DREAM-GO

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# Identified Short and Real-Time Demand Response Opportunities and the Corresponding Requirements and Concise Systematization of the Conceived and Developed DR Programs - Final release

Deliverable

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# 1. Introduction

The actual course of power systems operation and continued growth of consumption leads to an unsustainable future with a high impact on the environment. Moreover, this high impact complemented with a lack of awareness of the consumer's self-consumption and practices contributes significantly to a less efficient operation of power systems. In this context, demand response is a solution integrated into demand-side management, that provides a useful tool for the management of power system's operation in the way that it offers demand flexibility through the modification of load, given certain price signals or monetary incentives. In Figure 1, it is presented the proposed structure for the current work, namely, the context and points of interest regarding demand response implementation.

In the demand-side management environment, there are three essential terms: consumer awareness, consumer engagement, and demand flexibility. The first is related to how the consumer understands its position in the power system, how consumption costs and efficiency can be improved, and what is the framework of energy markets. The second term is related to the approach of the demand response providers, power system's management and operation, towards the inclusion of consumers in energy markets and efficient energy use. Finally, the third term is the basis for the other two, since it defines the capability of consumption-side adjustment based on the power system's operation. The current work focuses on demand response integration in the European Union (EU) and in the United States (US).

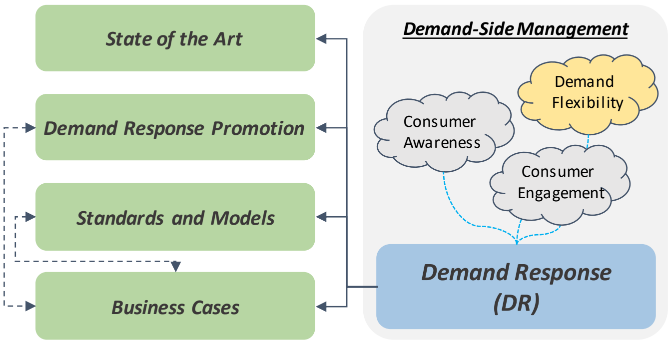


*Figure 1. Points of interest and context of demand response.*

Four main chapters are considered: State of the Art, Demand Response Promotion, Standards and Models, and Business Cases. The first chapter, State of the Art, presents the demand response framework, considering the main enablers and barriers of its implementation and the current stage of it in power systems. In the second chapter, Promotion, it is presented the entities that promote demand response implementation, which can be a relevant factor for its success. The third chapter approaches the available standards and models that provide the first steps in demand response implementation, and how these can be an important tool for an easier integration of resource's flexibility. Finally, in the last chapter, it is presented the main companies, aggregators, and operators that built business cases around demand flexibility provision.

# 2. State of the Art

The present section addresses the state of the art regarding demand response programs implementation, with special focus on its main participants either in the upper-level with managing entities (e.g. system operators, retailers, aggregators, regulators, amongst others) or in the lowest level of the power systems operation, and consumers (residential, commercial, industry, public facilities).

## 2.1. Demand-Side Management versus Demand Response

Today's electricity markets complement their operation with distributed energy resources, such that these provide flexibility in emergency or other grid congestion situations. In this context, demand-side management raises as one of the most attractive solutions for an easy flexibility implementation in power systems. This concept can be defined simply as intelligent consumption, i.e. conducting strategies that allow the consumer to pursue its objectives, such as minimizing costs, maximizing comfort, learning behaviors, amongst others. Demand-side management is built of several concepts [1], as follows:

- *Energy efficiency* – improve the efficiency of the appliances or of the building, so that energy losses are reduced, being this approach related to technical features other than changes in the consumer's personal comfort and behavior;
- *Time-of-use* – it is related to opportunities to consume at a lower cost, since most times in electricity markets, there are periods where energy tariffs are lower, and thus consumption is less costly at these periods;
- *Demand response* – consists of requests made by an upper-level entity (e.g. system operator) regarding with a consumption increase or decrease (more common), of which the consumer can choose or not participate. This is usually called a demand response event;
- *Spinning reserve* – is a way of seeing the consumer, namely, as a resource who is always available to correct system frequency, voltage level, or any other grid issue that needs a rapid consumption correction.

In recent times, demand response concept has gained more and more relevance, and somehow reduced the light over demand-side management. Demand response is usually divided into two major types, as Figure 2 illustrates, of which the latter one is related to another concept of demand-side management, time-of-use [2]:

- *Incentive-based:* demand response programs that are based on giving monetary incentives (e.g. payments, taxes relief) to promote the reduction of consumer's consumption when requested. These programs are usually implemented by aggregators or system operators;
- *Price-based:* demand response programs that are based on price signals (e.g. higher or lower tariffs, time blocks) sent to the consumers, intending to promote the modification of consumer's consumption profile according to a cost reduction mentality of the consumer.

The incentive-based programs are often associated with upper-level entities, such as direct load control, emergency demand response or interruptible loads, while the price-based programs are more often seen to promote demand response from the consumer's initiative, such as critical peak pricing or real-time pricing [1].

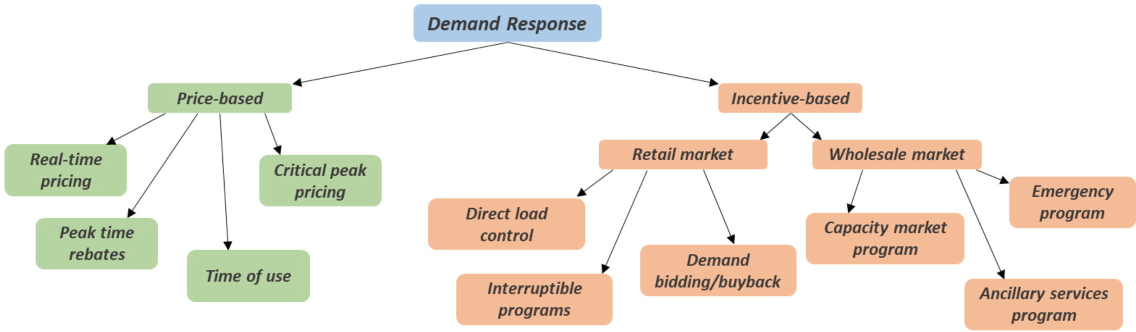


*Figure 2. Demand response programs classification. Adapted from* [3].

In terms of practical implementations, in demand response, there are three types: reduction, curtailment, or shifting of load. Reduction implies a continuous capability of load adjustment, curtailment is a discrete or by steps implementation, and finally, shifting implies that consumption is neither reduced or curtailed but rather transferred to another time (advantageous or necessary).

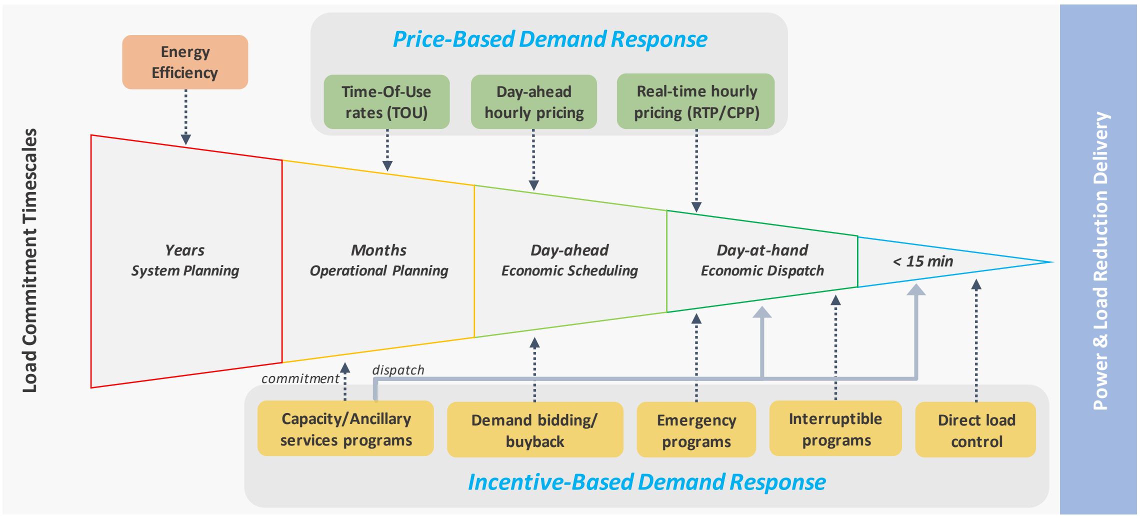


*Figure 3. Demand response programs timescale. Adapted from* [4].

Demand response implementation can have several timescales (Figure 3), from long-term to real-time depending on the program objective. Usually, short-term and real-time applications are programs that are implemented regularly, since these are associated with system corrections (i.e. incentive-based programs are the only ones that can be activated in a short-term to real-time timescale – less than 15 min). For example, voltage regulation and frequency stability are common incentive-based demand response programs implemented in a short to the real-time horizon, having the objective of improving or maintaining the energy quality and security of the power system.

As the timescale raises, several programs can be implemented in the day-at-hand, namely, both incentive and price programs. Interruptible programs are load shedding contracts where an availability period is defined, and at these times, a request to provide flexibility can be made given a notification time before the event (e.g. the consumer is noticed two hours before the event). Emergency programs are equally applied to these conditions but are less frequently implemented. Nonetheless, it can be applied in the day-at-hand situation where the consumer acts as a spinning reserve. As for price-based demand response in the day-at-hand, real-time pricing (RTP) and critical peak pricing (CPP) programs can be implemented. These are based on providing the consumer with a price schedule for the day, in the case of CPP, or access to each

period energy tariff, in the case of RTP. Henceforth, the consumer can adjust its consumption by considering the prices applied, thus inducing energy savings opportunities.

The day-ahead economic scheduling is the timescale with a huge potential when considering the energy market participation since the day-ahead market is one of the most active and where more resources usually participate. Therefore, the most relevant incentive-based demand response program in this scope is the demand bidding/buyback. The demand bidding program states that a consumer or a representative entity can propose a bid for energy reduction or increase in an energy market, thus offering demand flexibility to the power system. This action can also be called buyback, since the energy that was initially bought to satisfy consumption, is now sold back in the market in the form of load reduction. Regarding the price-based demand response program, the energy pricing for the next day can be made available to the consumer similarly to the previous timescale approach, thus inducing it to perform a scheduling for the next day to reduce its operating costs, focusing its consumption on low-tariff periods.

In case of months and years horizon, the demand response programs are considered for long periods of time, and are usually less intense on the consumer's consumption profile when activated, such as, in the case of incentive-based demand response, capacity/ancillary services are the most common. These offer stability, security, and energy quality services that are used by the power system in situations of need, replacing spinning and static reserves that are more expensive to maintain and operate (e.g. diesel generators). Also, in the case of energy efficiency, within years and the respective system planning, it is assumed that power systems tend to be better in terms of sustainability, security, and robustness. Time-of-use programs are represented by retailer's or supplier's contracts with consumers that undertake dynamic pricing schemes. These contracts can consist of the usual monthly electricity taxation that consumers have due to their energy consumption needs but undertaking a floating price.

One of the most important concepts to incentive and price-based demand response features is the elasticity of a consumer. The consumer's elasticity represents its behavior towards a change in a given factor, which in terms of electricity is usually the energy price (price-based) or energy income (incentive-based) [5]. These changes in behavior can be measured and analyzed in two different time horizons: short-run and long-run. The first defines an analysis throughout a year, in which the behavior of the consumer is observed when changes occur in the energy price or income. The latter implies a longer period and is attached to the methodology and entity that performs the analysis of the consumer behavior. The results usually lead to obtaining higher elasticity values than in the short-run [6], [7]. This kind of information provides load-serving entities, several conclusions and relevant observations that can improve their electricity and management offers to the consumers, knowing in advance or estimating the consumer's behavior to change the price of income.

## 2.2. Current Barriers of Demand Response

The main barriers to demand response implementation are shown in Figure 4. The figure defines three major pillars of interest that make up the barriers: technical, political/financial, and social.

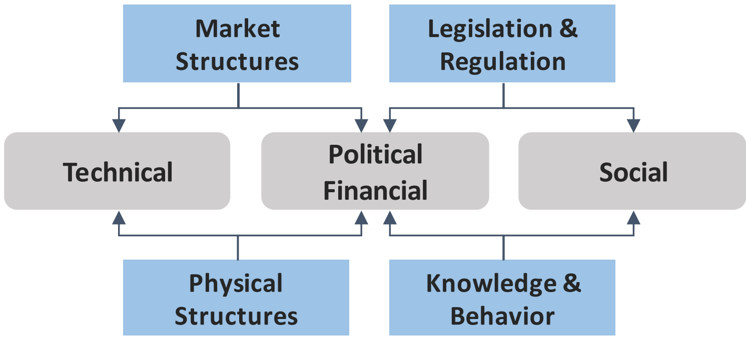


*Figure 4. Three pillars of the demand response barriers. Adapted from* [8].

The technical pillar intends to represent the actual physical difficulties that countries encounter when considering demand response implementation, i.e. the physical network equipment and communication infrastructure that is needed to implement demand response. The market integration of demand flexibility resources is important and addresses two of the pillars, namely, technical and political/financial. On the other hand, political/financial and social issues lead to the need for new legislation and political regulation that allows and facilitates the integration of demand response program in the consumer's behavior, mentality, and awareness or understanding.

Nowadays, the political/financial pillar has suffered a deeper development, rather than just an academic or conceptual level. Moreover, several countries, mainly European countries, and the US have registered many legislations and regulations that are focused on the inclusion of distributed energy resources (distributed generators and demand response) into the current power systems. This has been one of the most relevant enablers for the implementation of demand response and consumer engagement.

The social pillar is also of the utmost importance since it is related to the perception of the consumer towards demand response strategies, and how these affect their consumption and normal behavior [9]. The consumer awareness regarding the potential that demand response can have in their operation in exchange for some sacrifices in usual behavior, is not at a level that completely ensures the successful implementation of demand response in all sectors yet, moreover if the potential for the power system's operation is significant.

In sum, these three pillars provide relevant points on which the entities are focused to define the power system's operation, opening a clear path for the demand response implementation, promoted both by the consumers and the upper-level entities (e.g. operators, aggregators, retailers). This context of operation is translated into a multi-agent system that interconnects several entities building up to a more robust and secure power system. The smart grid is the concept associated to this robust and secure power system, integrating all the concepts mentioned before, and going further into several others that involve metering, data mining, intelligent decision support, forecast, optimization, amongst others.

Another important feature highlighted and addressed in [10] is the smart metering and data management responsibilities. The smart metering is an important part of the successful implementation of demand response since it allows a significant data collection that improves the monitoring of demand response program. Based on the information provided in [11], 58.5 million smart meters were placed in the United States in 2014, and it is planned to have 800

million installed smart meters by 2020. In fact, the main purpose of using smart meter is to reduce the overall electricity consumption with minimum impact on the end user's preferences and comforts, and also increasing the active participation of the electricity customers in the energy efficiency programs, especially demand response programs.

The monitoring of the stages of demand response implementation undergoes several steps, as seen in Figure 5.

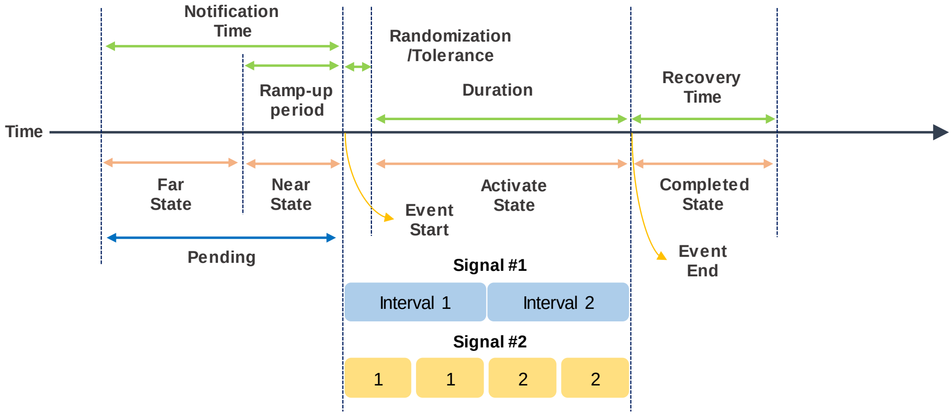


*Figure 5. Demand response timeline. Adapted from* [12].

As Figure 5 shows, there are instances that need to be monitored to verify that the consumer has followed the demand response program correctly, according to the request of the operator (in the case of incentive-based demand response). In this way, smart metering provides a solution for the advanced monitoring of consumers participating in demand response program and reveals the potential that exists in other consumers that are not participating. However, this leads to another issue, the responsibility and ownership of the data monitored by the consumers, which constitutes private information and compromises the consumer's security. The data monitored in each consumer represent valuable information for the unveiling of flexibility potential, thus it is essential that the data is available for aggregators, operators, or other demand response event creators, given certain use conditions.

In [13], the barriers to demand response program can be seen from a consumer's perspective according to three different factors: consumer behavior, load baselines, and data issues. Regarding the first feature, the authors consider that changes in the consumer's behavior, either significant or not, may cause a reduction in its comfort. These changes can provoke a negative reaction of the consumer towards demand response, causing a lower participation or a demand for higher benefits [13]. Additionally, [13] underlines that the consumer is more drawn to demand response through monetary incentives than by the so-called green mentality and concern about the environment. Therefore, the main interest of the consumer in demand response participation is conditioned by its capability of recovering investment and electricity bill savings. In the second feature, load baselines reside on the difficulty of consumption forecast that depends on the consumer's behavior, making harder the availability and potential of demand response implementation. In the third feature, the metering and monitoring come across again with the successful evaluation of demand response before, during and after the program actuation. These features and issues are especially important in a short and real-time timeline since in this type of environments it is crucial for the DR providers to have information about the current state of all the flexible resources so that any imbalance that may emerge could be solved quickly and effectively.

Another barrier related to the market structures is the conditions of the resource's participation in energy markets, i.e. the minimum requirements imposed by the market operator and regulation. Due to the small-scale contributions that consumers can provide

individually, the aggregator gains importance. The aggregator is an entity capable of agglomerating small-size resources contributions (reduction or increase), obtaining a virtual amount that can be negotiated in the market. Therefore, the aggregator goes to market as a single unit with certain bids, representing a given number of distributed resources that cannot do so individually [14]. According [3], the minimum capacity for the interruptible program is 100 kW, for demand bidding/buyback is 10 kW, and for direct load control is a few kilowatts, which makes small-scale contributions incapable to participate individually. The need for these entities (e.g. aggregator) becomes relevant not just for consumers but also for distributed generators since both can provide flexibility in their own way. This integration of distributed energy resources through aggregators is a focus in Europe, due to the existence of balancing responsible parties (BRPs). This has been the subject of several studies [15]–[17], and many countries have already adopted a strategy that symbiotically adjusts to both aggregators and BRPs (e.g. France, Austria).

## *2.3. Current Enablers of Demand Response*

The current enablers of demand response rely upon the developments and efforts made by the promoting entities, to introduce the demand flexibility term into power systems and consumer's way of thinking (leading to behavior). From previous research, it is noticed that the major push towards the demand response implementation is made by the retailers (in price-based programs) and system operators (in incentive-based programs).

In this context, there is an energy market focused on many demand response programs in Europe, promoted by the power system's operators, namely, ancillary services. This market intends to negotiate energy loads with the objective of ensuring the reliability and energy quality of the system through four main paths: restarting the system, frequency, voltage, and stability control. Frequency control is clearly the most implemented and often involves equipment installation that reacts when the frequency is out of bound. It can be divided into three types:

- *Primary reserve* – close to real-time actuation, it allows an automatic regulation of load to place frequency within bounds in a matter of seconds;
- *Secondary reserve* – after the primary reserve is successfully implemented and frequency is within bounds, the secondary automatic reserve is activated to place frequency at a target/standard value, as primary reserve returns to its previous level;
- *Tertiary reserve* – similar to what secondary reserve performs for primary reserve, this reserve implicates manual changes to the load that guarantee frequency stability and adequate value, as secondary reserve returns to its previous level as mentioned before for primary.

The demand for capability of flexibility in order to easily adjust load represents a great potential to replace traditional reserves (static or spinning), e.g. diesel generators, that imply considerable maintenance and operational costs. Also, for the consumer, the retrieval of this kind of traditional systems would be beneficial, since the costs mentioned before are obviously represented in the electrical bills and therefore supported by the consumers themselves. Therefore, system operators and regulators with the implementation of demand response by the consumers must reflect a reduction of energy tariffs, since the power system complements fewer operating costs.

Concerning price-based programs, as mentioned before, the biggest development is offered by retailers or other load-serving entities, since these usually implement dynamic pricing in their contract possibilities, inducing the consumer to gain awareness about its consumption periods and reducing its operating costs. Consequently, energy management systems can be useful for the consumer so that makes it easier the decision support regarding the load modifications that must be made. Additionally, the system automatization clearly introduces more advantages,

both in the consumer's comfort and operation. This kind of approach to demand response is useful throughout the several consumer classes (residential, commercial, industrial) independently of the amounts performed. Moreover, the use of aggregators to facilitate the participation of small-size resources in energy markets is an essential part of distributed energy resources integration into current power systems and therefore has been a topic of intense development. Several countries are currently accepting the participation of aggregators in several energy markets (e.g. Austria, Denmark, Finland, France, United States, amongst others) [18]–[20]. The demand response providers can be retailers, system operators or any other load-serving entities (as independent aggregators).

# 3. Demand Response Promotion

For the integration of demand response in current power systems, promotion is needed to complement the technological and political development. This promotion majority must come from the upper-level entities that manage and operate in the power system, such as retailers, utilities, aggregators, amongst others. In this way, upper-level entities must provide the means, conditions and attractive strategies that lead to a successful development of demand response implementation. Regarding a bottom-level approach, the consumers have of course a critical role in the success of demand response, since they are responsible for providing it. Thus, consumers also must have a sustainable approach towards demand response, but being aware of their personal interests and operating conditions, in order not to be overstepped by the upper-level entities. Moreover, the following aspects should be widely discussed and addressed in order to promote the implementation of demand response concepts [21]:

- *High initial costs* – for implementing demand response programs, amount of equipment, such as a smart meter and a home energy management module should be installed for each customer, which are costly. Therefore, the initial expenses of these automation infrastructures should be reduced to facilitate the implementation of demand response;
- *Coordination issues* – in the liberalized electricity grids that network and supply functions are separated, coordination issues associated with demand response may be raised. This is due to for example in a specific time horizon, some sectors need the energy to adjust downward, and simultaneously, other network players actually require upward demand adjustments. Therefore, reconsideration of regulation in liberalized electricity markets is required to be developed for demand response improvement;
- *Flexibility in typical markets* – currently, the demand flexibility within the distribution grid as well as industrial consumers provide sufficient capacity for the loading flexibility, somehow the role of residential customers is not much obvious. However, in near future, where a significant part of production would be done by renewable resources in the residential sectors, activating residential flexibility and real-time trading should be well reorganized to accommodate aggregated load flexibility;
- *Load shifting and increasing emissions* – load shifting schemes could be effective to reduce the consumption at peak periods, while it recreates a transferred peak. This can be tackled by differentiating prices, somehow depending on the sources of produced energy, the prices could be varied. As an example, consuming energy from a cleaner producer with a cheaper price could lead to having less usage of a non-cleaner producer with an expensive price.

Regulators and utilities have also a relevant role since they maximize the demand response promotion. Table 1 summarizes the characteristics that are required to be addressed by the different sectors of the network in order to successfully implement demand response concepts.

*Table 1. Features that need to be developed for demand response improvement* [20].

| **Features** | **Primary responsibility** | | | |
|---|---|---|---|---|
| | **Regulators & Authorities** | **Utilities** | **Consumers** | **Retailers** |
| Innovative, engaging and cost-effective customer feedback, response and home automation solutions including energy boxes | | ★ | | ★ |
| Increased knowledge sharing, industry-wide pilot research cooperation | ★ | ★ | | ★ |
| Clear and financially supported political mandates for SM/DR rollout and investment protection | ★ | | | |
| Modernization and unlocking of load profiling and incumbent tariff regulations to facilitate and motivate smart-tariff offerings from utilities | ★ | | | |
| Increased volatility of retail tariffs (in conjunction with response tools and efficiency rewards) to motivate customer awareness and response | ★ | ★ | | |
| A changing utility-consumer relationship paradigm, focusing on partnership, a common goal and fairly shared costs and benefits | | ★ | ★ | |
| Improved standardization of rules and processes concerning e.g. smart grids, communication and market access to data and technology | ★ | ★ | | ★ |
| The proliferation of integration and value-adding DR services | | ★ | | ★ |
| Holistic, comprehensive DR programs incorporating advances smart-pricing (peak and real-time pricing with at least 1:3 off-peak/peak differentiation), psychological and technological elements, supporting active and passive response | | ★ | | ★ |
| Initial kick-start induction of mass market DR commercialization and cultural momentum, followed by long-term visions, strategy, and patience | ★ | ★ | | |
| Major initiatives by consumer representatives, authorities and utilities to educate the general public about the benefits of DR | ★ | ★ | ★ | |

## 3.1. Europe

In the European context, there are several electricity markets, both individual (related to a given country) and aggregate (involving several countries, e.g. MIBEL, NordPool, EPEX, amongst others). There is also an initiative for a single European market, involving the countries that belong to the EU, in which generation produced in a country could be used in another country to meet demand in a similar way as in aggregate electricity markets. However, these concepts involve a significant investment of resources, planning and time, to successfully implement the infrastructure and framework needed. Although market liberalization all around Europe provided important features for the development of competition amongst market entities, demand-side resources have passed unnoticed through several years, mostly because of the interest increase in renewable and distributed generation resources accompanied by also a huge technological development in that area.

The distributed generation was and is still promoted in a way that demand response has never had. Although recent improvements have been made, there are many promoting activities that need to be done. This is observed in many countries, but there are others that represent

successful cases of demand response implementation, namely, France, Finland, Switzerland, Belgium, and the United Kingdom [18]. Figure 6 and Figure 7 illustrate a comparison of the demand response implementation level in Europe in 2015 and 2017.

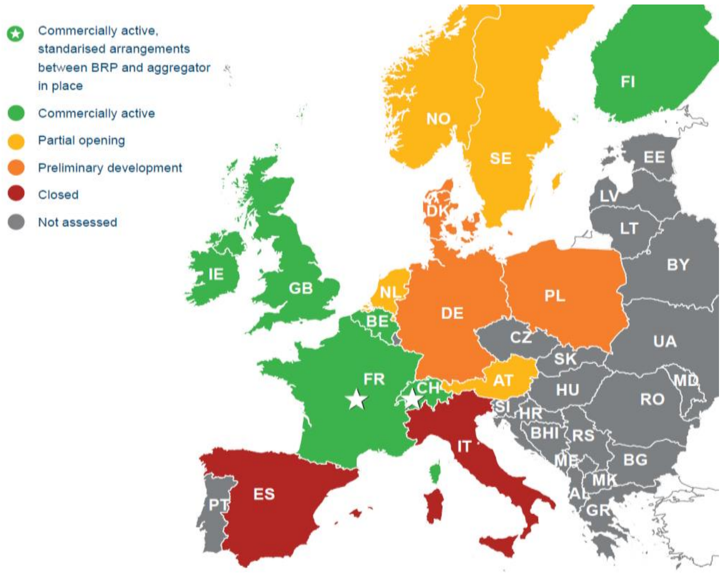


*Figure 6. Level of demand response implementation in Europe in 2015* [18].


*Figure 7. Level of demand response implementation in Europe in 2017* [22].

In Europe, the major concern with the implementation of demand response concerns the activities of balance responsible entities (BRPs) that, as the name intends to imply, are entities that perform the management of small regions of a power system regarding the balance between demand and available generation. The legislation of some of the above countries allows reducing the shortcomings of the relationship between the demand response implementation and the BRPs. To this end, we highlight one strategy: the establishment of agreements between the demand response providers (e.g. consumers, aggregators) and the BRPs. This provides information about the different energy processes occurring in the power system [16], [17]. This difficult relationship between the aggregators and BRPs is often the main feature of European reports regarding the barriers of demand response implementation in the power systems.

As it can be seen by comparing both Figure 6 and Figure 7, France and Switzerland have no longer standardized arrangements between BRP and aggregator, and they have detailed frameworks in place for aggregation, containing standardized roles and responsibilities of market participants. Also, Germany and Denmark have moved from orange status in 2015 to yellow in 2017, which indicates they have started to find a standard approach for the role of independent aggregation and to balance reserve markets to be opened for independent aggregation. Another noticeable difference between 2015 and 2017, is Portugal and Estonia, which are colored from gray to red that shows they have started to process the implementation of demand response programs. Although they have remained in red color since the aggregated demand-side flexibility is either not yet trustable because of the regulation or it is not accepted as a resource in any of the markets [22].

Across Europe, the majority of demand response programs comes from the system operators and more directed towards large consumer's participation, namely, through incentive-based programs. The programs implemented, as mentioned before, are mostly related to support services to the system (ancillary services) that place demand response as a spinning reserve (primary, secondary, and tertiary) that can quickly enter operation when the operator finds it necessary. These consumers' participation in energy markets can be hardened because in some cases the minimum requirements are misadjusted for the consumer's participation (thought out for producer's participation). This situation is even worse if aggregation is not allowed, since the consumers can only undergo the demand response programs proposed by the load-serving entity, leaving apart some of the energy markets for demand-side resources [23].

Small consumers are more involved in price-based programs rather than the ones mentioned before, and these are promoted in their majority by the energy retailers or some load-serving entities other than the operators. These programs usually consider two different prices across the hours of the day, although there can be more than two. In Europe, these strategies intend to induce the consumer with its consumption awareness and thus, gain interest in energy efficiency to reduce the operating costs.

In sum, the demand response implementation plays a role as an ancillary services resource with huge potential, as well as a complementary flexibility provider for the renewable generators uncertain production. As mentioned before, the European Union is focused on a high implementation and integration of renewable energy, however, the uncertainty of operation of these resources leads to issues in the power systems operation, and in some cases, causes additional costs. Demand response emerges in power systems as a cheaper resource to provide quick changes in the demand profile adjusted to the available generation. Figure 8 presents the timeline from the late 20th century until now, regarding the major legislation implemented in the European Union that is focused on the development of demand response and renewable generation (distributed energy resources).

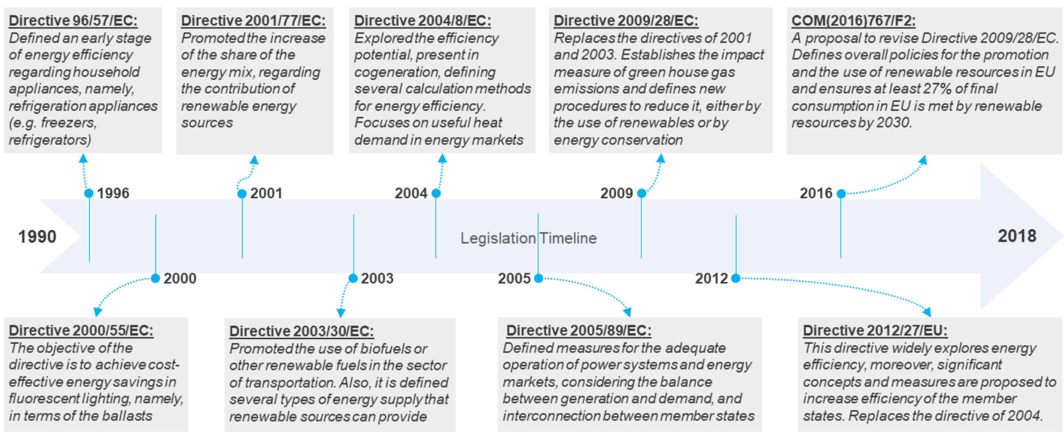


*Figure 8. Legislation timeline from the late 20th century until now in Europe.*

The two established directives (2009/28/EC and 2012/27/EU), have considerably pushed forward the development of distributed energy resources in the European Union, with the proposal of several energy efficiency measures and promoting schemes that aimed at the accomplishment of member state energy goals. Also, the proposal to revise Directive 2009/28/EC ensures that at least 27% of European Union energy consumption should be supplied by renewable resources by 2030, and all European Union countries must have at least 10% of their transport fuels come from renewable resources by 2020 [24].

## 3.2. United States

The US is the country with demand response development at a steady pace, i.e. technological concepts, innovations and posture towards demand response have come first from the US, and continues growing with a high effort from utilities, retailers, operators, and aggregators. According to [25], the concept of demand response has aroused during the 19th century in the US, with price-based initiates regarding time-of-day differentiated tariffs. Also, by the late 20th century, incentive-based programs were implemented through direct load control where the consumer would receive an incentive that could be a payment in dollars per kilowatt-month, or a discount in the final electricity bill in dollars per kilowatt-hour. Figure 9 presents the timeline of important legislation established in the US concerning the development and implementation of distributed energy resources, such as electric vehicles, renewable energy, and demand response.

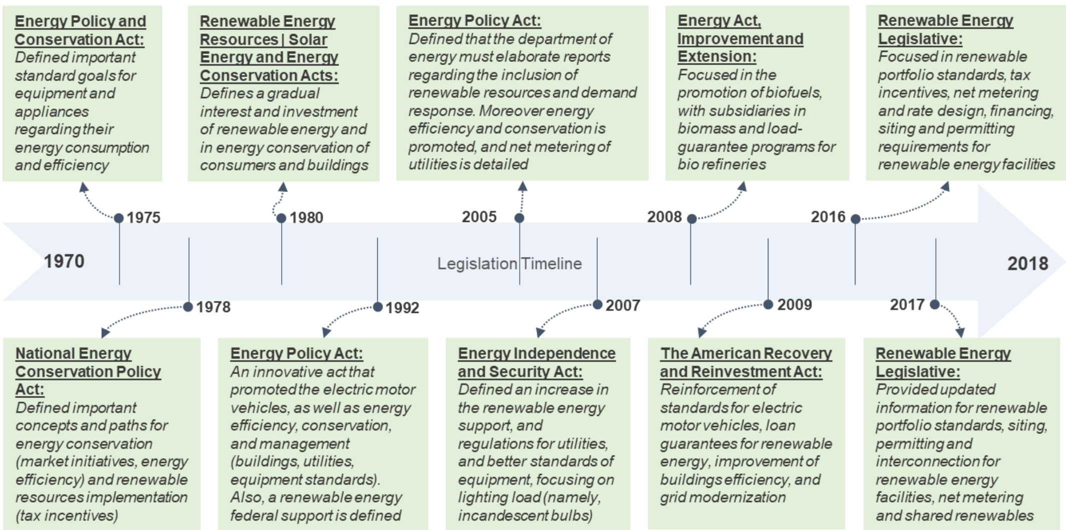


*Figure 9. Legislation timeline from the 20th century until now in the US.*

As it can be seen in Figure 9, since a long time, the US has been implementing new strategies and spending a significant amount of time in the inclusion of distributed energy resources in current power systems, namely, distributed generation, demand response, and electric vehicles in a near future. According to the information provided in [26], [27], 15% of the electricity generation in the US was produced by renewable resources in 2016, and 17% in 2017. This shows that the US has significantly focused on the renewable resources.

Demand response in the US can be proposed by many ways, since the number of entities that can offer this type of service is considerable and dependent on the consumer's location, due to the state's borders. The Federal Energy Regulatory Commission (FERC) defines several electric power markets, as presented by Table 2.

*Table 2. Comparison of electric power markets characteristics in the US* [28][29].

| ***Electric Power Market*** | ***Year*** | ***Generation Capacity (GW)*** | ***Peak Demand (GW)*** | ***Population (Million)*** | ***States Served*** |
|---|---|---|---|---|---|
| **California (CAISO)** | 2015 | 60,00 | 50,00 | 30 | 2 |
| | 2017 | 60,00 | 50,00 | 30 | 2 |
| **Midcontinent (MISO)** | 2015 | 190,54 | 130,92 | 48 | 16 |
| | 2017 | 174,72 | 127,12 | 48 | 15 |
| **New England (ISO-NE)** | 2015 | 31,00 | 28,13 | 14 | 6 |
| | 2017 | 31,00 | 28,13 | 14 | 6 |
| **New York (NYISO)** | 2015 | 39,04 | 33,96 | 20 | 1 |
| | 2017 | 38,77 | 33,96 | 20 | 1 |
| **Northwest Power Pool (NWPP)** | 2015 | 75,96 | 69,62 | 14 | 10 |
| | 2017 | 75,96 | 69,92 | 14 | 10 |
| **Pennsylvania-New Jersey-Maryland (PJM)** | 2015 | 171,65 | 165,49 | 61 | 14 |
| | 2017 | 165,56 | 165,49 | 65 | 14 |
| **Southeast** | 2015 | 238,00 | 170,00 | 57 | 10 |
| | 2017 | 238,00 | 170,00 | 57 | 10 |
| **Southwest** | 2015 | 50,00 | 42,00 | 11 | 6 |
| | 2017 | 50,00 | 42,00 | 11 | 6 |
| **Southwest Power Pool (SPP)** | 2015 | 78,95 | 45,30 | 18 | 14 |
| | 2017 | 84,94 | 45,27 | 18 | 14 |
| **Electric Reliability Council of Texas (ERCOT)** | 2015 | 75,96 | 69,62 | 24 | 1 |
| | 2017 | 75,96 | 69,62 | 24 | 1 |
| ***TOTAL*** | ***2015*** | **1011,10** | **805,04** | **297** | **80** |
| | ***2017*** | **994,91** | **801,51** | **301** | **79** |

Operating in these electric power markets, there are several electric utilities that provide supply to consumers. As Table 2 demonstrates, the total generation capacity has decreased from 1011.10 GW in 2015 to 994.91 GW in 2017, and for peak demand from 805.04 GW in 2015 to 801.51 GW in 2017, although there are 4 million increments in the populations. Moreover, it is worth to mention that some electric power markets may operate together in the same state (e.g. CAISO and Northwest, both supply the state of Nevada).

# 4. Standards and Models

The implementation of demand response must consider several features and must be specified so that the different relationships (human-machine, machine-machine) correspond adequately to what is intended. In this way, the present section approaches the standards (subsection 4.1) that are currently defined for demand response, and the business models (subsection 4.2) that are used by the demand response event creators to enroll consumers in these flexibility programs.

## *4.1. Standards*

Standards are critical features for the successful implementation of multilayered solutions, which involves different equipment that may not always use the same communication language. Therefore, standards define a common field of communication allowing a simpler information exchange between devices and/or users.

Regarding the demand response, the most developed standard is the Open Automated Demand Response (Open ADR) [30]. This standard is built by gathering several other standards into one, as illustrated in Figure 10, and conciliates the many approaches considered from the North American Energy Standards Board (NAESB), Utilities Communication Architecture (UCA), Energy Interoperation (EI) and Organization for the Advancement of Structured Information Standards (OASIS). According to [31], the Open ADR is defined as:

*"(…) open and standardized way for electricity providers and system operators to communicate DR signals with each other and with their customers using a common language over any existing IP-based communications network, such as the Internet."*

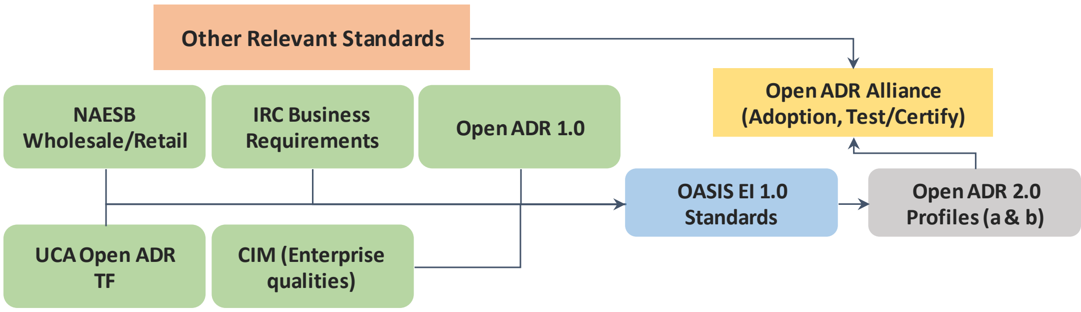


*Figure 10. Construction of Open ADR.*

This standard defines seven demand response programs that can be implemented using this same standard, i.e. critical peak pricing (CPP), capacity bidding (CB), thermostat (Direct Load Control – DLC), fast demand response dispatch (Ancillary services - AS), residential electric vehicle time-of-use (REV-TOU), and distributed energy resources demand response (DER-DR), defined as follows:

- <u>CPP</u> – dynamic pricing designed to encourage load reductions during periods where high prices or system contingencies are at play;
- <u>CB</u> – considers that consumers can participate in energy markets negotiation by presenting a bid relative to an energy amount;
- <u>DLC</u> – a consumer's load direct control access is made available to the demand response event creator, allowing it to manage conveniently and per contract;
- <u>AS</u> – considers that consumers can participate in demand response programs associated with the stability of the network, which is normally implemented by the grid operators;

- *REV-TOU* – applies different energy tariffs to electric vehicles to incentive the consumers to modify their vehicle's charging behavior;
- *DER-DR* – demand response program that intends to facilitate the integration of distributed energy resources.

Open ADR offers a data transmission framework for demand response, allowing communication between the promoting entity (Virtual Top Node – VTN) and the consumer's end-node (Virtual End Node – VEN). The end-node device can be an energy management system or an event receiver. In other words, Open ADR refers to the standardization of the DR event's transmission between the promoters and possible participants of these activities. Therefore, there are two main nodes in the Open ADR [12]:

- *VTN (Server)* – top level, as it contains the DR information and has the responsibility of broadcasting to the other players. Thus, VTN can be considered as a utility, market operator, or energy retailer, which are usually the promotors of DR events;
- *VEN (Client)* – lower level, as it is responsible for receiving the DR signals, execute and respond to it. VEN plays the role of end-users in the utility grid.

The Open ADR standard specification includes 4 applicable services, which stand for both VTN and VEN. These 4 services consist of [12]:

- *EiRegisterParty* – in this step, VEN should transmit a payload to the VTN called "oadrCreatePartyRegistration" containing the basic information that VEN determined to use in the communication (e.g. venID, requestID, etc.). Afterward, VTN replies with a payload called "oadrCreatedPartyRegistration" including all parameters related to the profiles and IDs;
- *EiEvent* – this is the main core of Open ADR. All of the information related to the DR events, such as starting time, event duration, prices, load shedding, event target, etc. have been retained in the payload called "oadrDistributeEvent" and passes from VTN to VEN;
- *EiReport* – this service contains the information related to the available resources in the VEN (e.g. reporting capabilities, report granularity, etc.). There are two type of reports: historic, and telemetry (real-time);
- *EiOpt* – this service enables the VEN to decide its participation in the event, by replying with "Opt-In" (agrees) or "Opt-Out" (disagrees) to the VTN.

In the same context, Open ADR presents a mutual language for all players of the power system, which enables them to communicate easily and cost-effectively. Since Open ADR is based on a Server/Client scenario, it uses Extensible Markup Language (XML) for standardizing the communication between the server and the client. This means that the DR data should be converted to an XML message in order to be transmitted between the network players. An example of transmitted XML payload between VTN/VEN are in the lines below [32]:


```
<oadr:oadrPayload>
    <oadr:oadrSignedObject>
        <oadr:oadrDistributeEvent ei:schemaVersion="2.0b">
            <pyld:requestID>OadrDisReq091214_043740_513</pyld:requestID>
            <ei:vtnID>TH_VTN</ei:vtnID>
            <oadr:oadrEvent>
```


This structure outlines several classes to a given variable and is represented through a hierarchy which complements its understanding and the important relation between the several variables. XML is the language implemented in all the messages considered in Open ADR. Considering the inclusion of an aggregator, the present standard proposes also a scenario where this entity is present in energy markets with a building management system, as illustrated in Figure 11. The figure shows the relation that needs to exist between the consumers (and their

assets), aggregator, and demand response offering entity. Note that three main structures are considered: grid, aggregator, and demand-side. These correspond to the major entities involved, namely, demand response promoting entity (grid), aggregator (has its own devices and communication structure), and all that concerns the consumers, considered as demand-side.

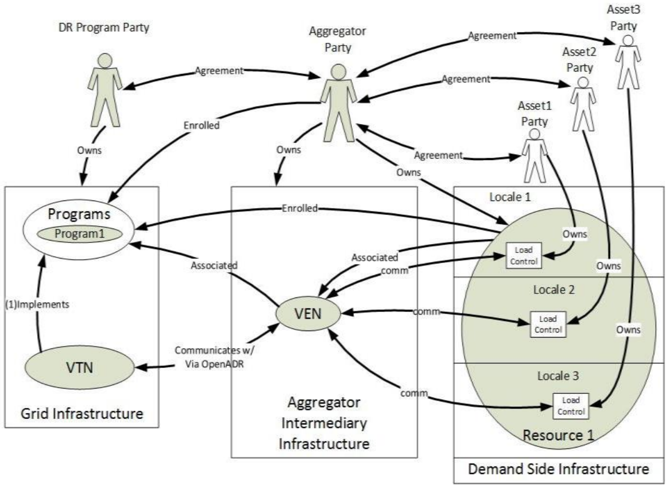


*Figure 11. Open ADR scheme for the inclusion of an aggregator* [32].

Furthermore, Figure 12 shows a specific Open ADR scheme for the European market based on The Universal Smart Energy Framework (USEF), where USEF roles are also integrated.

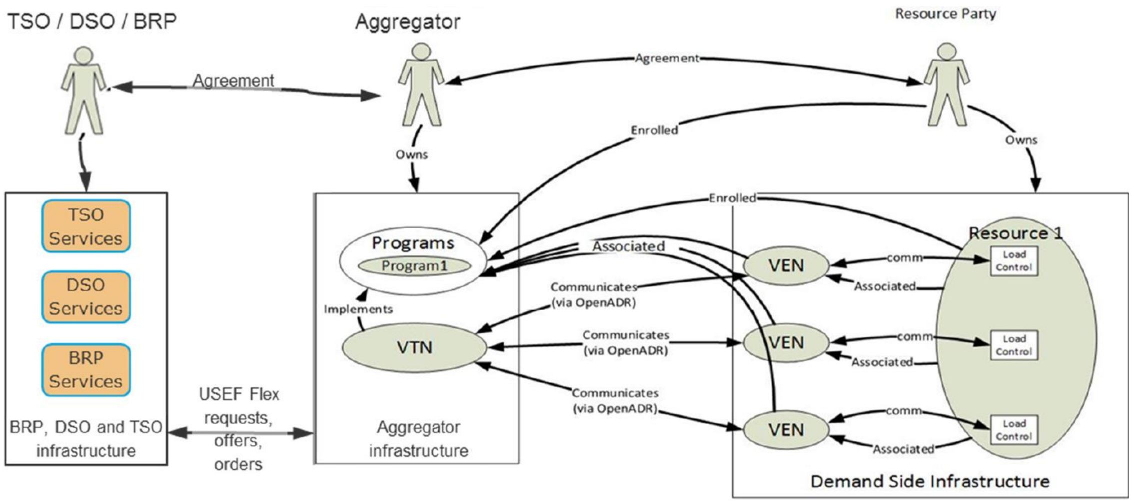


*Figure 12. Open ADR scheme for USEF/Aggregator scenario* [33].

As Figure 12 illustrates, the aggregator party are connected to both sides of the grid in order to offer and sell various flexibility services to the TSO, DSO, and BRP, and to provide the flexibility it has sold to the Resource parties. In fact, the aggregator offers flexibility services to the BRP, DSO, and TSO according to the business drivers of the latter parties. Moreover, the aggregators register several Resources on the demand response program for providing flexibility, somehow TSO, DSO or BRP have no visibility on each specific asset that aggregator is controlling [33].

## *4.2. Remuneration Models*

The remuneration models of demand response promotors and event creators represent a significant role in the consumer's interest in participation and sustainability, which must be achieved by the entities that create the demand response. In the grid-related demand response programs, the participation of consumers involves one of or both types of payments: availability and utilization, defined as follows:

- *Availability* – payment is made by the demand response organizing entity, that represents the consumer's compensation in exchange for making their load available to be modified, during a certain time horizon;
- *Utilization* – payment is made when the demand response organizing entity modifies the consumer's load, being the consumer remunerated for that intervention.

Note that these two approaches can be implemented together to increase the incentive for the consumers. In sum, availability represents payment for an amount of time where the load is modifiable, while utilization represents payment for modifying load during an amount of time. Other examples of incentive for the consumer are discounts on the energy price, tax relief, amongst others, when considering that the demand response organizing entity is a grid operator or a consumer's retailer.

However, when the demand response organizing entity is an aggregator, compensation for the consumer's participation may differ from the above, since the aggregator cannot decrease the consumer's energy tariff nor remove taxes from its energy bill (if the aggregator is a separate entity from the consumer's retailer/supplier). Consequently, the aggregator must find other forms of attracting resources for its activities, through participation in energy markets, energy engagement, consultancy, and advisory of the consumer's load profile. In other words, by performing an analysis of the consumer's consumption, the aggregator can identify demand response and efficiency potential. The aggregator can explore these opportunities to promote energy savings and arrange them to conciliate it with demand response events or energy markets negotiations in which the aggregator can participate. The consumer can also be paid by the aggregator to participate in the energy market. If the aggregator obtains its revenue, the result of the market negotiation must ensure fair payment for both the aggregator and consumer.

# 5. Business cases

The promotion of demand response tends to ease the inclusion of flexibility resources in current power systems. However, it is currently fading out to prompt business models that can successfully handle the demand response integration. Nowadays, the major integration comes from operators or national load-serving entities, and the programs are presented in the following subsections 5.1 and 5.2, for Europe and the United States, respectively. However, private and public-private partners are also opening a path to demand response implementation with sustainable business models, and therefore are worth mentioning in the present section. Moreover, these entities can assume different roles in their load-serving set of activities, namely, as aggregators, retailers, amongst others. In sum, these entities can participate in distinct energy markets and of managing/serving several individual resources. The detail of demand response programs is made by the country, when considering the European context, and made by the independent system operator when considering the US context. In the case of the load-serving entities (private or public-private), six features are detailed according to [20]: core activity, the purpose of flexibility, client profile, contracts with the final client, technologies, and client benefit.

## 5.1. Europe

The position of operators towards demand response is set mainly by ancillary services and interruptible loads offers. Table 3 presents a summary of the demand response programs provided by the operators in several countries of Europe, based on the data showed in [18][22].

*Table 3. Summary of European demand response programs in several countries.*

| *Country* | *Primary Control Reserve (FCR)* | *Secondary Control Reserve (FRR)* | *Tertiary Control Reserve (RR)* | *Interruptible Loads Program* | *Emergency demand response* | *Allows aggregation* | *Penalties* | *Time of Use* |
|---|---|---|---|---|---|---|---|---|
| **Austria** | Yes | Yes | Yes | No | No | Yes | Yes | No |
| **Belgium** | Yes | Yes | Yes | No | No | Yes | Yes | Yes |
| **Denmark** | Yes | Yes | Yes | No | No | Yes | N/A | No |
| **Estonia** | No | No | No | No | Yes | Yes | Yes | No |
| **Finland** | Yes | Yes | Yes | No | No | Yes | Yes | Yes |
| **France** | Yes | Yes | Yes | No | No | Yes | Yes | Yes |
| **Germany** | Yes | Yes | No | Yes | No | Yes | N/A | No |
| **Great Britain** | Yes | Yes | Yes | No | No | Yes | Yes | Yes |
| **Ireland** | No | No | No | Yes | No | Yes | Yes | Yes |
| **Italy** | No | No | No | Yes | No | No | Yes | Yes |
| **Netherlands** | No | Yes | Yes | No | No | Yes | Yes | Yes |
| **Norway** | Yes | Yes | Yes | No | No | Yes | Yes | No |
| **Poland** | No | No | No | No | Yes | Yes | Yes | Yes |
| **Portugal** | No | No | No | Yes | No | No | Yes | Yes |
| **Slovenia** | No | Yes | Yes | No | No | Yes | Yes | Yes |
| **Spain** | No | No | No | Yes | No | No | Yes | Yes |
| **Sweden** | Yes | Yes | Yes | No | No | Yes | Yes | No |
| **Switzerland** | Yes | Yes | Yes | No | No | Yes | Yes | No |

Most part of the countries allows for the aggregated load to participate in these programs, however, as mentioned before, the passive participation of the aggregators is only addressed and overcome by some. Additionally, time-of-use programs are more rarely found, which can be related to a lack of consumer awareness in some countries. From a previous analysis of this data, the summary consists on eight optional features: primary control service (FCR), secondary control reserve (FRR), tertiary control reserve (RR), interruptible loads program (that is out of the scope in control reserves), emergency demand response, aggregation allowances, penalties, and time-of-use tariffs. According to previous analyses, three factors are essential to successfully implement a demand response program: the ease of the aggregator's participation in energy markets, mechanisms of activity between the aggregator and balance responsible party and the requirements established by the regulators for flexibility resources participation in the energy market. Thus, success for a given country is not related to the number of programs that are available.

## Austria

Demand response is accessible to consumers through ancillary services in terms of primary, secondary and tertiary control reserves (upward and downward, load increase/ decrease). These reserves are also open to aggregators that may want to participate. However, this is dependent on the consumer's BRP/supplier permission. The total capacity contracted is 68 MW in FCR for either upward or downward regulation, 400 MW in FRR (200 MW for upward, and 200 MW for downward), and 405 MW in RR (280 MW for upward, and downward more 125 MW) [18].

In FCR, payments are only made by availability, while in other programs are made by availability and utilization. The complement between low payments is compared to the energy prices and misadjusted requirements, with a capacity of 1 MW for FCR, 5 MW as the minimum capacity for the others with reductions that can endure periods of 4 or more hours. This situation has been hardening the aggregator's search for flexibility from most consumers (residential and commercial) with only industry accepting to participate [34]–[36]. The lack of implementation, when needed, leads to penalties that are represented by periods of withdrawn from the program, and if regularly, removed from the resources portfolio requiring a new application.

## Belgium

Most of the demand response programs are closed to load participation or aggregation. however, when the programs are open, both types can be developed. In FCR, there are 27 MW of load available to perform frequency control in upward regulation only. FRR is divided into two classes: interruptible and non-interruptible. The first has 261 MW and the latter 60 MW, both also with a possible aggregation participation. In RR, strategic reserve involves 97 MW of energy [18].

All programs are more adjusted to consumers with minimum capacity requirements of 1 MW, and actuation periods of 1 up to 12 hours' maximum. Payments differ between the programs, i.e. the FCR and non-interruptible FRR are only paid for capacity. The interruptible FRR pays both availability and utilization, while RR only pays by utilization [37]–[40]. The penalties for the programs are 130% of the remuneration price, except for the interruptible FRR that considers 120% of the remuneration price.

## Denmark

The demand response implementation in Denmark differs from the ones approached before since it considers the distinction between two areas, western (DK1) and eastern (DK2). The FCR

in DK1 counts with 23 MW of aggregated load, while in DK2 there are 59 MW (not all from demand response) available divided by normal and disturbance operation (22 and 37 MW, respectively). In terms of FRR, there are 555 MW of load available for control reserve, accounting for DK1 and DK2 all together [18].

The requirements for participating in these programs are relatively small with some exceptions, namely, FCR has 300 kW minimum, while FRR has 5 MW minimum [41], [42]. Strategic reserves are also open to demand response, however, a minimum amount of 200 MW clearly indicates an aggregated-only participation of consumers. The payments depend on the market for the control reserves, while strategic reserve has a price range of 1000 to 2999,9 €/MWh.

### Estonia

In the last couple of years, Estonia has been intensely focused on the implementation of demand response. Although its wholesale markets are open to demand response, the explicit demand response participation is unclear and very limited. Since Estonia is connected to the IPS/UPS synchronous area, there is also no market for FRR and FCR. Furthermore, if demand response aggregators have a bidirectional contract with the consumer´s retailer, they will have access to the market, otherwise, they would not be able to participate [22].

The most important benefit of Estonian power system is related to the requirements for participating in demand response program, somehow the minimum bid size to enter to the market is 1 MW, which enables more providers to participate [22].

### Finland

Demand response in Finland has been considerably developed and, like in Denmark, FCR is divided into normal and disturbance operation (FCR-N and FCR-D, respectively). Since the beginning of 2017, the capabilities are established on 500 kW in FCR-N and 230 MW in FCR-D. Furthermore, FCR-D can be standard or on-off model. As for FRR, it is divided in automatic and manual (FRR-A and FRR-M, respectively), and since the beginning of 2017 has 100-300 MW in FRR-M, and none in FRR-A [18], [43].

The majority of the programs have high minimum capacity requirements (5-10 MW) except for FCR (100 kW in normal, and 1 MW in disturbance standard), in the intraday markets (Elbas - 100 kW), and in the day-ahead markets (Elspot – 100 kW) [44]. Regarding the period's duration, these are adjusted to the objective of the programs, and therefore must be something that consumers are prepared for and agree to [45]. Regarding the payments, only FCR-D on-off model and FRR-M consider both availability and utilization payments, while FCR-N and FCR-D standard consider only availability payments. The remaining programs consider only utilization payments and these are often obtained from marketplaces.

### France

France is considered an example in terms of demand response implementation in Europe, mainly due to the legislation that facilitates the inclusion of aggregators and consumers in energy markets [46], [47]. However, the requirements for participating in some programs are relatively high, namely, 10 MW, except for FCR and automatic FRR, 1 MW. As for payments, availability and utilization compensations are provided [18].

## Germany

Germany introduces interruptible load programs in 2013, and it considers the curtailment of significant loads connected to high or very high voltage levels. There are two programs: immediately interruptible (SOL) and quickly interruptible (SNL) [18]. The first amounts to 246 MW available while the latter to 648 MW. An important condition of these programs is that aggregators can only participate with a maximum of five loads, and with a minimum bid size of 50 MW. These conditions make it difficult for the aggregators to participate [48].

Regarding the control reserve programs, these all consider upward and downward regulation. In FRR, it is found two classes, normal and minute, both with a minimum of 5 MW, while in FCR, only 1 MW is required. In what concerns payments, FCR performs availability payment only, while FRR provides both availability and utilization.

## Great Britain

FCR firm frequency response and FRR are both divided into two classes, dynamic and non-dynamic, while RR short-term operating reserve is divided in committed and flexible, as illustrated in Figure 13.

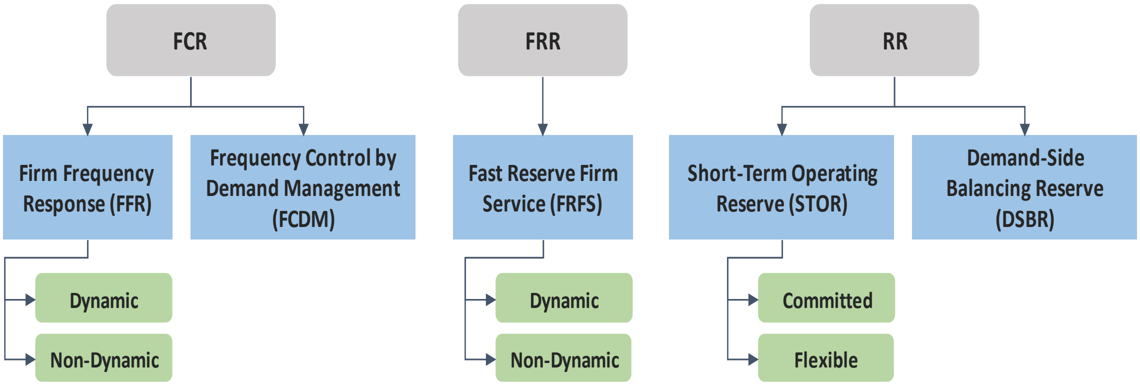


*Figure 13. British demand-side management programs.*

In the dynamic approach, the generation and consumption are modified automatically according to the frequency of the system [49]. In the non-dynamic approach, a predefined amount of energy is modified when frequency reaches a certain unwanted level. The minimum requirements in terms of capacity are more attractive in the tertiary reserves with 100 kW in DSBR, and 3 MW in STOR. In primary reserves, FCDM requires a minimum amount of 3 MW, while FFR has a high minimum capacity of 10 MW. An even higher minimum is required in secondary reserve, 50 MW to participate [18]. The programs that consider both the availability and utilization payments are STOR, FFR, and FRFS, while DSBR only considers utilization payments, and FCDM only considers availability [50]. Penalties for not compliance can consist of reductions in the payments and/or contract closures.

## Ireland

Ireland seems a little behind in the demand response trend with only two programs made available by the operators [51]. The interruptible load program is performed as a frequency control reserve, being activated when frequency drops below a certain value, having a minimum requirement of 4 MW [18]. The other demand response program defines dynamic pricing for the consumer in certain periods of the year, and strongly encourages aggregators to participate as demand-side units (DSU) [52]. Utilization payments are made in the interruptible load

programs and in the Powersave program (dynamic pricing for individuals) [53]. Aggregators receive availability payments only when using dynamic pricing to provide capacity provision.

## Italy

In Italy, load aggregation is not allowed, which makes difficult the entry of consumers in energy markets (minimum capacity requirement is high). In terms of demand response, only interruptible load programs and capacity markets exist, where the first differs between the mainland and the islands [54]. In the mainland, interruptible loads are divided into two categories, fast (3300 MW) and emergency (0 MW), while in the islands there is only fast (761 MW) [18]. The minimum capacity requirement for the interruptible loads program is 1 MW, both mainland and islands, and payments are made for availability and utilization. Penalties are applied when the consumer fails more than 3 requests, or the reduced load is less than 70% of what was contracted.

## Netherlands

Demand response programs are limited in some ways since aggregation is only allowed in manual FRR for reserve capacity and RR. Other than these, automatic FRR and manual FRR for emergency power are available for load participation. Except for emergency power FRR with 20 MW minimum capacity, the demand response programs require a 4 MW minimum capacity from consumers to participate [18]. Regarding payments, RR considers only utilization, and FRR provides both availability and utilization incentives in the cases of emergency power and regulating capacity. Penalties for non-compliance are harsh, reaching up to 10 times the payment value.

## Norway

The demand response programs in Norway involve several features in terms of primary, secondary, and tertiary control reserves, as described in Figure 14. RKOM is a marketplace that issues tenders for operation flexibility, and therefore, a place where consumers can participate on weekly, seasonal basis and in bilateral agreements [18], [55].

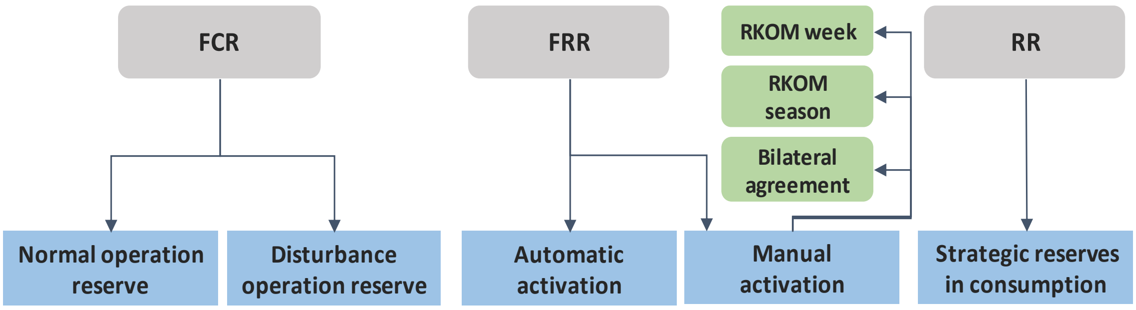


*Figure 14. Norwegian demand-side management programs.*

All the FCR programs and in automatic FRR, the minimum requirement to participate is 5 MW, while the remaining programs are 10 MW. Both requirements are difficult to meet by consumers that participate alone, however, it opens a path for the aggregator's integration. The balancing market is also open to consumers, individual or aggregated, and the strategic reserves (Energy Options) considers only the participation of individual consumers [56]. Payments in control reserves consider availability and utilization, and penalties are applied in case of failure to comply, namely, monetary compensations or payment cancellation, and public blacklisting.

## Poland

Demand response is implemented through emergency programs and balancing market, being also considered aggregated load possibility in both these programs [23], [57], [58]. The emergency program is defined through tenders where consumers can participate if they can provide a minimum of 10 MW in capacity. In the balancing market, consumers with a 1 MW of capacity can participate with their bids, however, other generation resources participate and extra incentives are not provided for the consumers. In both programs, payments are made only for utilization.

## Portugal

Demand response considers only interruptible load programs, with availability and utilization payments. In Table 4, it is presented the characteristics of the interruptible load programs and the several types that can be applied. Currently, the actual implementation of this program is lacking, with no activations made [59]. Since some consumers are enrolled (around 52), it is verified that no actual utilization is made in the several years that have been at play. This seems to describe the interruptible load program as an emergency-only solution for the system operator.

Minimum load reduction capacity is 4 MW, which limits the participation of smaller consumers (e.g. residential, small commercial), even more, when aggregation is not allowed as it is the case [23]. Payment methods are described in Portuguese legislation (decrees 592, 13416, and 1308 of 2010; 71, 268, and 310 of 2011; 200 of 2012; 215-A of 2013; and 221 of 2015), and in this way, are not easily readable by most of the consumers, therefore, demand response lacks promotion in the Portuguese scenario.

*Table 4. Portuguese interruptible load program characteristics.*

<table>
<tr><th>Type</th><th>Notice time (min)</th><th>Max. requests per week</th><th>Max. requests per day</th><th># of periods per request</th><th>Period duration (h)</th><th>Max. request duration (h)</th><th>Max. use (h/year)</th></tr>
<tr><td>1</td><td>120</td><td rowspan="5">5</td><td rowspan="5">1</td><td>3</td><td>4</td><td>12</td><td rowspan="5">120</td></tr>
<tr><td>2</td><td>120</td><td>2</td><td>4</td><td>8</td></tr>
<tr><td>3</td><td>60</td><td rowspan="3">1</td><td>3</td><td>3</td></tr>
<tr><td>4</td><td>5</td><td>2</td><td>2</td></tr>
<tr><td>5</td><td>0</td><td>1</td><td>1</td></tr>
</table>

The penalties for failure are related to the number of nonconformities made in the last twelve months of the amount requested:

- 1st time – monetary fine equal to 4 months of availability remuneration;
- 2nd time – monetary fine equal to 12 months of availability remuneration;
- More than 2 times – monetary fine equal to 12 months of availability remuneration, and cancellation of the contract with the consumer.

## Slovenia

In Slovenia, the aggregation is allowed, and all three reserves are possible for demand response participation. However, a limited number of accessible programs and small volumes of resources are considered as barriers for the participants to entire the market. The minimum aggregated bid size in Slovenia is 5 MW, and all aggregators have to submit a guarantee of 15.000 €/MW. Furthermore, all demand response providers are obligated to have 24/7

availability, and in the case of non-availability or non-deliverance of energy, there is a penalty of 4.000 €/MWh, which leads to most of the providers do not participate [22].

## Spain

In Spain, aggregation is not allowed, but individual loads can participate in interruptible load programs that, like Italy, differ in the mainland and islands [54]. The mainland interruptible load program considers 5 and 90 MW blocks, which can represent a barrier considering the latter. In the islands, the minimum to participate is 800 kW which represents an enabler [18], [23]. The capacity market is also open to consumers, however, there is a lack of participation possibly due to insufficient incentives or promotion. Payments consider both availability and utilization, and penalties are 100% and 120% of the availability price, islands and mainland, respectively.

## Sweden

Demand response in Sweden considers several programs. However, their participation is lacking, since FCR and automatic FRR is nonexistent. Although in the remaining programs exists 636 MW, there is still more potential to be achieved through flexible resources, even more, when aggregation is allowed in all programs [18], [23], [60]. Payments consider availability and utilization for the programs of FCR, automatic FRR, and strategic reserve, while in manual FRR only utilization is considered [61]. The program requirements are relatively low and easily accessed, i.e. 100 kW in normal FCR, 1 MW in disturbance FCR, 5 MW in automatic/manual FRR and strategic reserves, and finally, 10 MW in some cases of manual FRR and balancing the market.

## Switzerland

As France, Switzerland is one of the successful examples of demand response implementation, with total ancillary services market opening to consumers, individual or aggregated. The requirements to participate are relatively low and can be improved in FRR and RR, since the current minimum is 5 MW, while for FCR is 1 MW [62], [63]. Regarding payments, the FCR considers only availability while the remaining consider both availability and utilization. The penalties are often applied to balance responsible parties and can be from three to ten times the price defined in the bid.

## Private Companies

Private companies complement the implementation of demand response in energy markets, in a way that these propose attractive strategies and business models capable of reaching the consumer’s perception of electricity consumption. Table 5 presents some of the European aggregators, namely, Voltalis (France), Cybergrid (Austria), REstore (Belgium), SEAM Group (Finland), and finally, KiWi Power (United Kingdom). The present section details the activities of these aggregators and their key figures.

Voltalis is a demand-side aggregator, created in 2006, managing 500 MW of load distributed through 100 thousand members. Their solution involves the installation of a device in the consumer’s electric panel, that interacts with a central platform that monitors and controls the several controllable appliances of the consumer. In the central platform, consumption is optimized considering the local constraints, so that energy savings are maximized. Moreover, the energy reduced by the consumers is used by Voltalis in energy markets, namely, bid this energy to obtain revenue. The information coming from the consumer is treated by Voltalis

through Big Data or Data Mining techniques so that only relevant information is considered. Currently, Voltalis performs its activities only in national soil, France, having a feature that according to them is unique in the aggregator's environment: aggregation and synchronization modification of millions of appliances in real-time.

*Table 5. Examples of European aggregators.*

| ***Company*** | ***VOLTALIS*** | ***CYBERGRID*** | ***RESTORE*** | ***SEAM GROUP*** | ***KIWI POWER*** |
|---|---|---|---|---|---|
| ***Core Activity*** | Real-time demand response and energy management | Consulting and support for the implementation of Virtual Power Plants | Advance automated demand response and energy management | Energy optimization services | Demand response aggregator |
| ***Purpose of Flexibility*** | Negotiate flexibility on energy markets | Grid stability, negotiate in energy markets, and/or assets optimization for the client | Negotiate flexibility in ancillary services, capacity markets, and TSOs | Negotiate flexibility with "Fingrid" (Finnish TSO) | Negotiate flexibility in the energy markets and participate in demand response |
| ***Client Profile*** | Distributed generators, residential and commercial consumers | Network operators, utilities, retailers, and grid managers | Utilities, TSOs, commercial, and industrial | Large energy consumers | Large energy consumers, utilities and grid operators |
| ***Contracts with final client*** | Load shedding contracts | Purchase of optimization software and support in energy markets | Contract with consumers for curtailment a given number of times per year | Purchase of optimization software and support in energy markets | The contract for monitoring the consumer's action and provides management software |
| ***Technologies*** | Big data analysis and optimization | Resources management system | Cloud-based and energy management system | Cloud-based and automated DR software | Smart meters, automation controls, and monitoring |
| ***Client Benefit*** | Obtain energy savings and optimize consumption | Monitoring, forecasting, load aggregation (demand response execution) | Unlock demand response potential, obtain revenues from it, and energy savings | Obtain revenues from demand response, and energy savings | Obtain revenues and support for demand response activation, and energy savings |
| ***Comments*** | • Available only in France<br>• Around 100.000 members | • Scalable information and communications technology for virtual power plants<br>• Participating in several projects: Integrid, Flexiciency, Future Flow, etc. | • Multinational operation in several energy markets<br>• Always 545 out of 1500 MW available | • Available only in Finland<br>• Offers three strategies: load shifting, reserve, and curtailment | • Available only in the United Kingdom<br>• More than 650 members |

The utilities and energy suppliers do not see kindly the integration of aggregators (e.g. Voltalis). However, currently, these entities are working together, because Voltalis offers its clients the free installation of metering devices in their sites, optimizing their consumption and raising energy savings. This is made in exchange for the possibility of modifying load to enable participation in energy markets and there obtain revenue. For the utilities, the energy savings are monetary amounts that are not obtained, and thus it is possible to conclude that for the utilities, Voltalis reduces the business volume in energy supply.

Cybergrid was created in 2010 and focuses on the development of new solutions that can be integrated and improve the smart grid implementation, from an aggregator's perspective. The company outlines a path towards the virtual power plant concept (aggregated resources), with flexibility as the main feature. In the Cybergrid's scope, three benefits can be achieved from the virtual power plant's integration: participation in energy markets, support to the grid's operation

(stability, security, congestion, amongst others), and optimization of operation (energy savings, comfort consideration). The company's main product is "cyberNOC", which represents a flexible information and communication system on a second-by-second horizon, and collects measurement data, trying to obtain several important analyses (forecasting, optimization, aggregation of resources, energy market bidding, amongst others). Moreover, this company has been chosen to participate in several projects and pilots involving distributed energy resources and aggregators, namely, FutureFlow [64], Flexiciency [65], hybrid-VPP4DSO [66], evolvDSO [67], eBADGE [68], cyberPRICE [69], and EDRC [70].

This approach of Cybergrid towards the management of distributed energy resources, unlike Voltalis that deals directly with consumers, does not cause friction with the other entities (utilities, retailers, and operators) since the solution offered by Cybergrid intends to complement the activities of these entities allowing for a more efficient and even profitable operation. For instance, Cybergrid is participating in a project together with a distribution system operator from Portugal, Slovenia, and Sweden ("EDP Distribuição", "Elektro Ljubljana" and "Ellevio", respectively) and other entities of several fields, in the scope of Horizon 2020 research and development program.

REstore was created in 2010, introducing demand-side management solutions for commercial and industrial consumers, utilities, and transmission system operators in several countries. REstore has approximately 1500 MW of load that can be managed, which corresponds to a considerable capacity and negotiation leverage in energy markets. Important entities from different countries deal with this company, Elia (Belgian transmission system operator), Rte (French transmission operator), NationalGrid (UK's electricity and gas supplier), Total (French multinational oil, gas, and solar power), amongst others. REstore offers two kinds of solutions for demand-side management, namely, FlexPond™ for industries and utilities, and FlexTreo™ for energy managers. The company develops its activities in the following sectors: power utilities, petrochemicals, steel, pulp and paper, minerals and cement, non-ferrous metal, food and beverage, industrial gas, water treatment, glass, cold stores, and finally, commercial sector. In this way, the company does not offer solutions for the residential sector which has a high potential for demand response implementation.

REstore grew exponentially since its creation year, more specifically from 2013 to 2014, with a growth of revenue over 700 percent. The company seems like a future major flexibility aggregator due to its development and achieved awards for technological innovation. Since the company already is a multinational and is relatively close to several countries, it is expected that the number of clients (and thus load capacity) will increase in the following years.

SEAM Group is a major energy aggregator in Finland, contributing also for a better implementation of demand response programs offered by the system operators. SEAM identifies as the first Finnish company to provide energy optimization services, considering three types of demand response: shifting, curtailment, and adjustment. They were founded in 2011, as a subsidiary of Syncron Tech, and deal only with large energy consumers, providing solutions for energy savings and giving support to negotiate flexibility in energy markets and with the transmission system operator, Fingrid. In this way, SEAM acts as a promoter entity for the demand response programs made available by Fingrid, increasing thus the number of participants in them, which contributed for a positive analysis of demand response implementation made by the Smart Energy Demand Coalition (SEDC).

SEAM has not yet expanded to other countries, developing its activities only in Finland, which limits the load capacity and members that can adapt by their solutions. Moreover, more two aggregators can be found in Finland: There Corporation and Energia Kolmio. SEAM looks now

for the possibility of supporting smaller consumers instead of only industrial, enabling perhaps the potential that there exists.

KiWi Power is the leader of demand response aggregator in the UK, which taking account the several other companies that there exist, represents an important information about the quality and innovation that KiWi Power offers. Its activities are developed towards large energy consumers, utilities, and grid operators (e.g. Great Britain, Ireland), is the only one offering grid balance services. In a similar way as REstore, the KiWi Power won several awards in energy management-related competitions, although also is older (created in 2009). Regarding demand-side management programs, KiWi Power offers four: frequency response; capacity reserve services; network constraint management; energy intelligence and smart metering. The company defines three stages to implement their solution for the consumers.

Firstly, the KiWi Power evaluates the consumer's site characteristics and potential of which then a contract proposal is made to the consumer. Secondly, the equipment is installed by the company, providing the necessary automation and monitoring for the implementation of demand response programs evaluated before. Also, consumer awareness is promoted through the company which provides expert staff to train the consumers. Finally, in the last stage, KiWi Power registers the site into their portfolio and starts to perform the management of energy consumption, with a special focus on their participation in energy markets. In another topic, KiWi Power is bidding on a residential implementation of their programs, since the company has been commissioned by the London's mayor to develop a smart meter mobile application.

In a complementary analysis of the number of relevant aggregators that are currently operating in the European Union and their creation year, Figure 15 is presented. The aggregators deployment number is balanced after 2009 and before 2010, 44% and 56%, respectively. However, if considering the number of years into account, it is possible to see that 11 companies have been created between 2010 and 2017 (seven years), and 14 companies were created between 1995 and 2009 (fifteen years). Thus, a more significant appearance of aggregators has been noticed since 2009 beyond until now, from the ones considered.

It is important to notice that EnerNOC is an American company that joined the European environment, through the acquirement of European companies (e.g. Entelios AG, Activation Energy). This is related to the saturation of the American market, that pushes the aggregator companies towards other markets to continue to grow as a major power in demand response implementation. This shows how an American aggregator can enter the European markets, easily through the purchase of an already established and successful European aggregators.

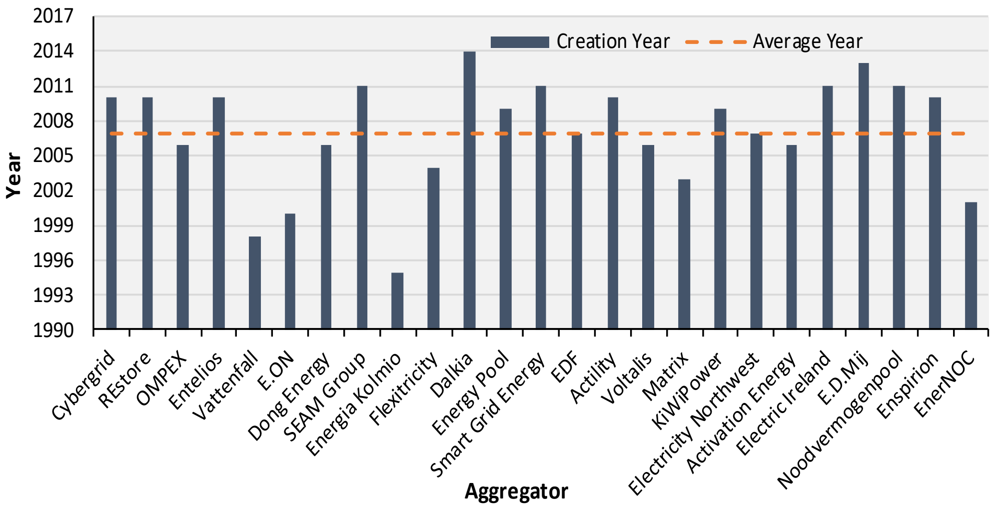


*Figure 15. The appearance of aggregators in Europe across the years.*

### Public-Private Partnerships

Public-Private Partnerships (PPPs) represent business opportunities where private and public partners cooperate in the development of a mutual benefit project. With this definition, it comes to sight a prospect to considerably promote demand response and smart grid implementation [71]. Also, according to [71], 71% of the smart grid survey respondents distinguish public-private partnerships as the path that will allow for a more rapid and efficient implementation of smart grid infrastructures.

An important contribution of the private sector is the proposal of sustainable and efficient business models which may not always exist in the public sector. This is a relevant feature, which is the basis of a successful demand response implementation, since it promotes the participation of consumers, while the demand response organizing entities obtain profit from their operation. Moreover, the parity between adequate business models and innovative and flexible technology, inserted on an appropriate legislation framework, guarantees that consumer engagement and awareness are fully achieved.

In Europe, Energy-Efficient Buildings Public Private Partnership (EeB PPP) is one of the initiatives that intend to promote strategies for the reduction of energy consumption and related carbon footprint in buildings. This partnership led to a potential of 34.8% average consumption reduction, over an average number of innovations equal to 4.3 over 127 projects. Most European PPPs are related to research and development projects, usually associated with the implementation of innovative technologies. For example, as mentioned before, the aggregator KiWi Power has a common project with the London's mayor to develop a residential smart meter application for mobile. Although it is not an official PPP, the outcome and project structure are similar to what is a PPP's concept.

## *5.2. United States*

Regarding distributed generation integration by the US, hydropower is the main renewable source with 48%, followed by wind with 34%, however, the share of renewable energy sources in the final energy mix of 2014, was 13%. In this year, coal was the most used resource, supplying near 39% of the country's electricity requirements. In this way, the US has three types of promotion strategies to assure the growth of renewable sources, as follows [50]:

- *Financial incentives* – a federal incentive is proposed to encourage the use of renewable sources. Also, financial incentives, such as grants, loans, and tax credits will be given;
- *Targets* – since May 2015, 29 states and the District of Columbia have implemented Renewable Portfolio Standards (RPS). These obligate suppliers to provide a share of their services from renewable sources;
- *Markets* – Renewable Energy Certificates/Credits (RECs) allow residential consumers and businesses to pay for a renewable generation without the need for physical or contractual delivery of electricity generated from qualifying renewable energy sources.

The US have remarkably developed DR resources and programs to a point where adequate solutions are available for demand resources at several levels (e.g. wholesale, retail, balancing, and others). Whereas Europe is initiating its path for DR with some successful projects, the US has already provided sufficient tools for the appropriate DR implementation, having a presence across the country. The ISO/RTOs allow a more reliable network operation since the use of these entities makes each region seem as another independent system. The ISO/RTO entities ensure (in resemblance with the TSO) the correct transmission of energy throughout their perimeter.

Demand response programs in the US consider several approaches to emergency situations, and the use of demand resources for ancillary services management – frequency and voltage regulation, and system balancing (e.g. ERCOT, ISO-NE, and NYISO). Regarding their market

integration, the most are available through bid presentation – in a similar way to Europe. In this way, the existence of ISOs, allow this situation to be simpler, enabling the consumers to contact directly with these entities that, on most occasions, are the DR event organizers. As one can see by Figure 16, currently it exists more implemented DR programs of type "Load Controlled" meaning, programs where the activation of flexibility is determined by the system. Also, market participation has a considerable amount of DR participants, such as capacity resources, being the negotiators of the wholesale market the major slice.

Residential consumers seem to be initiating successfully their implementation into energy markets, with a significant amount of DLC programs being applied in this kind of consumers. DR programs based on tariffs (price-based), are still not very attractive for any type of consumer in specific, predicting a future incentive research to determine if this type of DR program can grow substantially. Advance notification times are usually large (from the day before to several months in advance), while ramp times are small (rarely above two hours). The duration of the programs is very varied, large and small sustained responses considering also the bids presented (e.g. MISO and PJM).

The activation of these programs is mainly manual since the most of them use messages (email, phone, notification, and others) to communicate and order requests from consumers (e.g. ERCOT, and ISO-NE). Having this in mind, penalties for failure currently implemented, involve the consumers and their representative entities (aggregators, DR providers, Load Serving Entities (LSE), amongst others). These penalties include the payment of costs caused by the failure to participate as accorded, termination of the contract, complain by the Public Utility Commission (manages and verifies service contracts that the operators acquire), payment cancellation, amongst others. These vary between the several existing ISOs. Although DR is well developed, either in terms of individual or aggregate participation in energy markets, the US has not yet focused enough on the improvement of their physical energy infrastructure and supply features, namely, the lack of renewable sources and the on-going centralized operation. The discussion about either continue to improve DR or redirect efforts for DG, should be considered in a near future. Table 6 shows the capacity of demand response participants in US ISO and RTO.

Looking at what the US has accomplished so far, one can tell that the programs are already available, as well as the tools to provide consumers with technical (guides, courses, tutorial lessons) and commercial (informatics tools to support a better understanding) knowledge about their participation/integration.

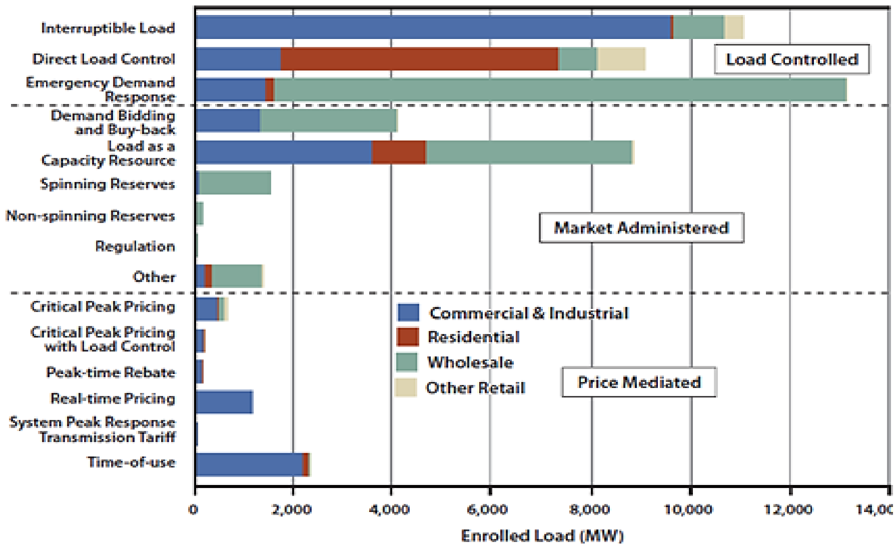


*Figure 16. DR programs in the US, considering type and implementation in 2011* [72].

*Table 6. Comparing demand response capacity in US ISO and RTO* [73].

| ***RTO/ISO*** | ***2015*** | | ***2016*** | |
|---|---|---|---|---|
| | Demand Resources (MW) | Percent of Peak Demand | Demand Resources (MW) | Percent of Peak Demand |
| California ISO (CAISO) | 2,160 | 4.4% | 1,997 | 4.3% |
| Electric Reliability Council of Texas (ERCOT) | 2,100 | 3.0% | 2,253 | 2.9% |
| ISO New England (ISO-NE) | 2,696 | 11.0% | 2,599 | 10.2% |
| Midcontinent Independent System Operator (MISO) | 10,563 | 8.8% | 10,721 | 8.9% |
| New York Independent System Operator (NYISO) | 1,325 | 4.3% | 1,267 | 3.9% |
| PJM Interconnection (PJM) | 12,866 | 9.0% | 9,836 | 6.5% |
| Southwest Power Pool (SPP) | 0 | 0% | 0 | 0% |
| **Total ISO/RTO** | **31,710** | **6.6%** | **28,673** | **5.7%** |

In the following sub-chapters, the major ISO and RTO entities mentioned before are detailed in terms of their DR integration and schemes for active consumers, namely, the programs currently implemented. The entities considered are: CAISO, ERCOT, ISO-NE, MISO, NYISO, PJM, and SPP.

## CAISO

CAISO is the independent system operator for the state of California, allowing consumer participation in DR programs, directly or as an aggregate. Aggregators, also called Demand Response Service Providers (DRPs), can participate in the day-ahead, real-time and ancillary services markets, both DR programs presented in Table 7. In any of the situations, negotiate directly or through an aggregator, it is needed a scheduling coordinator (doing a certification process, aggregators can become scheduling coordinators). Consumers that want to participate directly with the CAISO, need to become demand service providers, also requires a certified scheduling coordinator to communicate with the CAISO and to perform the bids in the energy markets. After this, a proxy demand resource agreement is made between the consumer and the CAISO. In order for consumers to participate in DR programs, the CAISO defines two types of applications for consumers [74]:

- *Demand Response Registration System (DRRS)* – enables direct and aggregate interaction with the CAISO, considering also an Application Program Interface (API) that allows data storage of consumer's participation;
- *Demand Response System (DRS)* – allows consumers to be automatically managed by the DRS computing, based on the metering data, a demand response energy measurement for both DR programs offered by the CAISO.

Both programs have an advance notification time of 1 p.m. of the day before, when in day-ahead market, and when in real-time market, this time is not considered, having only the ramp time of the resource. This participation of consumers comes with an associated cost, related to the installation of adequate equipment for bidding and certification. Telemetry is needed for consumers participating in DR programs when capacity is greater than 10 MW. The CAISO DR programs list is presented in Table 7, with their characteristics. In the DR programs considered, there are two units that need access to the consumer's information about flexibility, such as the Load Serving Entity (LSE, often is the Scheduling Coordinator to have this role) and the Utility Distribution Company (UDC).

*Table 7. CAISO demand response programs* [74][75].

| Program | Conditions |
|---|---|
| ***Proxy Demand Resource (PDR)*** | • Consumer/aggregator must have a minimum flexibility capacity of 0.1 MW when participating in the day-ahead and real-time energy market<br>• 0.5 MW, in the day-ahead and real-time energy non-spinning reserve market<br>• Aggregation is possible, with the same conditions as individually<br>• Can bid into the day-ahead and real-time non-spinning reserve markets<br>• Can bid in the 5-minutes real-time energy market |
| ***Reliability Demand Response Resource (RDRR)*** | • The consumer must have a minimum flexibility capacity of 0.5 MW<br>• Ramp time is 40 minutes<br>• Minimum event duration of 1 hour, to a maximum of 4 hours<br>• Load curtailment in discrete steps, i.e. full capacity or not any (max. 50 MW)<br>• Cannot self-provide ancillary services nor ancillary services bids<br>• Cannot<br>• Can participate in ISO for responding to a reliability event for the delivery of "reliability energy" in real-time<br>• Can participate in ISO for day-ahead market |

## ERCOT

ERCOT has several DR programs available for consumers, where ones are managed by the operator ERCOT, and others are managed by the Transmission and Distribution Service Providers (TDSPs). However, ERCOT has been allowed to, if needed, apply the resources from TDSPs programs. The following considers the DR programs of ERCOT, where all are without advance time [76], [77]:

**Dispatched by ERCOT:**

- Load Resources
  - Ancillary Services
  - Security Constrained Economic Dispatch (SCED)
  - Fast Responding Regulation Service (FRRS)
- Emergency Response Service (ERS)

**Non-Dispatched by ERCOT:**

- TDSPs Load Management Programs
- Four Coincident Peak (4CP) Load Reduction
- Price Responsive Demand Response Products
  - Block & Index (B&I)
  - Peak Time Rebate (PTR)
  - Non-Opt-In Entities (NOIEs) Load Control

Programs dispatched by the ERCOT means that ERCOT chooses when the programs are to be applied, instead of the consumers or aggregators (named demand response providers). In this way, the programs dispatched by ERCOT are based on the security and reliability of the network operations, while the non-dispatched programs by ERCOT are more focused on the energy tariffs and schedule. Just for ancillary services, ERCOT has more than 3 GW of capacity. This market is composed by load resources (loads with capacity flexibility, similar to a generator), offering several regulations and balancing advantages on daily basis auctions. In ancillary services, there are four inside programs:

- <u>*Responsive Reserves*</u> – when the amount needed is less than or equal to 50%, a 10-minute manual response is required, to an instruction from the ERCOT – due to frequency drops. When more than 50%, SCED is activated, with a ramp time of 5 minutes;

- *Regulation Up/Down* – in this program, loads are controlled automatically by automated generation control (AGC);
- *Non-Spin Reserves* – equal to responsive reserves greater than 50%.

*FRRS* is applied in the regulation market with fast-acting demand response resources. However, this program has not yet achieved great results, since participation is low. *ERS* has been implemented since 2007 using interruptible loads that would require, the consumer to make available its capacity in a maximum of 10/30 minutes. Participation in this program can be performed individually or in an aggregate form [77], [78].

*TDSPs Load Management* programs imply the use of monetary incentives in attracting consumers to reduce their consumption, to maintain network veracity. These programs were implemented to TDSPs comply with the state rules, that define a minimum share of energy saving in its growth.

*4CP Load Reduction* program defines that the consumers can reduce their energy transmission costs by curtailing load during energy peaks, in the months of June to September. The transmission charges to consumers are computed according to the consumption in peak times, therefore, the higher the consumption in peak periods, higher will the transmission charges be. This is mostly concerned with industrial consumers.

*Price Responsive* programs are related to the consumer's interaction towards aggregators (DR providers or Retail Electric Provider - REP). The programs use dynamic pricing (i.e. CPP, TOU, RTP, and B&I) and can be voluntary or mandatory, and the ramp times may not exist (immediate activation – automatic curtailment). The programs consist of price signals sent by aggregators to consumers, enabling energy costs reduction. More information can be found in ERCOT DR attributes file, present in [76], [79].

### ISO-NE

New England ISO also proves to have achieved successful DR integration, with their participation in wholesale markets – energy, ancillary services, and capacity markets. Four programs are considered [80]–[82]:

- *On-Peak* – this DR program provides load reductions during certain hours, when the consumption is at its highest, as follows:
  - *Summer On* – Peak Hours (for June, July, and August): 1 to 5 p.m., non-holiday weekdays – defined in the contract;
  - *Winter On* – Peak Hours (for December and January): 5 to 7 p.m., non-holiday weekdays – defined in the contract;
- *Seasonal Peak* – it is equal to the On-Peak program, however, the hours are not considered, being activated whenever real-time consumption is equal to or greater than 90% of the critical exceeding load value. Without advance notification time;
- *Real-Time Demand Response (RTDR)* – presents a demand bidding program for consumers, with a min. reduction capacity of 100 kW – advance notification time at 4 p.m. of the day before, when in the day-ahead market, and 30 minutes before the event, in the real-time market;
- *Real-Time Emergency Generation (RTEG)* – this DR program makes use of consumers with behind-the-meter generation, allowing immediate reductions of their load, with the introduction of own-generation instead of network supply. Consumers receive a dispatch instruction between 7 a.m. and 7 p.m. of non-holiday weekdays that must be accomplished within 30 minutes. Maximum capacity from DR resources is 600 MW. Has an advance notification time of 30 minutes, in the real-time market.

## MISO

MISO is in the central area of the US, surrounded by major entities such as PJM and SERC. In the MISO, DR programs can participate in the Energy (day-ahead), Operating (real-time), Regulation (ancillary services) and emergency (real-time) reserve markets. According to [83] and [84], there are five types of DR programs available in the MISO (described below). All programs, except for EDR and LMR, have an advance time notification of 4 p.m. of the day before – day-ahead market.

- *Demand Response Resource (DRR)*
    - Type I – interruptible load resource, managed by an LSE that allows participation into the energy and operating reserve markets;
    - Type II – flexible load resource, managed by an LSE that allows participation into the energy and operating reserve markets, as a controllable load.
- *Load Modifying Resource (LMR)*
    - Demand Resource (DR) – *flexible resources that can participate in emergencies, as interruptible load or Direct Load Control (DLC);*
    - Behind-The-Meter Generation (BTMG) – this type of program is destined for consumers that have generation such as, diesel generators, enabling it during emergencies [85].
- *Emergency Demand Response (EDR)*

These DR programs are usually used under emergency conditions, namely, when the network reliability is at risk. In these situations, and in resource planning, LMR, DR, and BTMG are obligated to participate when requested. DRR Type I can participate in the energy and operational reserve, while Type II can participate additionally in regulation. While the DRR resources are characterized by performing support tasks for balancing (e.g. Operation and regulation reserve) and network decongestion (e.g. energy capacity), the LMR resources are categorized only for emergency situations or for long-term planning under the supervision of the MISO. EDR is for emergency situations only. These programs, although in different contexts, can dynamically change, as DRR can become LMR, and LMR can become EDR. The resources remuneration in these programs context are determined by Locational Marginal Prices (LMPs) that depend on the region where the consumer is located, for DRR and LMR resources, while for EDR the prices are defined by the MISO bid plus additional costs (e.g. start-up/shut down costs) produced by the emergency request.

## NYISO

NYISO allows consumers to participate in four types of DR programs, differing on the conditions of participation and types of consumers, as shown in Table 8 [86], [87], [88], [89]. Four programs have been available for consumers since 2008. Curtailment service providers (CSPs) are needed, for consumers to be able to participate in the DR programs since this entity makes the connection between the consumers and the NYISO. In this way, for the NYISO, the programs are in two ways [87], by the bullets:

- Reliability-based – the NYISO determines the activation, such is the case for EDR and SCR programs;
- Economic-based – resources choose when to participate, such is the case for DADR and DSAS programs.

Aggregation, named grouped by zone, is possible in all DR programs, except for EDR. These allow consumers with less capacity to still participate in the energy markets. The following bullets present the market availability for each type of DR program:

- *EDR* – wholesale (real-time) and capacity
- *SCR* – wholesale (real-time), bilateral contracts and capacity
- *DADR* – wholesale (day-ahead)
- *DSAS* – ancillary services (spinning and regulation)

The NYISO also has available, in the archive, the number of activations and tests made to demand resources over the years, at [90].

*Table 8. NYISO demand response programs*

<table>
<tr><th>Program</th><th>Min. Flexibility (MW)</th><th>Advance Time</th><th>Ramp Time</th><th>Details</th></tr>
<tr><td>Emergency Demand Response (EDR)</td><td rowspan="2">0.1</td><td rowspan="2">Day-Ahead advisory</td><td rowspan="2">2 hours</td><td rowspan="2">• Used for energy shortage/reliability risk conditions<br>• Usually performed by commercial and industrial consumers<br>• Consumers are paid by the NYISO when requested<br>• EDR is manual voluntary, while SCR is manual mandatory to participate since the payment is in advance<br>• EDR only is possible through the interaction with a Curtailment Service Provider, while the SCR needs a Responsible Interface Party<br>• One consumer cannot participate in both programs at the same time<br>• EDR minimum payment is 500$/MWh<br>• Both have a 4-hour minimum for event duration<br>• Metering is hourly interval meter<br>• Penalties may be applied<br>• There is no limit for the number of calls</td></tr>
<tr><td>Special Case Resource (SCR)</td></tr>
<tr><td>Day-Ahead Demand Response (DADR)</td><td rowspan="2">1</td><td>Day-ahead by 11h00</td><td>-</td><td>• Enabled by demand reduction bids in the day-ahead market<br>• Payment at the market clearing price<br>• Minimum payment of 75$/MWh<br>• Activation based on bid<br>• Metering is hourly interval meter<br>• Penalties may be applied<br>• Market participant decides when to make load reduction available to the market</td></tr>
<tr><td>Demand Side Ancillary Services (DSAS)</td><td>Day-ahead by 11h00 or in 75 minutes for real-time</td><td>Immediate/ 10/30 minutes</td><td>• Oriented for small consumers, is based on real-time bids (telemetry) for load curtailment, for operating reserve and regulation markets.<br>• Minimum payment of 75$/MWh<br>• Activation based on bid<br>• Metering is in real-time<br>• Penalties may be applied<br>• Market participant decides when to make load reduction available to the market</td></tr>
</table>

## PJM

Consumers cannot participate directly in DR programs with the PJM. In order to participate, a Curtailment Service Provider (CSP) is needed to perform the interaction between the consumers and the PJM. CSPs can also provide aggregation in a similar way to an independent aggregator. The available programs for DR integration are shown in Table 9. In the PJM

Interconnection, the DR programs have a voluntary basis, however, certain requirements are needed to enable participation. DR [91], [92]:

- CSPs agents (consumers) have to perform an initial training module, available at the PJM page (www.pjm.com), before being able to be represented by the CSP and, consequently, participate in the available DR programs;
- Annually, consumers must review a short training module on the requirements, business rules of the regulation, synchronized reserve markets, and PJM All-Call responses.

The CSP, being a sort of aggregator, can provide valuable services to the consumers managed by it, namely, assistance on the equipment and system architecture needed by the consumer to economically benefit from the DR programs. Considering that currently, the wholesale market is open to DR through day-ahead and real-time, two types of initiatives are presented to the consumer [93]:

- *Day-Ahead* – the consumers can offer, with the help of the CSP, bids into the day-ahead wholesale market considering a certain amount of reduction, to the PJM (subject to acceptance);
- *Real-time* – the CSP provides the consumers useful information about actual energy prices, suggesting reduction at the appropriate times, which consumers may choose voluntarily to participate or not.

As other energy entities in the US, PJM presents an emergency program that consumers can participate. This is a voluntary program that proposes the reduction of consumption in emergency conditions (e.g. network reliability at risk, lack of generation) receiving afterward a payment according to to the emergency market. Regarding the Capacity market, DR resources can participate by acting as spinning reserves making flexibility available when needed. This capacity operates in three years-ahead auctions, with CSPs helping consumers to present bids concerning demand reduction. The bids are of 3 types [94]:

- *Limited product* – maximum of 10 activations during the summer months, during emergency situations (up to 6 hours of duration);
- *Extended product* – unlimited number of interruptions during the months of May until October (up to 10 hours of duration);
- *Annual product* – unlimited number of interruptions during June until May of the following year (up to 10 hours of duration).

CSPs can present demand reduction bids into the Synchronized Reserve, Regulation and Day-Ahead Scheduling Reserves markets [94].

- *Synchronized Reserve* – respond to a reduction request in 10 minutes;
- *Day-Ahead Scheduling Reserves* – respond to a reduction request within 30 minutes;
- *Regulation* – enables frequency response to PJM signals.

Currently, consumers cannot participate in the retail market, however, efforts are in play to include small consumers (residential mainly) in the DR programs portfolio. In this way, without the retail market possibility, PJM has presently available 12.314 MW [93].

In PJM markets, demand response participants have a wide variety, which provides different measures to reduce load, as Figure 17–A shows. Furthermore, load reductions from those participants are primarily implemented by running a behind-the-meter generator, and then other resources are involved (Figure 17–B).

*Table 9. PJM demand response programs*

| Program | Min. size (MW) | Advance Time | Ramp Time | Details |
|---|---|---|---|---|
| ***Economic Load Response*** | 0,1 | Up to 2 hours | 30 minutes | • Can be used for energy, synchronized, regulation, and day-ahead scheduling reserves with distinct ramp times<br>• Operation conditions are determined by the bid restrictions |
| ***Emergency Load Response*** | | | 1 or 2 hours | • Activation depends upon network conditions and proposed offers |
| ***Full Emergency Load Response*** | | | | • Uses the 3 bid types, mentioned above<br>• Is used together with a reliability analysis |


*Figure 17. Demand response implementation of PJM markets in 2015/16; (A) Capacity capability by different sectors, (B) Customers load reduction methods* [95].

## SPP

The Southwest Power Pool considers the integration of DR resources into their energy infrastructure, namely, wholesale and retail markets. In this case, retail markets are the most developed offering several possibilities of DR participation through internal and external entities, as consumer service utilities (e.g. cooperatives, DR providers, investor-own utilities, etc.).

At the level of the wholesale market, SPP only allows for one DR program, namely Variable Dispatch DR (VDDR), inspired by the DR Type II controllable loads program of the MISO, mentioned above. Besides this program, SPP has not yet developed DR potential extensively in its wholesale energy infrastructure. SPP also has a program named Demand Resource Load, which has a 5-minute advance notification time, ramp time and response duration.

- *VDDR* **–** this program is based on the behind-the-meter generation type, which defines that the consumer has flexibility capacity due to the ability of own-production. The program requires an advance notification time of 5 minutes, needing therefore quick ramp up/down durations (10 minutes for reserve, and 4 seconds for regulation). This program can be sustained up to 1 hour.

Regarding the retail markets, the main DR implementation is using interruptible loads, however, Direct Load Control (DLC), Dynamic Pricing, and economic programs are made available through consumer service utilities.

## Private Companies

In a similar way to what has been done for Europe, some of the aggregators operating in the US are presented and analyzed through Table 10: EnerNOC, Comverge, CPower, Enbala, and AutoGrid.

EnerNOC is by far one of the largest demand response providers in the world, reaching an amount of 27 GW of load under management. Moreover, with the purchase of several companies related to this activity (becoming subsidiaries), the company has grown considerably in capacity and in the number of markets that it participates. The company offers two kinds of products: for businesses (energy intelligence software, energy procurement, demand response, professional services) and or utilities (demand response and wholesale procurement). In terms of the businesses solutions, these are developed according to the consumer's characteristics with the objective of obtaining energy savings and maximizing profitability taking into consideration the consumer's comfort. Regarding utilities, the company supports these entities in the implementation of demand response programs and consumer engagement, increasing the chances of success. Additionally, behavior data is also considered so that not only incentive-based programs but also price-based programs are implemented.

Amongst the clients of EnerNOC, one can find several major businesses that reveals demand response potentials, such as General Motors, Midwest Energy, MGM industries, and more. This portfolio of consumers and utilities provides a high elevate statute company, is considered the world leader in terms of non-residential demand response.

Comverge, created in 1980, is also one of the most successful cases of demand response company in the US that, according to Navigant Research, is above EnerNOC in terms of competitive offers for demand response implementation. Comverge offers four types of demand response, namely, load control, dynamic pricing, optimization, and bring your own device. The first outlines a normal direct load control program that load-serving entities can use to obtain a high and aggregated peak load. The second program considers time-varying prices that is the consumer's behavior modeled, which can provide important reductions at periods when the price is high or other adverse situations.

CPower, created in 2014, offers a real-time monitoring and advisement system that enables the participation of consumers in several energy markets and promotes the benefits of automated demand response implementation in their solutions. Since it is a relatively young company with only 3 years, it has grown considerably, mainly because of their capacity of participating in the open energy markets of CAISO, NYISO, PJM, MISO, ERCOT, and ISO-NE.

Enbala, created in 2003, operates and provides solutions to several entities, namely, utilities, grid operators, energy service providers, and energy consumers. Except for energy consumers, the solution presented by Enbala is related to the management of distributed energy resources, and their participation in energy markets. The tools provided by the company involve monitoring, optimization, aggregation and control of the resources considered. In terms of energy consumers, the company implements smart buildings strategies and control, to reduce the energy consumption (improve efficiency), raise energy savings, and obtain revenue from demand response and energy market participation.

AutoGrid was created in 2011 at the Stanford University, built of several types of expertise, mainly regarding software development, data analysis, and energy. The company, in a similar way to Enbala, develops software tools for utilities, energy service providers, and energy developers, focused on the aggregator's roles towards distributed energy resources as follows: management optimization, monitoring and control, aggregation, and energy market participation. In this way, although consumers are directly approached by AutoGrid, the company has developed solutions to promote demand response in the scope of residential and other consumers (including also resources owned by the consumer, such as PV panels). The company counts on major important partners that support the development of the necessary

hardware to complement with the advanced software developed (e.g. Honeywell, Microsoft, Schneider Electric, amongst others). In this way, although AutoGrid has every condition and tools needed to be an aggregator of resources, the main activity of the company is to provide these services to other load-serving entities rather than become itself this type of entity.

*Table 10. Examples of North-American aggregators.*

| Company | ENERNOC | COMVERGE | CPower | Enbala | AutoGrid |
|---|---|---|---|---|---|
| **Core Activity** | Energy intelligence software, demand response, and energy procurement | Demand response program implementation and energy awareness | Optimization of energy management through demand-side management | Aggregate, control, optimize and dispatch energy from distributed resources | Development of aggregator tools for utilities to deal with distributed energy resources |
| **Purpose of Flexibility to Aggregator** | Analysis of solutions for power systems operation and market negotiation | Promotion of demand-side management strategies | Participation in the system operator demand response programs | Negotiate flexibility in energy markets, provide decision support and counseling | Management of distributed resources and their participation in energy markets |
| **Client Profile** | Utilities and businesses | Investor-owned and public utilities, cooperatives and retailers | Commercial and industrial consumers | Utilities, grid operators, energy service providers, and consumers | Utilities, energy service providers, and energy developers |
| **Contracts with final client** | Support on demand response solution, and software acquisition | Software to support the unveiling of demand response opportunities from the utility's view | Contract where support and remuneration is given to the consumer in terms of demand response programs participation | Offers a distributed energy resources management software for utilities, and provide smart building control for all types of resources | The contract for flexibility management, energy market negotiation and the participation of consumers in demand response programs |
| **Technologies** | Decision support and energy management intelligent software | Develops with the client the most adequate demand response programs to apply to consumers | Definition of demand response strategy for each consumer | Management tool for distributed energy resources | Optimization, management, control, and aggregation software |
| **Client Benefit** | The intelligent decision, monitoring, and analysis of demand response potential and implementation | Facilitated entry of demand response programs to the end-users and profit from it | Obtain revenue from demand response and energy savings | Support for the consumer's engagement and balancing services Unveil demand response potential and obtain revenues and energy savings | Facilitated distributed resources management in real-time or another horizon, focusing on Virtual Power Plant concept |
| **Comments** | • Multinational operation in several energy markets<br>• Bought leading European demand response provider, Entelios | • Collaboration with more than 500 leading utilities<br>• Three tools are offered: IntelliSOURCE-Customer, IntelliMARKET, and IntelliMEASURE | • Works in the national open energy markets: CAISO, NYISO, PJM, MISO, ERCOT, and ISO-NE)<br>• Have over 1000 clients enrolled | • Tools: regulation service, voltage and peak demand management, fast demand response, contingency reserve, and renewable firming<br>• The capacity of 45 MW (matches to 1052 resources) | • Around 2 GW of distributed energy resources under control<br>• Three major tools are proposed: DROMS™, DERMS™, and VPP™ |

In terms of consumer solutions, the company proposes four types of residential demand response: BYOT (Bring Your Own Things), behavioral/pricing, direct load control, and the community. In the first program, it is considered a plug n' play solution complemented with

AutoGrid DROMS™ that eases the management of appliances through smart thermostats, intelligent appliances, demand response events, amongst others. In the second program, also complemented with AutoGrid DROMS™, dynamic pricing is considered to incentive the consumer to reduce its electricity costs (e.g. Critical Peak Pricing, Time-of-Use) gaining awareness towards its own consumption. In the third program, complemented with AutoGrid DROMS™, utilities can directly control consumer's loads in exchange for a monetary incentive or other benefits. The fourth program considers a competitive approach that is based on the management of a consumer community, taking into account a higher involvement of consumers in demand response programs raising their awareness.

### Public-Private Partnerships

The importance of public-private partnerships in Europe has been addressed before. The same analysis is now performed for the US in terms of implementations examples.

The Smart Grid Interoperability Panel (SGIP), created by the National Institute of Standards and Technology (NIST), is a public-private partnership to fast-track the development of standards regarding smart grid operation and focuses on four main fields: distributed energy resources management, internet of things, cybersecurity, and standards & interoperability. For instance, the recently publication of the standard 201P by SGIP, the National Electrical Manufacturers Association (NEMA), and American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), provides a model for the management of loads, generators, meters, and energy managers that enables the implementation of several determinant concepts (e.g. demand response, peak demand management, direct load control) [96].

In [97], it is shown an example of how demand response aggregators (NuEnergen) and public organizations (U.S. General Services Administration's Northeast and Caribbean region) can perform a symbiotic partnership that achieves a higher goal. Moreover, the public organizations have received over 79000 dollars from the aggregator, for their participation in demand response programs that the NYISO offers.

In sum, public-private partnerships can improve the development and implementation of demand response in energy systems. This is achieved by providing a mutual benefit link between the partners involved, namely, a desire to grow in terms of control, efficiency, and productivity from the private sector, while the public sector ensures a huge implementation of the strategies defined considering the related regulation.

# 6. Developed demand response approaches

There are several approaches and advancement on the demand response program implementation developed in the scope of DREAM-GO H2020 project. A majority of the proposed works are focused on the remuneration methods, mathematical modeling, cost optimization, and real-time simulation of the demand response concepts. Table 11 provides a complete list of published papers with their main topics.

*Table 11. Scientific published papers in the scope of DREAM-GO H2020 project.*

| References | Achievements |
|---|---|
| [98], [99], [100], [101], [102] | Proposing remuneration methods, demand response aggregation, and scheduling approaches |
| [103] | Focusing on different remuneration approaches for demand response programs from network operator standpoint |
| [104], [105], [106] | Proposing an aggregator model for small-scale resources to be aggregated and participated in demand response programs |
| [107], [108], [109], [110], [111] | Resource scheduling, aggregation, and remuneration-based model by a Virtual Power Player (VPP) |
| [112] | Focusing on dynamic retail sales price by an energy provider considering price-based demand response |
| [113] | Proposing a real-time simulation model for demand response implementation by a curtailment service provider |
| [114], [115], [116] | Microgrid demonstration gateway for direct load control programs |
| [117] | Focusing on smart meters technologies for demand response management in a microgrid |
| [118] | Direct load control program for air conditioners in an office building |
| [119], [120] | Presenting several incentive-based and fixed-cost tariffs for demand response remuneration |
| [121], [122] | A review of energy policies regarding distributed energy resources and demand response programs in European electricity markets |
| [123] | Technical comparison of implemented demand response programs in North American electricity markets |
| [124], [125] | Presenting business models for electric vehicles demand response programs |
| [126] | Optimization-based aggregator model for plug-in electric vehicle |
| [127] | Evaluating and analyzing of price-based and incentive-based demand response programs implementation in Portugal |
| [128] | Real-Time Modeling of renewable energy sharing in a microgrid |
| [129] | Modeling energy resource management problem of a microgrid for a fully integrated transactive system |
| [130], [131], [132], [133], [134], [135] | Multi-agent based home energy management system |
| [136], [137], [138], [139], [140], [141], [142], [143] | A multi-agent based simulation platform for electricity markets scenarios |
| [144] | Focusing on a dynamic fuzzy method for estimating electricity market prices |
| [145], [146], [147], [148], [149], [150], [151], [152] | Focusing on optimization approaches for electricity markets |
| [153] | A study on the liberalization process in Portuguese electricity markets |
| [154], [155] | Demand response implementation in a home energy management system |
| [156], [157], [158] | Implementing optimal resources scheduling and demand response programs in a realistic smart city model |
| [159], [160], [161] | Focusing on real-time localization system for demand response purposes |
| [162] | A load shifting approach for home appliances controlled by a home management system |
| [163], [164], [165] | Proposing a simulator platform to integrate different independent simulation tools for overcoming energy system barriers |
| [166] | Controlling a wind turbine emulator as a distributed generation in microgrid |
| [167] | Distributed based microgrid implementation and demonstration for demand response validation |
| [168] | Radio-Frequency based-SCADA model for monitoring and controlling of an office building |
| [169] | Optimization based SCADA office system for dynamic resource scheduling and demand response interaction |

| References | Achievements |
|---|---|
| [170] | Case-based reasoning application for intelligent energy management in residential buildings |
| [171] | Implementing Open ADR technology for demand response programs |
| [172], [173], [174], [175], [176], [177], [178], [179], [180] | Presenting optimization methods for smart grid energy management systems |
| [181] | Presenting a system for learning from the behavior of the users |
| [182] | Q-learning-based model for decision support of energy contracts in electricity markets |
| [183], [184], [185] | Focusing on an organization-based agent system for periodic review of transmission towers in a distribution network using artificial intelligence methods |
| [186], [187] | A survey on current techniques for non-intrusive load monitoring |

For summarizing and a better understanding of the developed works, Table 12 classifies all the works in several major subjects.

*Table 12. Classification of research documents produced in DREAM-GO H2020 project.*

| Main topics | References |
|---|---|
| ***Energy management on smart grids*** | [172], [173], [174], [175], [176], [177], [178], [179], [180] |
| ***Energy management on microgrids*** | [114], [115], [116], [117], [129], [166], [167], [168] |
| ***Electricity markets*** | [136], [137], [138], [139], [140], [141], [142], [143], [144], [145], [146], [147], [148], [149], [150], [151], [152], [163], [164], [165] |
| ***Home Energy management system*** | [130], [131], [132], [133], [134], [135], [154], [155], [162], [170] |
| ***Electric Vehicles*** | [124], [125], [126] |
| ***Aggregation, remuneration, and scheduling*** | [98], [99], [100], [101], [102], [103], [104], [105], [106], [107], [108], [109], [110], [111], [119], [120], [156], [157], [158], [169] |
| ***Survey on demand response and electricity markets*** | [121], [122], [123], [127], [153], [186], [187] |
| ***Demand response implementation*** | [112], [118], [159], [160], [161], [171] |
| ***Real-time simulation models*** | [113], [128] |
| ***Artificial intelligence and learning methods*** | [181], [182], [183], [184], [185] |

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