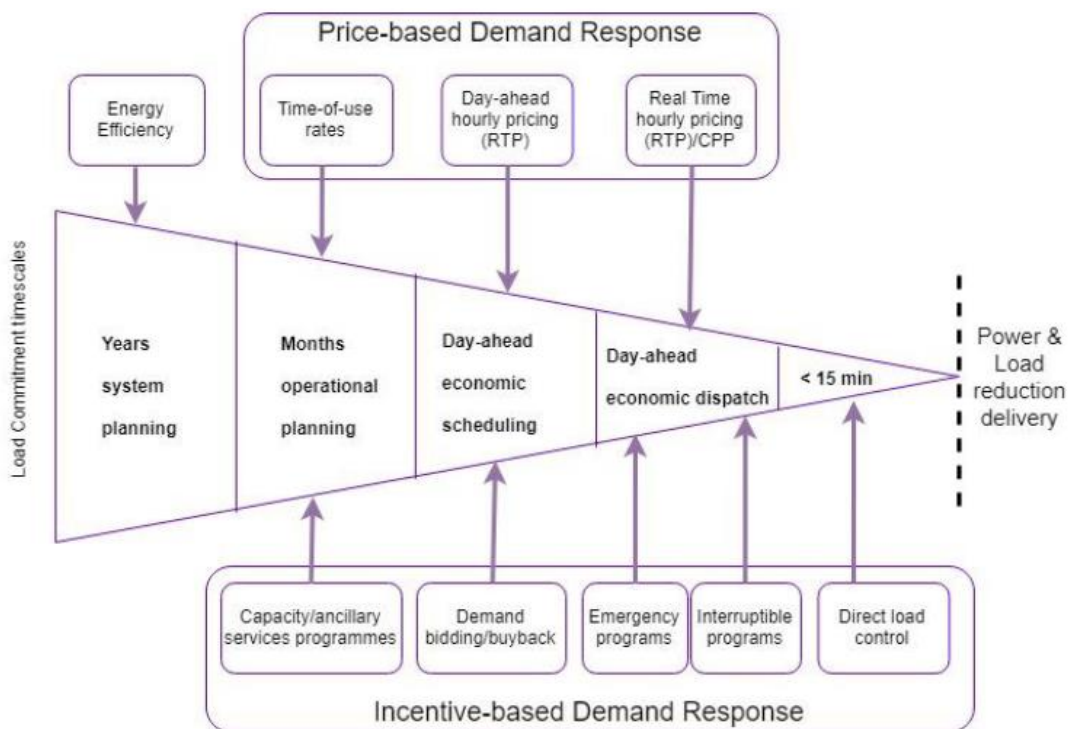


Figure 10. Demand response operation in the US electricity markets [27]

Currently, the US is a mature market for Demand Response services, mainly due to the application of policies that allow players of all sizes to participate in wholesale electricity markets, covering 60% of the US power supply [28]. In this case, residential consumer participation has the highest amount—around 90%, but the remaining sectors provide the major market share regarding flexibility, incentives, and savings. In 2016, California was the most active state in the US regarding DR markets—20% of the total Demand Response customers in the US and contributing 20% of the total peak demand savings [29]. The landscape of DR in California is quite chaotic (they have approximately 20 products, sometimes really specialised like a load reduction for agricultural pump system). In their processes, the ISO allows new products and it is then implemented by the locally-integrated power companies. Other companies can of course participate.

Parameters and specifications must be considered to create a successful DR program. Based on the Federal Energy Regulation Commission (FERC) and the North American Energy Standards Board a detailed set of business practice standards for measuring and verifying demand response and energy efficiency has been established on 21 February 2013 [30]. Four categories are considered in the applicability of measurement and verification standards:

- Energy Service—Demand resources deliver a quantity of electricity, measured in MWh;
- Capacity Service—Demand resources are required as a means of managing demand over a defined period, measured in MW;
- Reserve Service—Demand resources are obligated to be available to produce reduction upon deployment period;
- Regulation Service—Demand Resource fluctuates load in response to real-time signals from the System Operator. These resources are subject to dispatch continuously during the commitment period.

The minimum eligible resource size considered varies between 10 kW and 100 MW, but the minimum reduction amount lies between 1 kW and 10 MW.

Several benefits can be identified by the implementation of demand response.

- Participant financial benefits, which are the savings in the electricity bill and the incentive payments earned by customers that adjust their electricity demand in response to time-varying electricity rates or incentive-based programs.
- Market-wide financial benefits, which are the lower wholesale market prices that result because demand response prevents the need to use the costly power plants during periods of otherwise high demand, driving production costs and prices down for all wholesale electricity purchasers.
- Sustained demand response lowers aggregate system capacity requirements, allowing load-serving entities (utilities and other retail suppliers) to purchase or build less new capacity, in the longer term. These savings may be passed eventually onto most retail customers as bill savings.
- Reliability benefits, which are the operational security and adequacy savings from demand response, that lowers the likelihood and consequences of forced outages which impose financial costs and inconvenience on customers.
- Market performance benefits, which correspond to demand response's value in mitigating suppliers' ability to exercise market power by raising power prices significantly above production costs.

3 Technology and socioeconomic enablers for residential demand response

3.1 European projects overview and related work

The importance of implementing demand response innovations and measures is being illustrated in several EU funded projects, mainly focusing to promote on a wide scale the European targets to overcome the EU's energy crisis and reduce the dependency on Russian fossil fuels. Several initiatives and EU-funded projects and solutions are being created to successfully implement the DR concept in real European markets.

The EcoGrid EU project creates a concept for a real-time market for demand response in the future smart distribution networks, including the high penetration of distributed generation, renewable-based technologies, and active consumer participation [31]. The idea is to reduce the need for flexibility on the production side, which can be expensive—thus balancing the power system by giving real-time and updated price signals to the active resources to provide the needed flexibility—increasing the price when there is a power deficit in the system, and vice versa.

Furthermore, the InterFlex project investigates distinct flexibility market models, DSO-steered flexibility activation channels, autonomous functions and grid automation following several factors such as observed grid congestion, national regulation, and economic principles [32]. Focusing only on the use of local flexibility for the benefit of the distribution grid, it shall be recalled that flexibilities also serve other markets and purposes. From the conclusions withdrawn on their report's Demand Response and Consumer Empowerment section, data privacy and protection rules are highlighted since access to smart metering data for input to grid constraint forecasts and flexibility procurement for grid optimisation is crucial. The consumers must fill out consent forms to access any metering data, and the complexity of those is too high for residential consumers. Therefore, it is necessary to simplify without reducing the awareness of exactly how the data are employed and managed. Further studies must guarantee data protection, evaluating and adjusting the rules from data aggregation.

The DRIMPAC project aims to close the gap in the interaction between the energy market and the active participants, providing a framework that enables the end-to-end communication of essential information to provide demand flexibility and, at the same time, enhances building management intelligence mutual benefit of the prosumer and the energy system while preserving comfortable and healthy living conditions [33].

The SENDER project develops energy service applications for DR, home automation, convenience, and security. Furthermore, with a consumer-centric approach, they engage them in a co-creation process with other players from the energy sector during the specification of pro-active DR mechanisms to supply for the consumers' long-term motivation [34].

On the other side, the FEVER project has the objective of implementing and demonstrating solutions that control flexibility (energy storage, including batteries and V2G, and DR) to give electricity network services and address problems of the distribution grid, thereby providing the EU with a secure, efficient and resilient electric grid [35].

The SmartNet project compared five different TSO-DSO coordination schemes—different typologies and roles for the network operators, for three national scenarios—Italy, Denmark, and Spain, where four were implemented in simulation and compared their technical and economic performance. The project defines a new grid planning methodology where new flexibility resources and storage systems are introduced instead of grid expansion by adding new grid elements. The tool integrates T&D planning, full inclusion of environmental analysis, probabilistic contingency methodologies replacing the N-1 criterion, and optimal planning decision over several decades. With this, six regional cases demonstrate the viability in real scenarios casting a view on grid planning, almost covering Europe until 2050.

The INTERFACE project is looking into the legislative proposals made by European Commission on how network operators must cooperate to balance the energy market and other ancillary services as well as provide congestion management. It focuses on TSO-DSO coordination enabling more efficient and effective management, increasing Demand Response and the capacity of the Renewable Generation. Considering Digitalisation as the key driver to achieve the goal, an interoperable pan-European grid services architecture was designed, developed, and exploited to act as the interface between the network operators and the consumers, enabling the coordinated operation of all stakeholders to use and procure common services.

The MERLON project developed an integrated modular local energy management framework in the presence of high shares of Distributed Generation. This project enables the comprehension and development of business models focusing on local energy communities introducing consumers to local flexibility markets [36].

The FleXunity project wants to deploy novel services for retailers and aggregators, enhanced by VPP technology empowered with artificial intelligence algorithms developed to minimise the cost of energy that can be bought in the market and optimise the use of DG from the managing entities as well as from local community's portfolio. In addition, FleXunity promotes the active participation of community members evaluating their flexibility and energy-sharing actions. While there are some overlapping themes, each reference presents unique findings and conclusions based on their specific research focus and methodology. Nevertheless, some common themes that emerge include the importance of demand-side management and flexibility in achieving a more sustainable and resilient energy system, the need for effective coordination between different stakeholders and network operators, and the role of digitalisation and innovative technologies in enabling this transition.

The OneNet project targets to develop an interoperable architecture that enables the whole European electrical system and the value chain of ‘TSO-DSO-consumer’ to operate as a single System of Systems. A variety of markets enables the universal participation of stakeholders regardless of their physical location – at every level from small consumer to large producers. It targets to create the conditions for a new generation of grid services able to fully exploit demand response, storage and distributed generation while creating fair, transparent and open conditions for the consumer [37].

3.2 Technology challenges and enablers for residential demand response

The variability of wind and solar power generation and other market issues are demanding demand response flexibility resources, thus opening opportunities for a range of companies offering services, hardware and software and automated control systems [38]. These enabling technologies may include smart meters, smart plugs for load control, home energy management tools, energy information tools in order to monitor customer’s performance and communication infrastructure for facilitating the fast response [39].

All these smart grid technologies are the perfect enablers of digitalisation in the energy sector and further the adoption of DR applications, through ensuring the communication improvements, the data management strategies and analysis, as well as the improvement of technology that gather the data. The digitally connected and distributed intelligent assets are enabling the two-way flow of energy and information, especially when distributed RES generation and self-consumption allows injection of clean electricity back to the network, allowing utilities to efficiently manage increasing complexity.

Additionally, demand response enabling technology can facilitate energy market stakeholders i.e., retailers, DSOs and Balancing Responsible Parties, to monitor, predict and manage peak-time energy demand of machines remotely. With real-time information, System Operators can analyse, predict and control the energy system in all periods and circumstances, carrying out Demand Response strategies to mitigate efficiently several energy issues. However, DSOs access to data should be carefully considered as unbundling requirements were, for some DSOs, more loosely applied than for TSOs. Regulation should ensure that, if they are linked to a parent company, it will not have access to information falling in the competitive field.

Demand Response can also leverage telecom innovations as enabling technologies like 5G. The 5G technology is specifically designed for M2M (machine to machine) communication. The 5G proposes a high bandwidth with the aim of supporting large volumes of data being generated from the growing number of end-point devices. Telecom service vendors have already tested 5G speed ability to provide adequate data transmission capabilities for advanced edge-intelligence applications for DR [40].

Another relevant enabling technology for DR that is booming the last decade is the Internet of Things (IoT). The IoT is unleashing the full potential of the current energy systems data collection, management and analytics through intelligent cyber-enabled systems. It facilitates

faster and better smart grids development and valorisation of flexibility resources at the edge by expanding intelligence to customers and appliances. Currently, there is a barrier at the smart meter interface since devices use their own 'communication protocol and IoT technologies should be interoperable with it. These differences in communication protocol used, the devices decision making variability and competitiveness between developers of these technologies and devices, are enabling easy expansion of intelligence to smart devices. However, this should be also developed in an interoperable way in order to fully valorise the benefits and capabilities for the energy systems. Several projects and architectures are dealing with interoperability and energy data exchange [41], as this is regularly examined in the BRIDGE Data Management Working Group.

The smart meters, smart thermostats, and automatic control switch, improve the ability to monitor the real-time electricity utilisation in electricity networks, manage and control to leverage full benefit of data analytics. This Advanced Metering Infrastructure (AMI) technology plays a critical role in implementing the Demand Response strategies. The smart meters, as new generation electronic meters with the capability of bi-directional communication between the consumer and the other entities involved in the energy value chain, are essential for demand side monitoring and control, whether the consumer is participating in a dynamic price system to which reacts voluntarily or if he has an agreement with a third agent by which allow direct control of his consumption. In this case, a higher level of technological development is necessary with certain capabilities for remote control and intelligent management of the loads, apart from the exchange of information.

Additionally, the implementation of remotely controllable Heating Ventilation Air Conditioning (HVAC) equipment such as thermostats, water heaters, and alternating current (AC) controllable switches are growing in popularity across North America and Europe as well, in order to provide the possibility for remote monitoring and control.

Moreover, advances in ICT and AMI have allowed the development of Home Energy Management Systems (HEMS) and Building Energy Management Systems (BEMS), which allow (i) effective control on a house or building level, for the consumer loads and (ii) more effective communication abilities [42]. These new devices are important for the application of DR programs because they gather data from different devices of households.

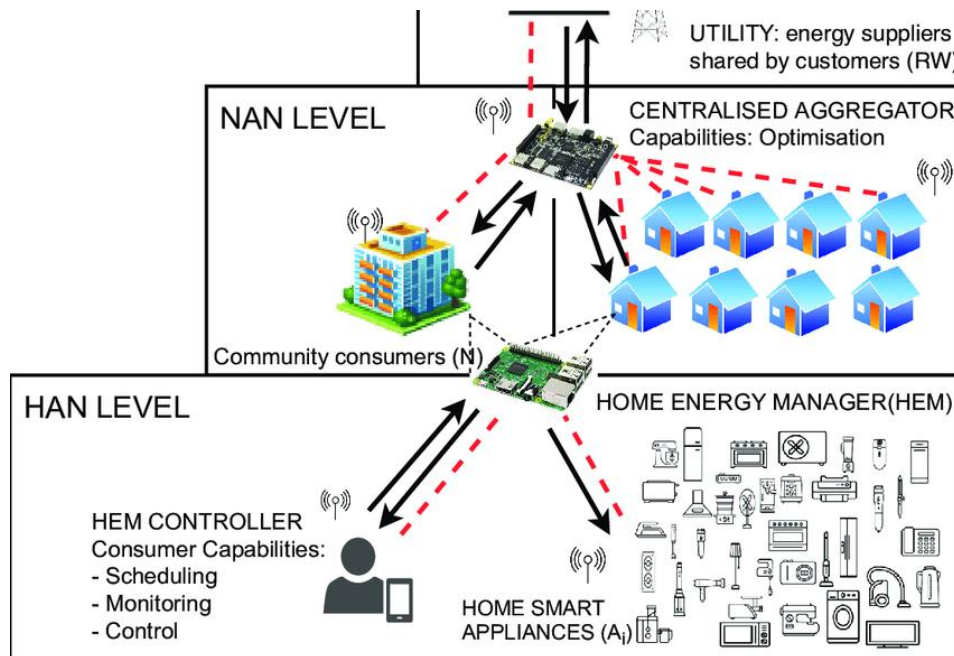


Figure 11. Smart system for demand response layout, as presented by Cruz.

As identified in the above Figure 11, a possible approach for the smart technology system supporting demand response can be divided into Home Area Network (HAN), Neighbour Area Network (NAN) and Wide Area Network (WAN) [43].

Smart meters can be directly connected to the AMI network which can be constituted by a series of networks known as Neighbourhood Area Network (NAN). This AMI network connects a central unit or data aggregator with the smart meters of a same point of consumption that 'represents' the Home Area Network (HAN). The HAN networks may communicate with the smart meter so that (i) the price signals and other data can be sent and displayed on-site through the display devices, in-home displays or mobile applications, (ii) the smart meter provides real-time consumption data to HEMS, which collects the information from flexibility available from consumer. These networks are the infrastructure that allows automatic response optimizing algorithms of DR, at local or area level. Likewise, consumption control in the reaction to signals can be controlled manually, but it is more efficient and has a greater potential for savings and impact on the system if response is automated.

The costs and benefits from Demand Response are many-folded and differ greatly based on the various 'angles' of view. That is to say, barriers and enablers, advantages and difficulties 'pushing' or 'halting' respectively the demand response, can be very well analysed from a stakeholders' perspective. Having determined the stakeholders' roles and their responsibilities, there can be a clear understanding of their needs, aspirations and potential barriers for a wide adoption and implementation.

From the consumer point of view, the consumers are expected to respond to price signals channelled through the retailer, aggregator or a third party which modulates consumers' consumption profile. A significant barrier from a consumer point of view is the design and deployment of effective DR programs and the lack of quantitative understanding of their behaviour and end-use activity adaptive capacities. By mitigating these, they are expecting to

achieve the reduction of the energy costs, capitalisation of flexibility in electricity markets and delivery of more power on the electricity market.

From the aggregator point of view, the aggregators promote and manage the actions that are carried out under the DR framework. The independent aggregators more particularly, are not affiliated to the customer's supplier, and negotiate with their clients the amount of loads to increase flexibility and reliability and reduce participants' risks. Aggregators are acting as enablers of demand response and their aim is to help small consumers to participate in the electricity market due to its complexity. Without being a retailer of electricity, they play the role of intermediaries between consumers and all markets, providing them with manageable loads in certain nodes. They operate as a service provider who manages a set of demand facilities in order to sell pools of electric loads of different characteristics as one bigger unit in the electricity market. Currently they are not widely established across Europe, having different regulation among countries, and in the role of independent aggregators is even less scarce, and they include the ability for aggregators to contract with customers without needing prior permission from the customers supplier. Despite the obligation falling from European laws, the status of independent aggregator, its perimeter of actions, and a strong framework for the transfer of energy from the supplier's perimeter to the aggregator's perimeter still need to be addressed in several European countries.

One other approach for demand response wider penetration can be the retailers/suppliers acting also as aggregators; directly or in cooperation with independent aggregators, but some business model factors can make retailers difficult to provide aggregation. The main business of retailers is risk management. Retailing services with demand response entail a high knowledge of loads performance, which is already their case through retailing, but at the same time enlarge their business models, by creating a new risk from unknown customer demand which comes from demand response of distributed generation, independent aggregators. Some barriers which slow down their desire of demand response deployment from this retailers' perspective are the upfront costs and the uncertainty of revenues.

The DSO is the actor responsible for the final delivery of the electric power to the consumer premises. If the DSO participates in demand response business, it may act as a market facilitator and/or a flexibility buyer. The DSO may provide communication services through AMI system to the aggregators but in that case the DSO does not make decisions. As already briefly mentioned, the demand response network code that is under public consultation will certainly outline the mechanisms for DSO participation, coordination with TSO and rest actors, and role in demand response for voltage control and congestion management services. When demand response tools are focused mainly for small consumers, operators of distribution systems have the ability to control potential load reductions in each node of the transport network. In this way, demand response allows us to fulfil the standard of service quality at lower cost (valorising existing flexibility resources) and in the long term reduce the cost of investment in network reinforcements as seen explained in this chapter. The barrier that currently exists regarding the clear regulatory environment will be alleviated following the guidelines set by the new demand response network code.

Another important actors are the developers, maintenance companies, ESCOs, builders, building management system (BMS) integrators, who are involved in the construction of the

end consumer infrastructure, especially in the residential sector. They play an important role in the definition and recommendation of the energy project objectives, investment and targets. They can influence the key features and components to facilitate energy awareness and efficiency, execute the work following the specifications from the owner/designer, take over the upkeep of buildings including their energy infrastructures and the surrounding area. Thus, they are essential to the efficient and effective running of buildings and their energy systems, as well as enabling demand response by ensuring that the systems and controls are operating as intended. Some ESCOs also offer building maintenance as part of integrated energy supply contracts.

It is also worth mentioning that the energy monitoring and smart metering systems used in the market should enable a faster and more comprehensive information exchange regarding energy consumption and pricing. However, some smart meters may not be able to deliver all information and functionalities required for demand response services. Standardisation of the communication interfaces is a priority, to ensure fast enough transmit of the control signals between market players. The automatization of processes (with consumer consent) would significantly foster demand response widely. If the end-consumer needs to activate manually its devices, it can create fatigue leading to less participation in the long-term. Creating an automated process taking into account consumer preference and comfort could lead to higher system efficiency.

3.3 Socioeconomic challenges and enablers for residential demand response

In spite of Energy Efficiency Directive requirements, participation requirements exclude demand response for small customers to day-ahead, intraday, and balancing or other markets. This has been also described in the country wide presentation above with their respective references. Regarding the industrial customers, these have their own bilateral power purchasing agreements. These differences have arisen due to an incomplete regulatory environment in the majority of Member States and the lack of flexibility of electricity suppliers. In most countries, the amounts of responsive bid units that can bid are mostly for largest consumers. This participation is made with contracts between individual market stakeholders, direct market bidding planned many hours ahead or in emergency [44].

Furthermore, there is a lack of connection among electricity prices, that reflect the average electricity costs, and the system operation challenges. In this way, the consumer cannot have an indication of the system issues resulting from electricity flows, renewables volatility and electrification of sectors that influence demand profile. This low awareness of system operation issues does not incentivise the customers to change their behaviour. As the money expended for electricity during a year is provided by the customers in interval payments, consumers use electricity when needed, without prioritising to minimise the cost over the consumption. In other words, there is a weak understanding of electricity markets from the general public.

These challenges and needs for better visibility of system needs is very much related with the rapid electrification of activities where more and more electric equipment has been deployed

in daily life. The peak load of power system continues to grow or fluctuate significantly, which demonstrates the importance of maintaining power system balance.

In order to satisfy peak load demand, two options could be adopted, (a) to invest new power transmission and distribution facilities or (b) to introduce demand response. Compared with the high investment and low utilisation rate of new power facilities, it is more economical and practical to carry out demand response to improve system operation flexibility.

Regarding the widespread deployment of demand response, there is a strong enabler of balanced budgets and financing mechanisms for consumers to face upfront investments for DR across different Member States. In other words, the establishment of demand response opportunities with clear benefits can foster further investments in distributed renewables with storage (facilitating clean energy integration) and smart technology, as well as the electrification of sectors, i.e., mobility heating and cooling. In the same direction, the networks tariffs and fees should encourage all participants equally, i.e., industries, tertiary sector, residential sector, while the tariff structures of the current network could create an unfair allocation of costs among users, particularly due to lack of smart metering that cause users to be on the same tariff despite creating different costs. As the number of "prosumers" increases, this fact poses some additional stress on the network and there could be an impact on network fees.

Even though researchers' focus is on social contexts such as policy, individual behaviour, education, and income level, the simulation of residential consumers' demand curve is very difficult due to its dependence on other external factors. A better understanding of households' electricity usage could avoid misleading conclusions [45]. Customer behaviour does not reflect the economic behaviour expected in many cases. It has been observed [46] that electricity demand approach is not elastic, depending on diverse factors. It is necessary to solve the asymmetry response, considering that the magnitude of the response to a high price may be different than the response to a low price. Furthermore, among aggregated loads, demand types behave differently, many different load types with many diverse operating characteristics and constraints which makes it uncertain.

Load monitoring and identification is a tool for estimating the usage of energy and the consumption of individual appliances based on analysing the aggregated load measured from the main power in smart homes. Although the intrusive load monitoring (ILM) approach is more accurate in measuring the energy using real meters at each appliance, it has a number of practical issues: (i) increasing the number of monitored appliances leads, to increasing the cost of the measuring system;(ii) the data of the measuring system must be grouped in a single central unit, which is another component of the system; (iii) electrical meters must have a suitable interface, like a radio interface since the data of the measuring system must be linked to a central unit; (iv) the current flowing through the monitored appliances must also flow through the meter which decreases the dependability of the power supply;(v) as the number of measuring system components increases, the energy consumption by measuring equipment increases. This led to the emergence of the Nonintrusive Load Monitoring (NILM) technique which provides significant benefits over ILM, including lower installation and maintenance costs since there are fewer components to install, maintain, and remove improved dependability, and fewer space needs. NILM is a method used for energy

disaggregation which can estimate each appliance's power consumption from composite data [47].

In this topic there are also some ethical issues. The system operators already have data from a smart meter which they use for the management of their grid. The provision of extra information for every electrical appliance is an issue that should be examined regarding data protection.

Demand response can certainly support the alleviation of significant load peaks largely correlated with high energy price, by shifting time of consumption in low-priced hours (implicit demand response), as with flexibility services through markets (explicit demand response) for balancing and congestion management. These can be also differentiating the pricing also by regions to solve these new challenges in other times, where regions can have different prices for DR in order to smooth loads in desirable ways.

In this line, to enable properly the implicit DR, smart meters should be largely deployed and useful, with adequate interfaces allowing data flow. Also, self-consumption helps to enable remarkable mitigation of consumption peak and should be promoted through regulation across Europe, with specific incentives and adjustments in connection supplements and network fees. If the consumer self-consumption is solely connected to grid and uses hybridisation with batteries and proper control for grid delivery, it is locally more efficient, and the consumers can shift consumption having more options and controllability.

Another challenge for DR is the 'consumer inertia': which can limit the participation in DR programs from residential end-users, as many of them simply won't consider changing their energy consuming habits. Additional challenges for DR appear, when these users place significant value in 'hard to quantify' merits like loss of comfort or privacy. These consumer values can prevent end-users giving up control over some of their devices to participate in an automated response and sharing data that is required for the measurement of the response. Other consumer values such as environmental values could stimulate participation in DR. This also suggests that it matters by whom the DR program is sold to residential end-users and which values are signalled. Thus, these "costs" are probably not fixed, but they can be influenced by aligning DR with the consumers values. For example, trust between the aggregator or energy supplier and end-user is an important factor that will influence the end-users decision to participate in DR [48].

Another possible challenge can be generated by the form of information that is exchanged between the end-user and the aggregator or energy supplier is another factor that can influence the decision to participate in DR. For example, implicit DR requires timely information about prices that the end-user can respond to, while the explicit DR requires some instruction from the energy supplier or aggregator to adjust the load. Especially in the case of a behavioural response poor design of the user interface can be a barrier to DR, but also in case of an automated response it is important that the end-user is informed about the adjustment of the load in a proper way.

4 Conclusions

In this deliverable, the participating entities have provided the outline of technical, market and socioeconomic drivers and barriers for consumer engagement in residential demand response, targeting to identify the parameters of an enabling environment.

Additionally, a review of the current demand response market status has been presented, including the countries of the demos, other European countries with mature demand response markets and the US paradigm. The European projects and regulation initiatives, mainly the demand response network code and several Horizon Europe projects have been briefly presented to outline the current situation.

The idea is to define the most important elements identified up to now and link with the technologies of the DR RISE, highlighting what the pathway of future activities in the project.

Key artifacts of the abovementioned analysis are:

- ✓ Based on the Electricity Directive, RepowerEU and respective Network Codes, Demand Response (DR) has great technical and economic potential while promoting the interaction and responsiveness of the customers in the energy markets, contributing directly to the respective needs/challenges they face, i.e., peaks, shortages, price fluctuation etc.
- ✓ Currently, residential consumers across Europe are inelastic in most countries, since there are few demand response mechanisms operating in energy markets. On the other hand, industrial customers are more active in demand response since in many countries when their operations process changes cost is lower than electricity cost, based on specific pricing schemes.
- ✓ Demand response can be an active reserve resource for balancing markets as well as for the provision of non-frequency ancillary services i.e. voltage control and congestion management.
- ✓ The Network Code for demand response is coming to bridge any coordination and harmonisation gaps providing a complete set of guidelines and recommendations for market design for congestion management and voltage control, system operators coordination and data exchange processes.
- ✓ Spain has shown progress in the adoption of demand response while still there are several areas that require attention regarding regulation tariffs and technological update.
- ✓ In France, demand response is appearing in four markets Balancing market (MA), Wholesale market (only for demand response operators), capacity mechanism (MECAPA), Service systems (SSy).
- ✓ In France, demand response cannot compete economically with production and this barrier to entry could in effect prevent DR to participate in the market and provide its flexibility to the power system. Directive 2019/944 [4] guarantees that such barrier to entry should be removed, if it is implemented correctly by the Member States.
- ✓ In Germany the market for demand response is still very small, since the smart meters are not widespread in German household, so that they cannot react on price signals and cannot participate in Demand Response. Thus, more and more DSOs offer

dynamic tariffs, but only for those end-consumers who are already equipped with smart meters. the market for demand response

- ✓ Italy is working on demand response mechanism and there have been some pilot projects regarding demand response programs, such as the UVAM. In this mechanism, an explicit DR mechanism is followed, and participation is possible either through an offer of services in the MSD ('Mercato dei Servizi di Dispacciamento'-dispatching market), paid for the activated energy, or with a forward contract, paid for the capacity, through auctions conducted by the TSO to secure upward services at a price below a strike level fixed by the Regulator. Thus, the UVAM project can be considered as an explicit spot and forward DR mechanism.
- ✓ In Greece, the Law 4986 introduced the regulatory framework for the participation of Demand Response in the Balancing Market. The plan of 7.3 million smart meters installations across the country will be fulfilled by 2030 and will enable the residential demand response participation.
- ✓ In Bulgaria, there is a plan to finance the decarbonisation actions in the residential sector i.e. solar heating installations, PVs and electric vehicles charging stations. The bid limit to participate in DR currently is 5MW and pose significant barrier for the residential sector to participate in a wide scale.
- ✓ In Belgium, the DR resources can participate in the Primary (FCR) and Tertiary Reserves (mFRR), as well as in the Interruptible Contracts program, classified under the Tertiary Reserve. The FCR volume must be deployed in full within 30 seconds with a minimum contracted capacity of 1MW. The mFRR DR product should react within 15 minutes and for a period of 2 or 8 hours, depending on the product chosen, and that have a minimum of 1MW of DR resources. Various pricing tariffs are not allowed yet, only in derogations of living labs.
- ✓ In Ireland there are several tariff-based programs for Demand-Side-Management that motivates the electricity usage to more affordable hours. Most of them refer to industrial and commercial customers that represent higher capacities in the energy markets (Demand Side Units) that are directly controlled by the National Control Center. There are certain tariffs to incentivise demand peak reduction in specific time frames.
- ✓ In the UK, the demand response market is mature, consumers can participate in the demand response market as large industrial and commercial customer, or small to medium enterprise, or aggregator. Their contribution in the energy system may be delivered by redistributing predicted demand, responding to unpredicted supply and demand changes, or managing national and local network constraints.
- ✓ In the Netherlands there is also a mature demand response market, where for the participation in FCR, aFRR and mFRR markets, there is a minimum threshold of 1MW for bids, this 1MW can be aggregated from multiple smaller units.
- ✓ In the US, there is also a mature demand response market with several tariff products, while especially in California there are 20% of the total Demand Response customers in the US and contributing 20% of the total peak demand savings. The minimum eligible resource size considered varies between 10 kW and 100 MW, but the minimum reduction amount lies between 1 kW and 10 MW.
- ✓ There have been several EU funded projects that explore the demand response opportunities through developing efficient tools for control and operation of flexible resources and consumers' installations. The developments include data exchange architectures, smart grid automation technologies, digital platforms and propositions

for markets and regulation updates, to enhance the consumer participation for flexibility provision.

- ✓ Analysing the landscape across Europe and US, it is evident that there is a strong need in several countries to invest in smart grid technology i.e., smart meters, communication infrastructure, in order to fully exploit the capabilities of storage and flexible resources at the edge of the grid.
- ✓ The grid upgrades should be promoted at the transmission and distribution level with incentives to system operators, as well as incentive to end consumers for home intelligence, storage and energy efficiency investments with controllable loads i.e., heat pumps, hybrid PV-storage etc.
- ✓ There is a need for data analytics tools and interoperable data exchange technologies that will leverage the big data generated by IoT and equipment at the edge of the network, to fully predict and exploit demand response potential.
- ✓ The existence of these enablers can mobilise also market reforms that are needed in order to harmonise the rules of demand response across Europe, especially regarding the minimum bid size, the interrelations among stakeholders, the data exchange processes, the services to be provided.
- ✓ Consumers in some cases show a lack of quantitative understanding of their behaviour and end-use activity adaptive capacities they can deliver, as well as they show 'inertia' to participate in DR programs and change their energy habits.
- ✓ The role of the aggregators should be enhanced as an enabler to promote the consumers' participation in the market, especially in the sense of 'independent aggregator' acting without the permission of the energy supplier.
- ✓ Consumers do not really have an indication of the challenges that the grid is facing, resulting from the electricity flows. The information of understanding the system needs should be presented in an illustrative and clear way to the end consumers in order to engage them in the process of demand response and 'energy consciousness' as a whole.
- ✓ A strong enabler for demand response would be the balanced budgets and financing mechanisms for consumers to face upfront investments for DR across different Member States

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