RESPOND
DEMAND RESPONSE FOR ALL

Integrated Demand REsponse Solution Towards Energy POsitive NeighbourhooDs

WP1 Pilot site characterization

Task 1.2: Demand response programmes

Demand response programs overview

D1.2 Demand response programs overview

The RESPOND Consortium
2017

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768619

PROJECT ACRONYM	RESPOND
DOCUMENT	**D1.2 Demand response overview**
TYPE (DISTRIBUTION LEVEL)	■ Public ☐ Confidential ☐ Restricted
DELIVERY DUE DATE	2018-03-31
DATE OF DELIVERY	2018-03-28
STATUS AND VERSION	Final Version
DELIVERABLE RESPONSIBLE	NUI Galway (NUIG)
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DOCUMENT HISTORY

	ISSUE DATE	CONTENT AND CHANGES
	15/12/2017	Table of contents circulated for partners overview
	10/02/2017	Literature review study
	19/03/2017	Complete first draft circulated for partners review
	22/03/2017	Review from official reviewers
	27/03/2017	Final version

EXECUTIVE SUMMARY

Task 1.2: Activities of this task are targeted at the analysis of contemporary demand response (DR) programs and solutions already applied EU and Worldwide. Analysis will be carried out both from ICT and business model point of view. As a result of this task, an overview of efficient DR programs will be reported and provided to other tasks in WP1. In particular, to Task 1.4 aimed at specifying adequate DR strategies and actions for the project pilots. The analysis will cover different types of DR schemes, both direct (quantity-based) and indirect (price-based) programs. In addition, experiences of end consumers that were actively engaged though the analysed DR programs will be gathered and properly reported. Furthermore, contemporary ICT solutions that are specifically developed for DR and direct load control will be analysed. As an outcome, this task will draw corresponding conclusions and adequate lessons learned will be extracted and reported, from analysed DR initiatives. Gathered information will be further aggregated in order to set the baseline and targeted recommendations, which should be followed by the RESPOND approach and further exploited by its integration activities.

Purpose: this reports presents an analysis of the contemporary demand response (DR) programs and solutions, already applied at European and Worldwide level. The document is divided into two main parts: the first one characterizes the DR programs from the point of view of the most relevant aspects found in literature: programs classification, ICT and business model. While, the second part provides an overview of the current DR programs at European and Worldwide levels. The overview reports and analyse efficient DR programs. The DR status in the pilot countries is described and recommendations are provided for design and implementation of the DR programs based on the previous findings. The analysis is intentionally focused on DR programs aspects related to residential building.

Key findings and conclusion:

The document reports an overview of **11** contemporary successful DR programs, implemented at European and Worldwide levels. "LINEAR, PowerMatching City, SmartView, EcoGrid and EirGrid Power Off and Save" projects resulted the most relevant DR programs for RESPOND (Table 9). The selected DR programs will be used by the RESPOND project as guidelines for a successful design and implementation of DR in the project pilots. The document also includes two other studies [40] and [46] which analysed a total number of 43 DR programs. General recommendation for successful implementation of the DR schemes on pilots can be retrieved in sections 3.4.1 and 3.4.2, describing general barriers and drivers for DR implementation.

The following paragraphs summarize the main findings and lesson learned from the (i)**ICT**, (ii)**business model** and (iii)**customer engagement** points of view, individually linked with the project pilots. The analysis will be at disposal to other task in WP1, in particular T1.4 specifying strategies and actions for project pilots.

ICT

The fundamental aspects of DR programs from the ICT prospective are presented in section 3.2. The basis of metering and control technologies and communication infrastructure/protocols are introduced in sections 3.2.1 and 3.2.2. Relevant real market ICT software and hardware products are reported in section 3.2.3. Chapter 5 reports DR potential in the pilot countries (Table 5, Table 6, Table 7).

The comparison between the successful DR programs and DR potentials defines the most suitable DR schemes and ICT scenarios for each of the pilot sites, which are described in the table below.

Pilot	DR programme type	ICT (control scenario)
Aarhus	Price-based (RTP/TOU)	Local loads: - Smart thermostats for heating systems; - Load control switches for smart appliances; - Smart meter for different tariffs and consumption information; - Smart load shift control for solar photovoltaic; - Mobile/PC application for system management and remote load control. District loads: - Smart thermostats for heating systems; - Smart load shift control for energy storage (hot water tank); - Load control switches for common areas (e.g. public illumination). - Mobile/PC application for system management and remote load control.
Aran Island	Price-based (RTP/TOU) Incentive-based	Local loads: - Smart thermostats for heating systems; - Load control switches for smart appliances; - Smart meter for different tariffs and consumption information; - Smart load shift control for solar photovoltaic; - Mobile/PC application for system management and remote load control. District loads: - Smart thermostats for heating systems; - Smart load shift control for energy storage (hot water tank and electric vehicle); - Load control switches for common areas (e.g. public illumination). - Mobile/PC application for system management and remote load control.

Madrid	Price-based (RTP/TOU)	Local loads: - Smart thermostats for cooling and heating systems; - Load control switches for smart appliances; - Smart meter for different tariffs and consumption information; - Mobile/PC application for system management and remote load control. District loads: - Smart thermostats for cooling and heating systems; - Smart load shift control for energy storage (hot water tank); - Load control switches for common areas (e.g. public illumination). - Mobile/PC application for system management and remote load control.

BUSINESS MODELS

Section 3.4.4 describes a study, where 147 business models were analysed. It defines the most common business models for DR. Two archetypes: one is **market based**, the other is **utility based**. The Danish and Spanish pilots are better fit for the utility based one, while the market based business model is the more appropriate for the Irish pilot.

CUSTOMERS ENGAGEMENT

The key success of residential DR programs is the consumer motivation and engagement, through incentives offered by the utilities. DR schemes must increase the customer awareness of the benefits of DR to adopt or change their electricity usage. The major reasons for encouraging customers to participate in the DR schemes are including cost saving, blackout prevention, and social responsibility. Also the study [40], reported in section 3.3.1, underlines as DR schema tariffs should be simple to understand for the end users and an important condition to make dynamic tariffs work is that the end users should be engaged with them.

The study [46], reported in section 4.3, underlines that to increase the effectiveness of a DR program, it should deployed in urban areas, particularly in faster-growing cities, that are likely to have greater infrastructure spending. There might be a reason for this: the higher densities of populations in urban areas may create economies of scale and reduce the costs of such programs. So, Aran Island customers engagement process could be more difficult, so the authors advise the RESPOND consortium to take into account of this lesson learnt. A possible solution could be the organization of dedicated workshops and others local initiatives to monitor and encourage the customers participation, evaluating the effectiveness of multiple engagement approaches.

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ABBREVIATIONS AND ACRONYMS

ACLM	A/C Load Management
ADR	Automated Demand Response
AMI	Advance Metering Infrastructure
AMR	Automated Metering Readers
API	Application Program Interface
C/I/M	Commercial / Institutional / Municipal
CHP	Combined Heat and Power
CIM	Common Information Model
CPP	Critical Peak Pricing
CPUC	California Public Utilities Commission
DOE	US Department of Energy
DLCs	Direct-load controls
DR	Demand Response
DRFM	Demand Response Flexibility Market
DSO	Distribution System Operator
DSU	Demand Side Units
EEM	European Energy Market
EMS	Energy Management Systems
EMA	Energy Monitoring and Analytics Application
EU	European Union
EVs	Electrical Vehicles
HAN	Area Network
HVAC	Heating ventilation and air conditioning
IBP	Integrated Business Planning

ICT	Information and communication technology
IC	Interruptible / Curtailable
IEA	International Energy Agency
IED	Intelligent Electronic Device
IETF	Internet Engineering Taskforce
ISO	Independent System Operators
I-SEM	Integrated Single Electricity Market
PAC	Program Administrators Cost
PTR	Peak Time Rebate
PV	Photovoltaic
ROI	Return Of Investment
RIM	Ratepayer Impact Measure
RES	Renewable Sources
RTO	Regional Transmission Organizations
RTP	Real-time pricing
SEDC	Smart Energy Demand Coalition
SEM	Single Electricity Market
TOU	Time-of-use
TRC	Total Resource Cost
TSO	Transmission System Operator
USB	Universal Serial Bus
USM	Unbundled Smart Meter
USNAP	Universal Smart Network Access Port
VGA	Video Graphics Array
WW	Worldwide

1. INTRODUCTION

Throughout the world, residential energy consumption ranges from 30% and 40% of the total energy demand. Users' consumption patterns contribute directly to sporadic peaks of demand and, to support this variation, utilities companies need to increase their generation in order to avoid interruptions in power supply [1]. Demand response (DR) programs help both consumers and utilities to reduce the peak demand and price volatility.

DR provides responsive and interactive consumers with a wide range of potential benefits on system development, operations, and market efficiency. Through DR programs, consumers can play a significant role in grid operation by reducing or shifting loads during peak load, in response to any incentives or time-based rates [2].

When compared to commercial and industrial customers, demand response performs better in residential areas because the consumers are more susceptible and responsive to the price signal from the utility, adjusting or shifting the time of use of their appliances, such as washing machines, tumble dryers, water pumps and heaters [3].

Nowadays, there is no critical need for residential demand flexibility in most of European countries because they have sufficient generation to supply the energy even during peak times. There is also some provision from industrial customers that can be used if necessary [4]. This scenario is starting to change. The use of renewable sources (RES) is increasing affecting directly the energy matrix. Renewables represented almost two-thirds of new net world electricity capacity additions in 2016, with almost 165 gigawatts (GW) coming online [5]. Between 2017 and 2022, we expect global renewable electricity capacity to expand by over 920 GW, an increase of 43% [5]. In order to reach the goal set by the European Union (EU) of 20% of renewable energy in 2020 [6] and at least 27% in 2030 [7], this growth has to continue and some challenges regarding renewable electricity must be resolved. The intermittent capacity of those resources will tend to increase the variability of the overall electricity supply challenging their integration into the grid [8]. Depending on weather conditions, solar and wind generation are considered more reliable intermittent resources and, consequently, residential demand flexibility will play an important role in balancing the network [4].

Contemporary solutions which achieve the matching between energy generation and demand, are based on increasing the generation capacity. Backup power plants are a costly solution, which should be used for a short time periods of time. Building traditional power plant will provide the necessary energy back up to match demand during peak events, but also increasing greenhouse gas production [8]. An alternative could be found on storage technologies. However they are currently expensive and not efficient [9]. Demand response can be a possible solution, aiming to managing the demand in order to meet the available energy [10].

Demand response is defined as “changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized” [11].

Demand response initiatives have become quite popular recently as a new tool for, both, supply guarantee and energy efficiency and cost saving measures. But until now these initiatives have always been focused on large consumers.

The RESPOND Project objective is to develop a demand response solution dedicated for households. The feasibility of the developed solution will be verified on three test cases located in Aarhus, Aran Island and Madrid, respectively.

This document presents an analysis of the contemporary DR programs and solutions, already applied at European and Worldwide levels. The document is divided into two main parts; the first introduces DR from the point of view of the most relevant aspects found in the literature: programs classification, ICT, customers, benefits/barriers and most common business models. While, the second provides an overview of the current DR programs at European and Worldwide level. Criteria to assess the success of demand respond programs are reported. The DR status of the pilot countries is described and recommendations are provided for a successful design and implementation of the DR programs, based on the previous findings. The analysis is intentionally focused on DR programs aspects related to residential buildings, as they are the declared customer target of the project.

2. SCOPE AND METHODOLOGY

The interest around DR has been growing over the number of last years. A number of review studies have been carried out related to DR. All of these publications focused on particular parts of a comprehensive framework of DR. For instance, [12] carried out a review on DR challenges, issues and barriers, which is crucial for the DR penetration into the energy market. [13] explores different DR programs to find the most appropriate for the state of Kuwait. [14] presents an overview of the DR enabling control, metering and communication technologies; the same study also explores different DR programs and consumers types and the current status of development at global level. [15] reviews and made a comparison of local DR deployment methods for better use of renewable energy. [1] presents an overview of the literature on residential DR systems, load-scheduling techniques, and the latest ICT that supports residential DR applications. [16] provides a review on DR programs and schemes, based on the motivation of the consumers to participate in the program. [17] provides a review of existent DR models, identifying gaps and recommendations for future model developments. Reviews studies on DR are focused on different aspects of it, a comprehensive approach to guide the design of a DR program is missing.

The methodology employed to address the DR programs overview, reported in this document, is mainly based on desk research techniques via literature review. The research was performed using a Web of science research tool [18]. The basic terms for the review were identified as “Demand response”, “programs”, “review”, “smart grid”, and the first search on the database was performed using the combinations of those terms. A further filtering was carried out, based on key words as “contemporary”, “residential”, “direct load control” and ”ICT”. A final filtering, based on complete review of them, led to collect a final list of references reported in Appendix I. In particular, the Table 11 shows 72 relevant documents between journal papers, reports and web pages. The Table 11 describes how the different documents covers different aspect of DR (X mark on the table): type of programs, ICT, business models (drivers, barriers, customer engagement) and programs example at European and World level.

3. DEMAND RESPONSE OVERVIEW

3.1 TYPES OF DR PROGRAMS

This section provides a basic overview of the types of DR programs options currently available. [17] classified DR models on criteria based on: thematic, methodological, temporal, spatial, technological and practical properties. Another classification is proposed in [19], dividing DR types between potential impact of efficiency and service to the customers (Figure 1).

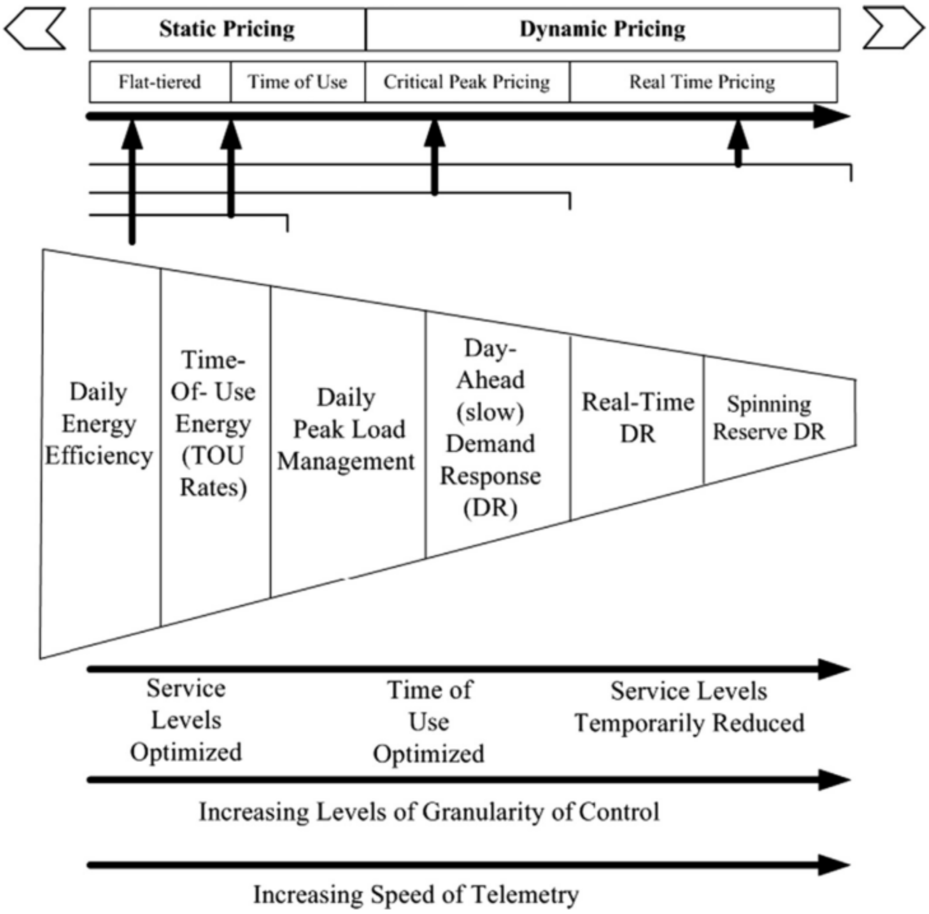

Figure 1 – Classification of DR schemes based on efficiency and services [19]

The authors decided to use the classification of DR programs proposed by the US Department of Energy (DOE) [11], because it is the most commonly used. In particular, the current DR programs can be categorised in two main types: incentive-based and price-based. Figure 2 shows the proposed classification, the following sections will discuss in details the different subcategorizes.

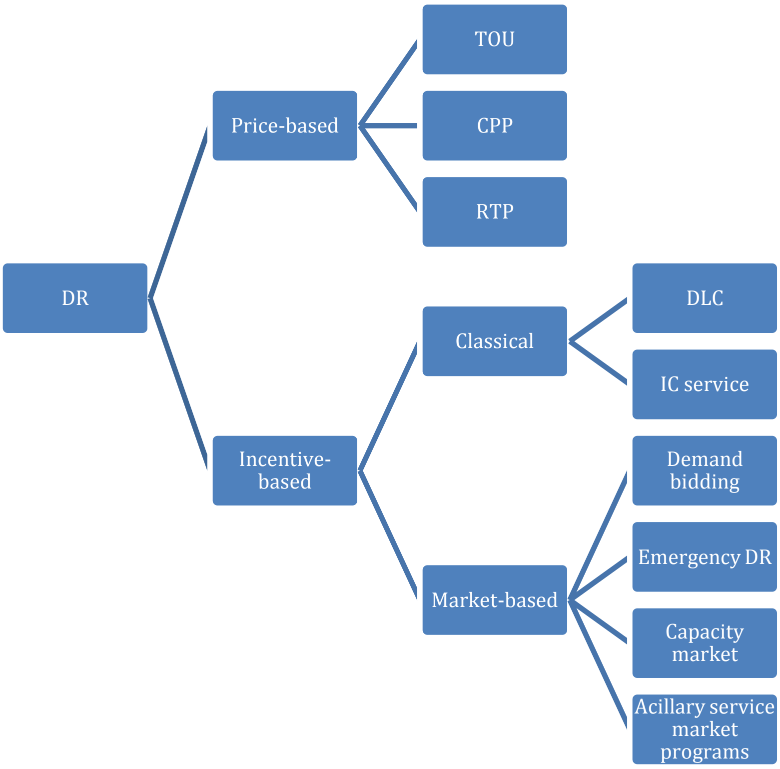

Figure 2 – DR programs classification

3.1.1 INCENTIVE-BASED DR

End users get a recompense to reduce their electric loads on request or for giving permissions to regulate their electric loads [13]. This typology of programs began with industrial and large commercial customers. Recently, residential customers have been included to those programs as well. Following the categorization proposed by the DOE in [11], there are six different incentive-based DR programs. They can be grouped into two main categories: classical and market based Figure 2. Classical ones are direct-load controls (DLCs) and curtailable load. The others belong to the marked based programs.

3.1.1.1 DIRECT LOAD CONTROL

DLCs reduces the household electrical loads, shutting down appliances on a short notice. The loads are distinguished as controllable and critical (not controllable). The loads include space heating/cooling, washing machines, dryer machines, water heaters and Electrical Vehicles (EVs).

In the USA, this type of program is usually applied to small customers such as residential and small commercial [20]. While, in Europe, it is currently at the first stage [21].

3.1.1.2 Interruptible/Curtailable service

IC services includes a discount or bill credit to the customers for agreeing on load reduction to a certain level (predefined by a contract), for a short period of time, during system contingencies [22]. These programs are mandatory: in case of failure to respond, the customers may be charged with penalties or excluded from the program. This type of programs suits large electricity users, mostly industries [10].

3.1.1.3 Market-based demand response

Market-based IBP include Emergency DR Programs, Demand Bidding, Capacity Market, and the Ancillary services market [23]. In market-based programs, participants are rewarded with money for their performance, depending on the amount of load reduction during critical conditions [23]. Demand Bidding (also called Buyback) are programs in which consumers bid on specific load reductions in the electricity wholesale market. A bid is accepted if it is less than the market price. When a bid is accepted, the customer must curtail his load by the amount specified in the bid or face penalties. On the other hand, in Emergency DR Programs, participating customers are paid incentives for measured load reductions during emergency conditions [11]. Furthermore, Capacity Market Programs are offered to customers who can commit to providing pre-specified load reductions when system contingencies arise [11]. Participants usually receive a day-ahead notice of events and are penalized if they do not respond to calls for load reduction. Ancillary service market programs allow customers to bid on load curtailment in the spot market as operating reserve. When bids are accepted, participants are paid the spot market price for committing to be on standby and are paid spot market energy price if load curtailment is required [11].

3.1.2 Price-based DR

Price-based demand response are programs where the electricity price is not fixed, but varies in time. This categories is divided in three major groups: time-of-use (TOU) rates, critical peak pricing (CPP) and real-time pricing (RTP). The common goal is to reduce the electricity consumptions over a certain period [24].

3.1.2.1 Time-of-use tariffs

Customers charged with flat prices are not aware of the varying cost of the electricity. The TOU tariffs work following the variations of the electricity cost previsions, in different time domains (from hour to season) [24]. TOU works dividing the day by time domains and assign a different price for each domain. In this way, customers are subsidize to shift their consumption from high demand periods, which corresponds to high energy price to low demand periods, so low energy price. TOU programs are successfully and widely applied from USA [25] to Europe [26].

3.1.2.2 CRITICAL PEAK PRICING

Reducing the peak demands periods by strongly racing the energy price is the objective of the CPP programs. The critical peaks are not known, usually they are forecasted and the users receive the communication of the events, only shortly in advance. The user participation is compensated by offering a base lower tariff. CPP is the most suited pricing method for peaks reduction [27].

3.1.2.3 REAL-TIME PRICING

RTP is a price schema where only the maximum and minimum prices are defined in advance, so the current price can vary continuously between them. The energy price is updated in a very short notice, typically hourly [14]. In some RTP programs, a price period with a fixed duration (for example of 1 h) is included, and the tariffs are communicated to the customer by 1 day in advance, creating a form that has some characteristics of TOU rates and is known as quasi-RTP [28].

3.2 ICT AND DR

The following sections will provide a basic overview of the ICT framework for households, commonly used in DR programs. In particular, metering/control technologies, communication infrastructures, market ICT solutions and residential customers are reviewed.

The development of new technologies and smart devices in the smart grid area can provide flexibility for the electricity market in addition to social benefits for consumers, especially through programs such as demand response, which rely on such technologies for good management and control of the consumption. Among the main elements of the system, we can mention smart meters, smart sensors, control devices and the management systems [19].

As a system example, home area networks allow customers to connect multiple wi-fi enabled devices to help monitor and control electricity usage [29]. Software on these networks allows customers to set preferences for when their appliances operate according to their needs or even due to some price signal from the utility, in order to reduce energy consumption during peak and critical peak price periods. Additionally, customers who opt info certain types of DR programs can allow the utility to make small adjustments to the energy consumption. Controlled appliances connected to home area networks may receive DR commands direct from the utility.

3.2.1 METERING AND CONTROL TECHNOLOGIES

The smart meter is the measurement element that provides the means of communication between consumers and the utilities, thus enabling the integration of other technologies such as DR. Consumers and utilities can check the energy consumption in almost real-time, acting to reduce it if necessary. Additionally, smart meters can provide real time pricing of the electricity or indirect load control known as dynamic price response including [30]:

- Time of Use (TOU) tariff: this scheme encourages consumers to shift their consumption from a peak to off-peak period.

- Real-Time Pricing (RTP): The price of the electricity in the market changes hourly (or half an hourly in some markets). It provides incentives to consumers to limit their consumption when the wholesale price of the electricity is high and increase their consumption at lower electricity price periods.
- Critical Peak Pricing (CPP): CPP tariffs augment a time-invariant or TOU rate structure with a dispatchable high or "critical" price during periods of system stress. Participating customers receive notification of the dispatchable high price, typically a day in advance, and in some cases are provided with automated control technologies to support efficient load drop.

Smart metering installations are usually led by utilities and are part of a wider smart grid project, typically combined with innovative automation and control systems on the grid side or with DR and energy management applications in the smart home (e.g., Smart City Malaga, Grid4EU, Inovgrid, Low Carbon London, Price)[19]. Smart meter types are distinguished according to the combination of some features such as the data-storage capability of the meter, the communication type (one-way or two-way), the connection with the energy supplier.

Vulnerabilities in Smart Grids are most common in smart meters, intelligent devices in electricity supply and demand, components in insecure physical locations, outdated equipment that may be incompatible with current devices, device-to-device communication, unorganized communication among teams involved and IP-based components that are prone to attacks [31].

Load control devices consist of technologies such as load control switches and smart thermostats. For instance, load control switches are used for remote control of specific loads such as compressors, motors, dishwashing machine and dryers that are connected to the utility by means of communications systems [19]. Furthermore, smart thermostats can be remotely controlled by the utility and/or the customer and allow programming of variations in temperature settings. Some smart thermostats can act like a repeater and provide reliability, price and event signals to other appliances and loads [19].

The ICT & DR management system, by receiving market and system signals, can trigger the control devices and manage loads, heating, ventilation and air conditioning (HVAC) systems, storages and local generation units, according to user preferences. Customers may also program smart appliance, such as innovative washing machines, water heaters, dryers, dishwashers, refrigerators, in order to automatically respond to price, reliability, and other DR event signals [19].

The Denmark EcoGrid project [32], which will be better detailed in section 4.1.1 of this document, is a good example of a general ICT solution for residential households. The general architecture can be seen in the Figure 3.

The metering and controlling architecture is composed by smart meter, temperature sensor, controlled power-node and communication equipment, as well some interfaces used by the users and/or utility to manage the load control [33].

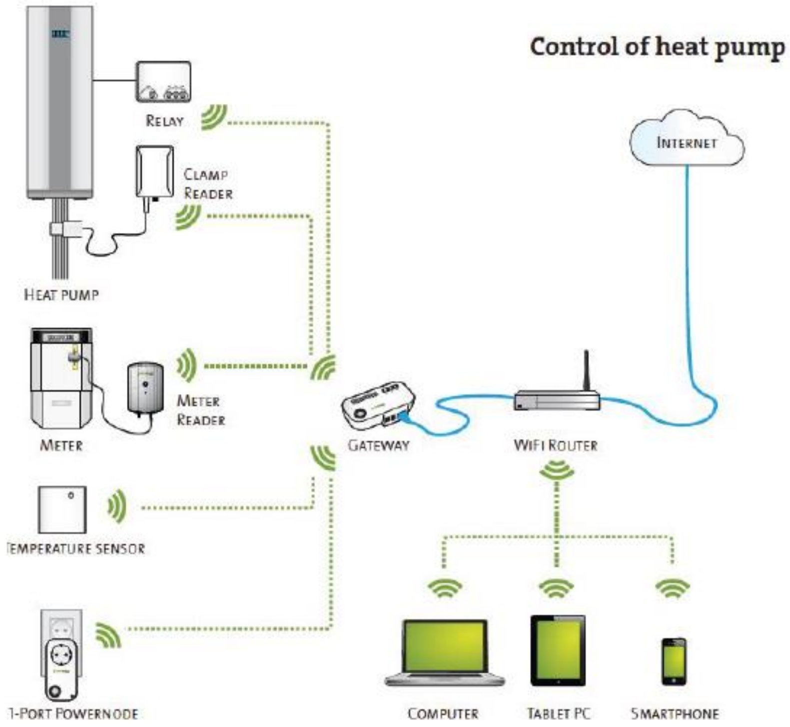

Figure 3 – EcoGrid general ICT architecture [34]

3.2.2 COMMUNICATION INFRASTRUCTURE AND PROTOCOLS

Communications systems are the core of DR programs, all the information to and from utilities and consumers related to tariff pricing, consumption and load control signals flow through the network by means of the metering infrastructure or gateways, even using one-way or two-way communication depending on the architecture deployed. Although more expensive, two-way communication control technology is the most appropriate as it also allows monitoring the number of facilities available at the time of a DR event and get reply from the consumer. This kind of technology is more accurate when monitoring DR, because it is possible to measure every customer's load reduction during an event in near real-time. The advantages of one-way communication are the low cost and easy deployment. However, it is used just for alert programs, without automated control or accurate precision of the individual to the grid [19].

For residential application, usually the communication network uses an area network (HAN) to connect the appliances and devices within the home and the smart meter to the communication gateway. There are a range of different communication network technologies, the choice of the most suitable way will depend on the type of equipment and the installation distance between them, besides the characteristics of installation of the place and susceptibility to external noises. The Figure 4 shows the main technologies and some characteristics of each one.

Technology	Standard/protocol	Data rate	Coverage range	Application	Limitation
Wired communication technologies					
Fiber optic	PON,	155 Mbps to 2.5 Gbps	Up to 60 km	WAN	Costly installation fees.
	WDM,	40 Gbps	Up to 100 km	WAN	
	SONET/SDH	10 Gbps	Up to 100 km	WAN	
DSL	ADSL	1–8 Mbps	Up to 5 km	NAN	Not available everywhere due to the signal limitations based on the distance.
	HDSL	2 Mbps	Up to 3.6 km	NAN	
	VDSL	15–100 Mbps	Up to 1.5 km	NAN	
Coaxial cable	DOCSIS	172 Mbps	Up to 28 km	NAN	Limited bandwidth; limited application (Thinnet)
PLC	HomePlug	14–200 Mbps	Up to 200 m	HAN	Noisy channel
	Narrowband	10–500 kbps	Up to 3 km	NAN	
Ethernet	802.3x	10 Mbps to 10 Gbps	Up to 100 m	HAN, NAN	Short rang
Wireless communication technologies					
Z-wave	Z-wave	40 kbps	Up to 30 m	HAN	Low data rate short rang
Bluetooth	802.15.1	721 kbps	Up to 100 m	HAN	Low data rate short rang
Zigbee	802.15.4	250 kbps	Up to 100 m	HAN	Low data rate short rang
Wi-Fi	802.11x	2–600 Mbps	Up to 100 m	HAN,NAN	Noise channels
WiMAX	802.16	57 Mbps	Up to 50 km	NAN	Not widespread
Cellular	2G–4G	Up to 100 Mbps	Up to 50 km	NAN	Costly spectrum fees
Satellite	Satellite internet	1 Mbps	Up to 100–6000 km	WAN	Costly installation fees, sensitive to the heavy rainy day

Figure 4 – Communication technologies for smart grid [1]

To ensure good dissemination and scalability, the components of the system have to be interoperable with most widely used protocols on the Internet, this ensures that new equipment and smart appliances will work together without the necessity of critical changes in the network infrastructure. To address this need, Internet engineering taskforce (IETF) working groups are undertaking the definition of standard protocols at different layers of the network stack to facilitate the translation in to Internet solutions [1]. The new IPv6 addressing protocol for constrained devices (6LoWPAN) is replacing the expensive fragmentation of IPv6 packets into small link-layer frames.

Besides the communication technology, the integration of increasing numbers of intelligent electronic devices (IED) and applications should follow a common format for data exchange in the electrical power domain. The standard for the exchange of information of the distribution networks is based on Common Information Model (CIM) [19]. It defines a control architecture that can deal with the complexity of smart grids, and a bus of information, accessible to the different control functions, that can exchange the information related to the state of the system, on the basis of a common format.

There are others groups emerging that aim to create standards that will ensure the compatibility between products and solution from different vendors. The Universal Smart Network Access Port (USNAP or CTA-2045) is a standard published by the Consumer Technology Association in 2013 for a “modular communication interface for energy management.” In effect, this is a standardized hardware plug and associated standards for communication across that plug, akin to USB or VGA [28]. It would be built into appliances such as water heaters, thermostats, or air conditioners. A utility can then provide a communication module that plugs into the appliance’s port and receives communications from the utility telling it when to change its behaviour. It will also allow utilities to enable those appliances to participate in DR programs with the addition of a single standardized device, rather than developing custom means of interfacing with each appliance type. The standard port allows the utility to provide interfaces that communicate via their choice of radio frequency, Wi-Fi, power-line carrier, or Zigbee. Standardization should also allow lower costs for all parties [29].

Finally, the OpenADR alliance is a group that works in a communication standard for automated demand response (Auto-DR or ADR). Basically, the OpenADR defines the expected behaviour when exchanging DR event related information between utilities, grid operators and customer end-use systems. This standard allows interoperability between different control systems. Specifically, it avoids the need for a custom solution to communicate between a particular utility control software system and a particular manufacturer's building or facility energy management system [29].

The OpenADR data models facilitate price-responsive and reliability demand response. As shown in Figure 5 below, this is achieved through open Application Programming Interfaces (APIs) that provide two-way communications between the service provider (Utility/ISO) and customers (Sites) through a logical interface of an OpenADR server (called a Demand Response Automation Server) [35].

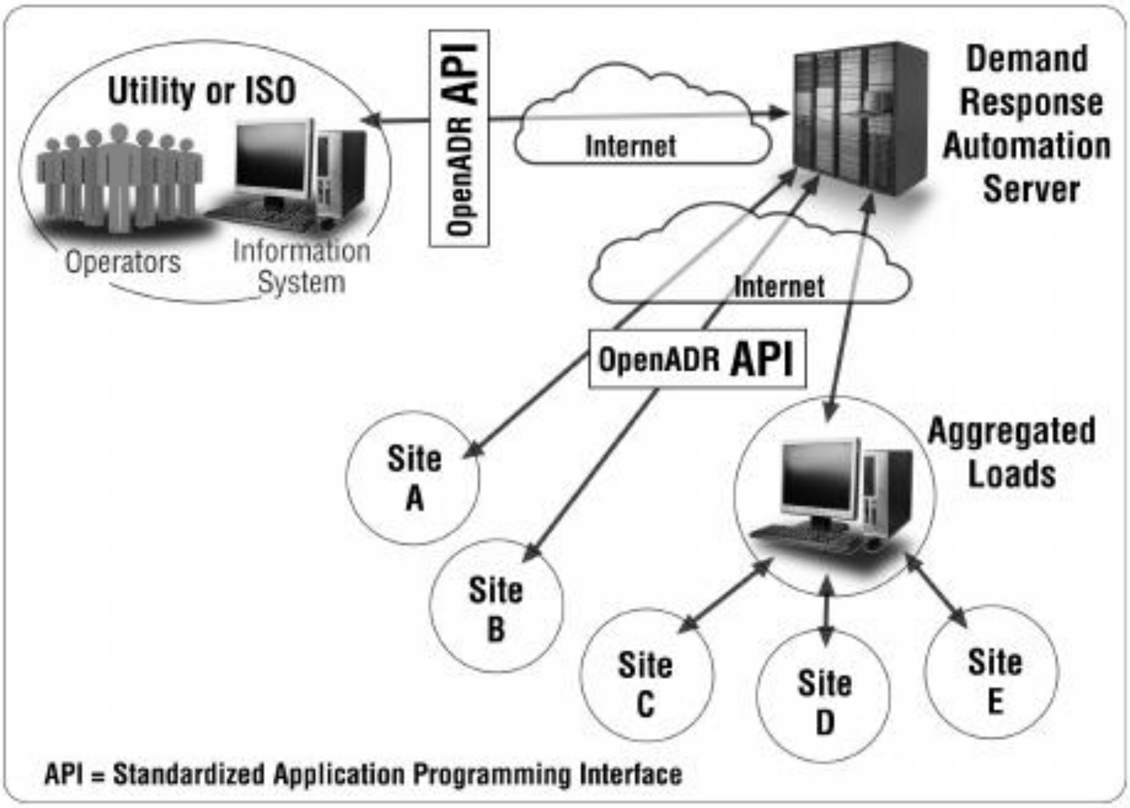

Figure 5 - OpenADR Communication architecture [35]

3.2.3 ICT SOLUTIONS FOR DR ON THE GLOBAL MARKET

The global market offers different solution to enable DR programs to the customers. Below, the most relevant for RESPOND are reported and classified by software (Table 1) and hardware (Table 2).

Table 1 – Examples of market ICT software solution relevant for RESPOND

Provider	Software	Description
GE	PowerOn Precision Solution	PowerOn Precision Solution is a Demand Response Management System. It allows organisations to manage DR programs, field assets and operational activities and includes a range of features such as load forecasting, load shaping, dispatch and ROI projection.
Comverge	IntelliSOURCE	Cloud-based software that gives utilities a single operational view into all of their DR and energy efficiency programs, as well as automating every phase of mass-market demand management programs. It includes a Demand Response Management System that enables event control, pricing including cycling, temperature setback, critical-peak pricing.
Siemens	SureGrid	Siemens offers a fully automated cloud-based Intelligent Load Management solution. SureGrid can monitor and control major energy consuming devices, such as HVAC, lighting, refrigeration etc, SureGrid technology enables each building to dynamically interact with the electricity grid based on local business rules and real-time asset and environmental conditions.

Table 2 – Examples of market ICT hardware solutions relevant for RESPOND

Provider	Hardware	Description
Kiwi Power	Power information Pod smart meter	The Power information Pod is a smart meter approved by system operators such as National Grid UK and it is designed specifically for demand response. It is cloud-enabled and has a powerful, embedded Linux platform which allows for real-time power measurement, monitoring, logging and control.
GridPoint	Controllers, Sub-meters, Thermostats and sensors	The controllers, sub-meters, thermostats and sensors work together to set desired equipment schedules and temperature set-points, as well as gathering circuit-level power usage and building environment data. In addition to standard functionality for scheduling it can also dynamically adjust building operations to changing site conditions and so optimise energy consumption
Siemens	SICAM SGU	Siemens SICAM Smart Grid Unit is a field device that can be used for smart grid purposes such as demand response, DER controller for virtual power plants, renewable integration in microgrids, or small RTU installations. It can be used with an integrated GPRS modem to connect remote distributed energy resources and it provides a cost-efficient alternative to expensive wired installations and separate configuration of an external cellular modem.

3.3 DR CUSTOMERS

3.3.1 RESIDENTIAL

Research carry out by Sia Partners estimates that at European level a total of 800 TWh of energy consumption with potential for demand response programs in 2012, this represents 29% of the total electricity consumption in these countries [36]. The distribution over the different shows that the industrial, tertiary and residential sectors have similar shares. Four processes found in tertiary and residential sectors account for 42% of the DR potential: refrigerators & freezers (12%); heating systems and boilers (10%); space & water heating (10%); ventilation (10%) [36].

After determining the installed capacity per process, the capacity guaranteed at peak per process and the reduction potential per process, Sia Partners estimates that total DR potential in Europe amounts 52,35 GW, Figure 6 shows the potential per category. Residential application corresponds to 42% of this total potential whereas 31% comes from industry and 27% in the tertiary sector [36].

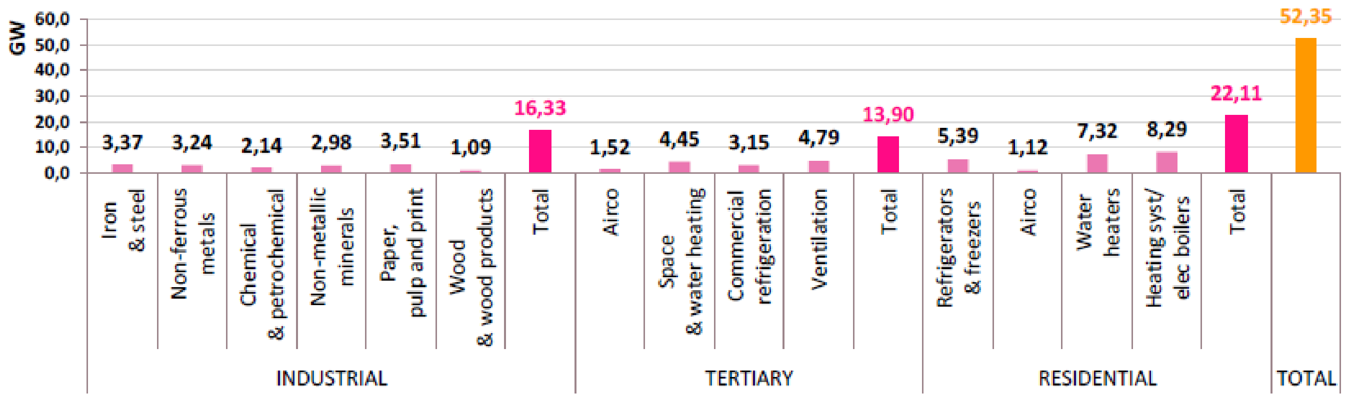

Figure 6 - Total DR Potential [36]

Studies carried out around the world show evidences that residential demand response program contributes positively in demand peak reduction [37]. A state-wide pilot experiment in California generated residential response to time-of-use tariffs and critical peak pricing in the order of 5% and 13% respectively [38]. Another recent study into Canadian households' response to a TOU tariff showed that dynamic tariffs bring about a 2.6% and 9.2% reduction in peak demand [39]. An extensive research developed in 15 European countries, U.S., Canada and Australia on residential demand response programs, showed that the average effect of such measures in terms of demand response ranges from 20% to 50%, the highest rates are found in studies involving enabling technology and also automated reductions in peak demand [39].

The key success of residential DR programs is the motivation and consumers engagement, through incentives offered by the utilities. DR schemes must increase the customer awareness of the benefits of DR to adopt or change their electricity usage. The major reasons for encouraging customers to participate in the DR schemes including cost saving, blackout prevention, or responsibility sensing. The big DR challenge is to balance energy and save costs for both the customers and the utility. In summary, consumers seek to minimize their energy cost above all other priorities, whereas the utility aims to manage the available energy accurately with minimum cost, the most important factor for DR systems is to maintain balance between the beneficial requirements of both the utility company and the consumers [1].

Based upon existing literature and analyses of 12 current smart grid projects, a study reported in [40] presents key lessons on how to encourage households to adjust energy end use by means of dynamic tariffs. The paper identifies four key hypotheses related to fostering demand response through dynamic tariff schemes and examines whether these hypotheses can be accepted or rejected based on a review of published findings from a range of European pilot projects. The paper concludes that dynamic pricing schemes have the power to adjust energy consumption behaviour within households. In order to work effectively, the dynamic tariff should be simple to understand for the end users, with timely notifications of price changes, a considerable effect on their energy bill and, if the tariff is more complex, the burden for the consumer could be eased by introducing automated control. Although sometimes the mere introduction of a dynamic tariff has proven to be effective, often the success of the pricing scheme depends also on other factors influencing the behaviour of end users. An important condition to make dynamic tariffs work is that the end users should be engaged with them.

3.3.2 ELECTRICAL VEHICLES

The electric vehicles (EV) will play an important role in energy management in the next years. According to a report from Bloomberg New Energy Finance's (2017), it is expected that by 2038 sales of electric vehicles will exceed those of combustion engines, and by 2040 the number of EVs will represent one-third of the total vehicles in the world. Hence, new demand response programs will have to be deployed in order to address this new challenging energy scenario.

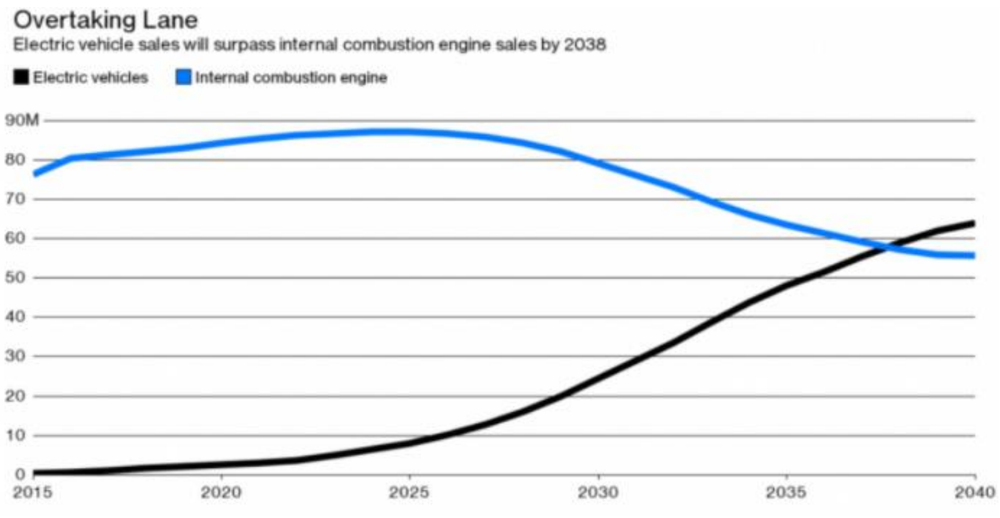

Figure 7 - Electric Vehicle sales forecast. [38]

Deployment of Electric Vehicles is considered as one of the solutions for achieving cleaner and greener mobility in highly urbanized cities around the world. In the case of highly urbanized cities, EVs are generally parked in multi-storey car parks and it is inevitable in commercial and office buildings. Hence, EV deployment will eventually increase the load demand of buildings from which EVs are electrically charged. Furthermore, there is high risk that the total demand of building exceeding the limit imposed by utilities if the EV load demand added is not managed adequately [41].

On the other hand, EVs can be an important support in DR programs as they can act as a supplier of electricity to the grid or an energy storage device. Through a good energy system management, EVs will contribute for load-shifting reducing energy consumption during peak times, bringing stability to the grid and economy to the consumers. Another important benefit, in case of energy fault, EVs can supply energy to houses for certain period of time.

There are two methods for EV and grid integration. The first is G2V, which works in a single way, the EV battery can be charged from the grid using stored electricity originating from external power sources. The second one is the V2G, that can bring smarter DR possibilities. In this configuration the power flow is bidirectional, the EV can be charged from the grid and can supply energy to the grid while discharging [42]. V2G-enabled EVs earn incentives while discharging power to the grid and make payments while charging batteries from the grid. The integration of EV supply equipment with distribution automation provides utilities better flexibility and reliability in managing and delivering electrical energy [43].

There are some mechanisms, such as dynamic electric vehicle charging, that can reduce the impact of the vehicle to the grid. In a generic way, vehicles charge when prices are low and there is an oversupply of electricity, and then cease charging when prices are high and there is a scarcity of supply [41]. A conscious decision can be made by the consumer or even through automated systems about when to store power in the EVs. This practice works well in price-based TOU DR programs. This strategy can also be used to incentivize drivers to charge EVs during periods when supply from renewable energies is at its highest, reducing the demand for fossil fuel powered plants [41].

3.4 DR DRIVERS, BENEFITS AND BARRIERS

3.4.1 BARRIERS

Research carried out extensively by [12] aimed to identify the main barriers to demand response programs, besides classifying them and thus presenting some possible solutions. The fundamental classes used in the analysis were economic, technological and social, which relate to intrinsic human nature (social/economic barriers), and to essential enabling technology (technological barriers). From these, some other subcategories were created, such as political/regulatory, market structure and understanding. Table 3 summarizes the main points of the study, presenting the barriers and solutions proposed.

Table 3 – DR barriers

Barrier	Description	Enablers
	Market Failure	
Imperfect information	Classical economics assumes that all parties have access to free and perfect information. In reality this may not occur, which constitutes a failure.	Development of bespoke DR markets to bring together buyers and sellers, improving access to information; Develop metrics for effective communication of user preferences, to enable quantification and trading of flexibility.
Incomplete markets	Markets in which property rights are not well defined can be termed incomplete. This is a failure as it can result in a discrepancy between private and social costs and benefits.	Pricing of externalities, such as emissions; Adoption of 'DR exchanges' or similar, to eliminate 'free riding' in DR exercise.
Imperfect competition	Uncompetitive markets, where one or more parties have, and exercise, market power.	Monitoring of market power, especially in market with few participants.
	Market	
Access to capital	Some DR may require additional capital investment. For some parties, with little reserves and/or poor credit rating, accessing capital may be problematic.	Preferential (government backed) loans.
Uncertainty	Uncertainty on future revenue/costs can pose a substantial barrier.	Contracts for difference.
Hidden costs	Hidden costs related to market participation i.e., negotiation and enforcement costs associated with transactions may be a barrier.	Subsidy of DR market operating costs.
System value/Demand for DR	It is possible that flexibility is simply not valued in a system. This can be a barrier to DR.	Long term evaluation methods (to appreciate the possible changing value of DR).
	Behavioural	
Form of information	If information is not regarded as intended by the sender, the corresponding behaviour of the recipient will not as expected by the sender.	Careful design of user interfaces.

Credibility and trust	How the recipient of information regards the sender will dictate how such information will be perceived.	Penetration of new third-parties (such as aggregators); Legal clarity on data rights; Modular design of IT systems, to increase security; Data anonymization.
Values	Besides cash cost minimisation, consumers may be influenced by their values (e.g., environmental values, energy conservation values). This may prompt behaviour which does not align well with DR.	Evolution of DR institutions.
Inertia	The entrenchment of behaviour may be a barrier; as such behaviour can take time to change, even if there is clear benefit to doing so.	N/A.
Bounded rationality	Cognitive capacity of an individual is naturally limited, which may mean that, even with the necessary information, they may not reach the optimal DR related decision.	Automation.
	Technological	
Metering and Sensing	Standardised technical architecture is necessary for interoperability between different vendors. Barriers to DR may exist where the necessary metering infrastructure is not present. The primary issue relates to sensing at high frequency, with high reliability, but in a way that is flexible and extensible with respect to enabling additional, often yet to be envisaged, Smart Grid services and/or devices, and all at an acceptable cost.	Installation of metering at necessary resolution/specification; Monitoring of final energy services (comfort, appliance availability, etc); Good requirement elicitation, to ensure DR schemes compensate according to user preferences on various energy services.
Computing	Sensing can generate large amounts of data, whilst uncertainty, in the determinants of DR potential and in DR prices can increase the computational load, especially when at scale. Whilst 'big data' technologies can deal with voluminous, heterogeneous, near-real-time and static data, there are limits, especially when decisions are critically time constrained. Finally, data exchange and the standardisation of same arguably a bigger barrier than the computational capacity.	Optimisation simplification; Distribution of computation load; Leveraging of additional network resources (e.g. cloud).
Communication and security	Interoperability has traditionally been, and continues to be, a very slow process taking many years due to competing approaches and alliances. Central to communication are barriers pertaining to data security and privacy which all relate to imperfect information, credibility and trust.	Open, agnostic technologies; Plugin-based architectures; Alliances/ Collaborations to develop standards; Agreement on semantics; To develop a common language across industries; Adopt security & privacy design; Have a data life cycle mgmt strategy; Allow for intuitive end-user configuration tagging of data.
	Secondary	
Political and regulatory	Markets can be distorted by the applicable tax code, which may treat various expenditures differently. Regulation may also cause distortion in markets if goods that are	Disaggregation of consumption, generation and storage, to enable application of taxes; improve cost reflectivity in energy markets; Forward

	practicably substitutable are precluded from competing with each other. A further political barrier may result from uncertainty derived from unclear policy and role definitions.	guidance on energy policy; Greater emphasis on innovation and new solutions.
Market structures	Even with aggregation of DR resources, the number of DR agents may cause significant complexity in operation of Smart Grid/DR markets, especially if those DR agents wish to restrict the amount of information they reveal.	Agreed baseline methodologies, for various markets; Review standard definition of products in energy markets; Decentralized optimisation (system-of-systems approach).
Understanding	A lack of understanding of DR, and the benefits that it may bring, is a considerable barrier to DR. Such a lack of understanding generally reduces interest in DR, which then results in less attention and investment from parties who may benefit from developing DR.	Cost-benefit analysis framework, to demonstrate benefits of DR, under realistic assumptions.

3.4.2 DRIVERS

In order to achieve all the European's energy goals and meet the political promises, both price-based and incentive-based demand response will be strongly required for all groups of consumers (industrial, commercial and residential) through different approaches. This will give energy resource flexibility to the utilities and price benefits to the consumers. The SEDC has developed a set of regulatory requirements to enable Demand Response, these requirements are structured around four main criteria [44]:

- Enable market access for Demand Response;
- Enable different service providers to access the market;
- Create viable products;
- Develop measurement and verification requirements and ensure fair payments and penalties.

Furthermore, the penetration of distributed generators, the prevalence of competitive electricity markets, the advancement of end-use technologies and control systems, and the advent of smart grids result in the reform of conventional demand side management theoretical frame [45]

Low energy prices are a natural demand response driver. When consumers change their consumption patterns reducing the demand peak, the utilities and grid operators can avoid making additional investments in generation or buying expensive peak power on the spots markets. In theory, regions with high electricity costs would benefit the most from DR and should therefore pursue more programs and resources [45].

Another important driver for DR development is the market structure. In many cases an organized wholesale power market facilitates DR and the rules and conditions of the particular market define the opportunity for customers, enhancing or hindering participation [45]. One of the most frequently mentioned benefits of DR is its ability to alleviate short-term reliability concerns on the electric grid and, due to its ability to be quickly deployed without major infrastructure investments, DR has been proposed as one solution to maintain sufficient reserve margins.

Overall, there are many other drivers that could foster the demand response programs over the world. Studies carry out by the Institute for Building Efficiency (U.S) presented the most relevant ones, the results can be seen in the [45].

Table 4 – DR drivers

DR Driver	Description
Market expansion	While DR has evolved from interruptible power arrangements between utilities and large industrial customers and direct load control programs that cycle off residential air conditioning, it has been slow to penetrate the bulk of the commercial sector, where customers insist on maintaining control over their operations and require attractive terms to participate. As the marketplace evolves through innovative business models and enabling technology, more customers will be interested in an expanding array of DR opportunities, expanding the resource around the world.
Climate policy	As economies around the world evolve toward reduced greenhouse gas emissions and low-carbon growth, there is a need for technology and market solutions that enable this change. DR is part of a more flexible electricity system, allowing both supply and demand to interact frequently and at scale. In a carbon-constrained world, this flexibility can shift generation away from greenhouse-gas-emitting sources and therefore reduce carbon emissions in a meaningful way.
Renewable energy policies	Such as Renewable Portfolio Standards and Feed-in Tariffs – In many U.S. states and European nations, significant amounts of renewable, variable energy resources are expected to come online in the next five to 10 years. Grid operators are tasked with identifying cost-effective ways to integrate these variable resources into the market without sacrificing system reliability. DR is being considered as one potential solution. In particular, automated (technology based) DR, such as direct load control, has the potential to provide fast response that could potentially participate in ancillary services markets, such as spin or even regulation.
Wholesale energy markets	In addition to the capacity markets that have been central to the development of DR in parts of the United States, wholesale market operators administer energy markets in which participants (traditionally power generators or day-traders) buy and sell power on an hourly or more frequent basis. Some of these markets have opened up for DR resources to participate, and policy has been proposed that would encourage the inclusion of DR in energy markets across the country.
Electric vehicles	Another potentially valuable future use of DR is to encourage efficient charging patterns in regions with high levels of plug-in electric vehicle (PEV) adoption. Left uncontrolled, PEV charging could lead to significant increases in the system peak, as owners return from work in the early evening and plug in their vehicles. A well-designed time-of-use rate could encourage charging during lower-priced off-peak hours. Additionally, direct control of the charging devices could be used to address location-specific reliability issues caused by unexpected levels of PEV charging.

3.4.3 COSTS-BENEFIT ANALYSIS

According to [29], the cost-benefit analysis should considered, if the expected resource savings will be greater than the investment made for the installation of demand response programs over an estimated period of time. To determine this, several items from different perspectives need to be considered in the analysis, such as equipment costs, cost of power generation, administration costs and also cost benefits to users. Furthermore, tests of effectiveness should be done in order to validate the impact of each cost component to achieve a successful DR program. The benefits of DR programs come primarily in the form of costs avoided [29]. These may be energy, capacity, ancillary services or wires (transmission or distribution) costs.

According to a report made for Northwest Power and Conservation Council (U.S.) in [47], the total program cost needs to considerate the cost of technology enablement as new participants come onto the programs as well as the ongoing cost of program implementation. The enablement cost includes technology costs, installation costs, and customer incentives, while the implementation cost includes the costs of program administration, DR program management systems, and evaluation studies [47].

The measurement of the effectiveness should consider at least a full period, usually one year, variations in the costs of generation and reduction of energy are generally different when comparing summer and winter, since the pattern of consumption of the user and generation through renewable resources does not occur in a linear way [29]. Additionally, program design or public policy may need to intervene to make a societally cost-effective choice favourable to both utility and participant. Program design should reflect benefits and what is necessary to move a sufficient market to provide the resource necessary, while limiting free-ridership [29].

According to California Public Utilities Commission (CPUC), determining the cost-effectiveness of a DR program is very important and prior to approving a program, they do a cost versus benefit analysis of the program in order to determine whether the program provides positive value to electric ratepayers [48]. This is a complex analysis that involves several steps, in summary it takes into account four different test perspectives: TRC (total resource cost), PAC (program administrators cost), RIM (Ratepayer Impact Measure) and Participant [48].

The TRC test calculates the costs and benefits to “society” of a demand-side resource. Its benefits are avoiding costs of supplying electricity and tax credits (if available), social non-energy benefits (environmental, job creation, healthy, etc), utility non-energy benefits (fewer customer calls, improve relationship) and market benefits [48]. From the perspective of TRC, the costs are administrative and capital, participant costs and eventual increased supply costs.

The PAC test measures cost-effectiveness from the perspective of the Load Serving Entity (LSE) or other entity administering the Demand Response program. The benefits are to avoid costs of supplying electricity, utility non-energy benefits and market benefits. The main costs for PAC are the same as TRC costs [48].

The RIM test, also called the non-participants test, measures the costs and benefits of a demand response program from the perspective of its impact on rates. Among its benefits are: avoiding costs of supplying electricity, increase participation in energy markets, revenue increases and market benefits. The main costs in this category are administrative and capital costs, incentives paid, increased supply costs and eventual revenue loss from reduced sales [48].

Finally, the Participant test measures the cost-effectiveness of a Demand Response program from the perspective of a participant. The benefits are bill reductions, incentives received, participant non-energy benefits and, depending on the program, tax credits. The main costs are eventual bill increases, operation and maintenance of DR equipment, lost productivity and comfort costs [48]. The Table 7 presents a summary of the costs and benefits for the four groups aforementioned.

	TRC	PAC	RIM	Participant
Administrative costs	COST	COST	COST	
Avoided costs of supplying electricity	BENEFIT	BENEFIT	BENEFIT	
Bill Increases				COST
Bill Reductions				BENEFIT
CAISO Market Participation Revenue	BENEFIT	BENEFIT	BENEFIT	
Capital costs to LSE	COST	COST	COST	
Capital costs to participant	COST			COST
Incentives paid		COST	COST	BENEFIT
Increased supply costs	COST	COST	COST	
Market benefits	BENEFIT	BENEFIT	BENEFIT	
Non-energy social benefits	BENEFIT			
Non-energy utility benefits	BENEFIT	BENEFIT	BENEFIT	
Non-energy participant benefits				BENEFIT
Revenue gain from increased sales			BENEFIT	
Revenue loss from reduced sales			COST	
Tax Credits	BENEFIT			BENEFIT
Transaction costs to participant	COST			COST
Value of service lost	COST			COST

Figure 8 – Cost-benefits characterization [48]

3.4.4 BUSINESS MODELS

[49] performs an empirical analysis of the most common business models for the deployment of DR and Energy management System (EMS), electricity and thermal storage, and solar PV distributed energy resources. The study classifies revenue streams, customer segments, electricity services provided, and resources for 144 business models from regionally diverse companies. They identified a set of business model "archetypes" in each resource category.

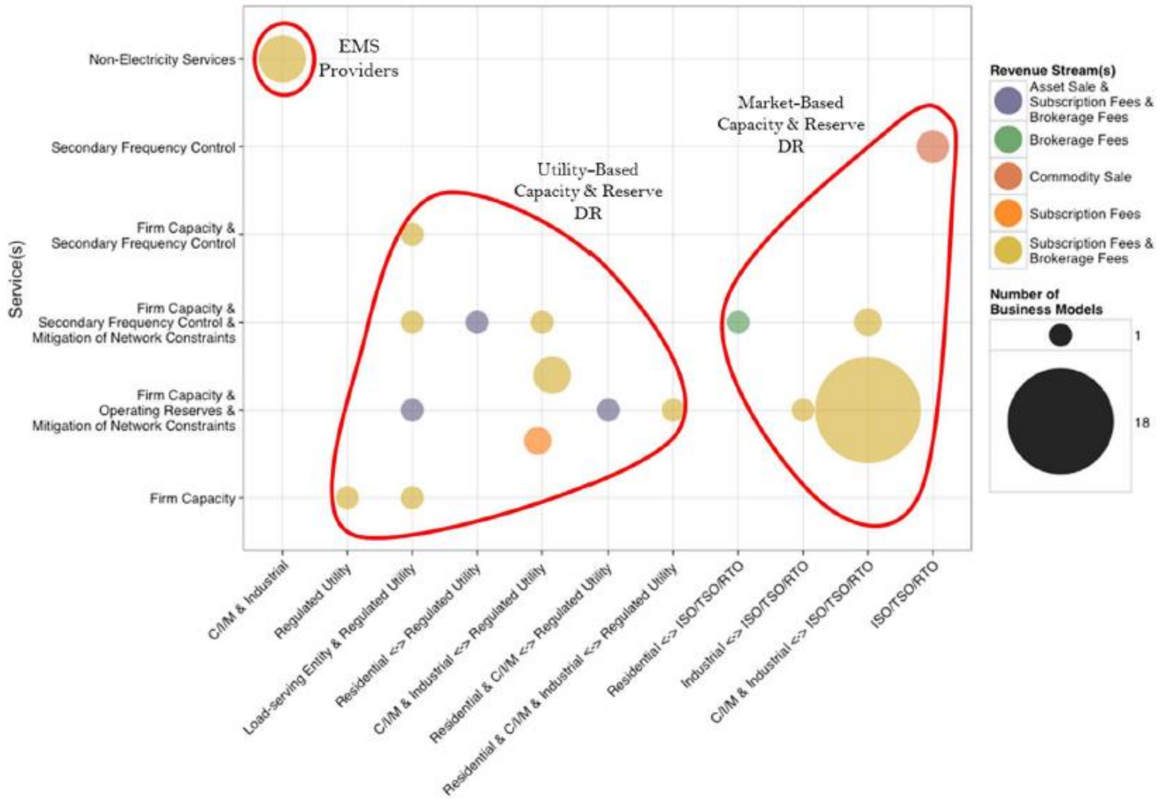

Figure 9 – Demand response and energy management systems business model taxonomy [49]

Figure 9 shows the DR and EMS customers targeted, services provided, and revenue streams leveraged by the business models. The size of the circles on the Figure 9 represents the number of business models. From the Figure 9, the three red circles represents the three major business model clusters with similar characteristics. Between the three archetypes, the two ones applicable to residential sector are “Market-based capacity and reserve DR” and “Utility-based capacity and reserve DR”.

Market-based capacity and reserve DR

The product provided by the DR business models depends mostly on markets rules, so it varies from market to market [50]. Nevertheless, a common structure can be found to define this type of archetype, which is showed in Figure 10 and described below.

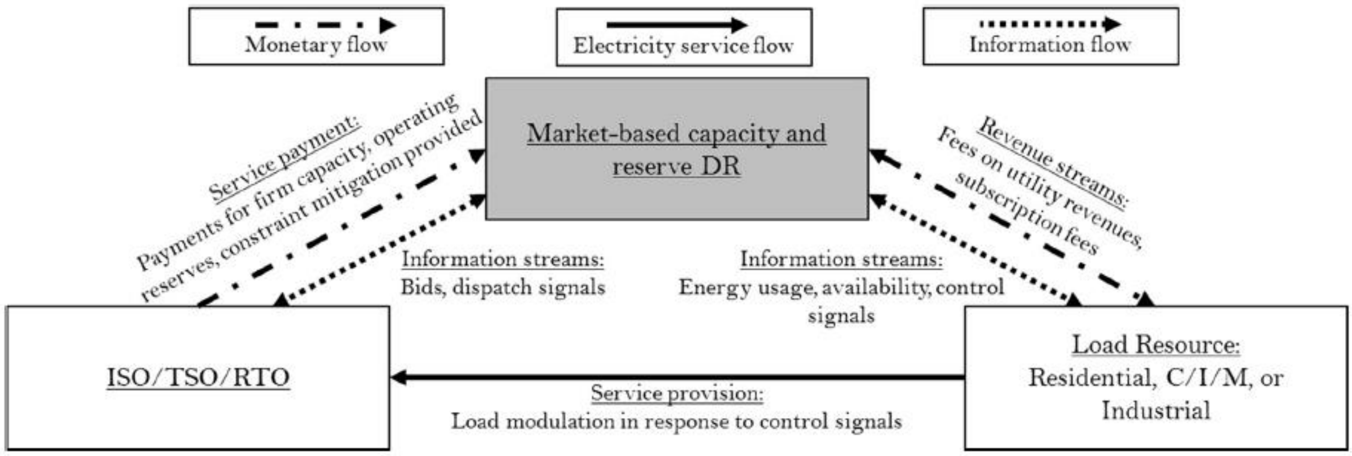

Figure 10 – Generic market-based demand response business model structure [49]

The typical targets for this business model are large Commercial/Institutional/Municipal (C/I/M) customers, industrial but also residential, even if it is less common. The customer receives an EMS to control energy consumptions and production and also to participate to ISO-based DR program. Manual response is also allowed if the EMS is missing.

The common customer loads are lighting, HVAC, refrigeration units and customer-sited generation as backup diesel or gas units, fuel cells or batteries. DR businesses typically make a profit by taking a portion of the revenues generated from the sales of capacity and reserve services (brokerage fees) and/or by charging for the use of the energy management tools that enables the demand control (subscription fees). Note that the business model's revenue is a brokerage fee, rather than a commodity sale; the business distributes the revenues associated with commodity sales to the customers under contract.

OhmConnect [51] is a business example, which selling this product to residential customers. OhmConnect is a free platform which rewards residential customers, for saving energy during specific times in an effort to reduce the load on power plants, during peak energy-use times. The rewards customers earn can be converted into money deposited via a PayPal account, donations to a customer's favourite charity, or credits towards energy-efficient products. The process is simple. The customer sign-up for OhmConnect, install an app (Figure 11) on a portable device and authorize to access the home’s smart meter and any supported internet-connected devices.

A few times a week, they alert you to energy spikes and ask the customer to cut back power consumption, or it will dial-it back through smart thermostat and other smart devices. Then the customer gets paid for the energy not used.

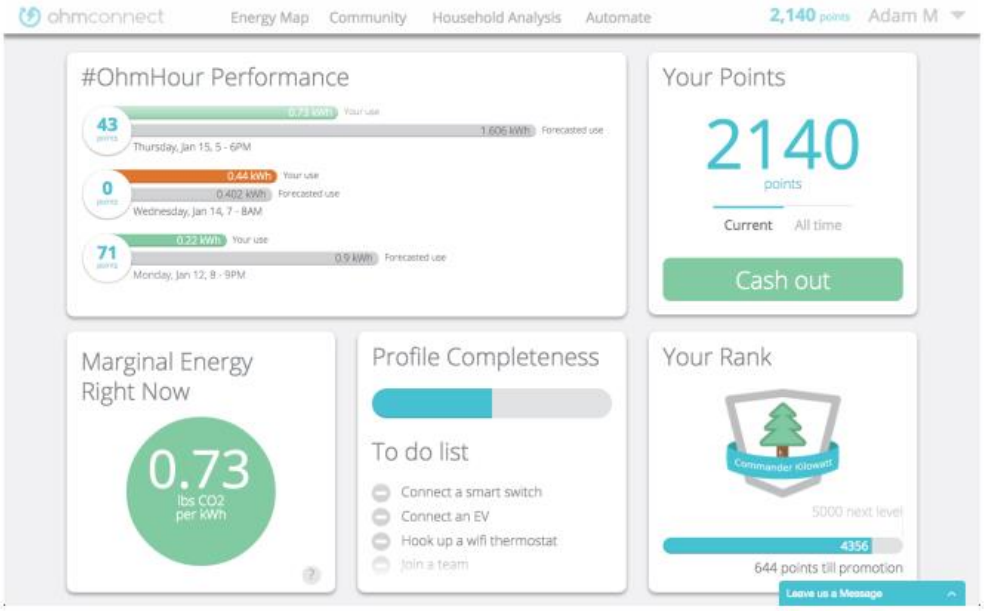

Figure 11 – Screenshot OhmConnect app for portable devices [51]

Utility-based capacity and reserve DR

This business model sell demand response products directly to regulated utilities, which contracts with DR providers to procure firm capacity, operating reserves and mitigation of network constraints (Figure 12).

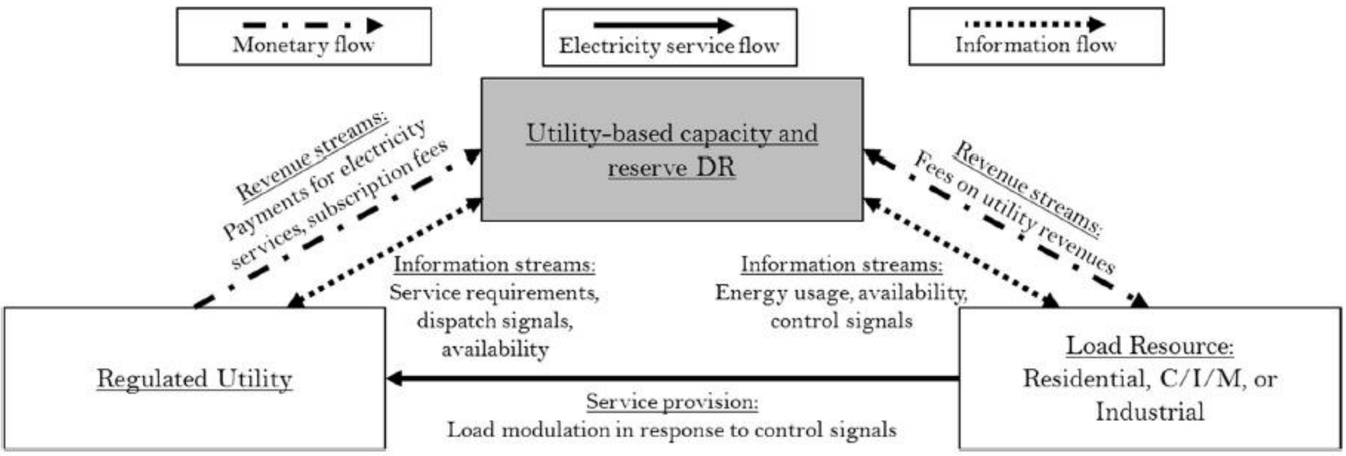

Figure 12 – Generic utility-based demand response business model examples [49]

These utilities operate under constraints of their regulators (i.e. Edison [52]). DR businesses provides DR resources at a certain price, which is negotiated between utility and regulatory body. DR aggregators share the revenues earned with the participating load resources. The DR providers focus on selling the products to utilities and working with the utilities to connect with the customers.

These businesses earn revenues through subscription fees or brokerage fees and they operates mostly on regulated environment, allowing greater participation of residential loads. The technical requirements of coordinating very fast responses from residential loads has limited the majority of the business models in the archetype to providing only capacity and secondary reserves [58]. The most common load for residential customer is coming from the HVAC units.

Examples of this business model are Comverge ([53], Table 1), EcoFactor [54] and "Rush Hour Rewards" program from Nest (smart thermostat provider).

EcoFactor provides three main services:

- The EcoFactor Proactive Energy Efficiency service uses data collected from Internet-connected thermostats to run patented energy algorithms, and automatically minimizes homeowner energy consumption.
- Optimized DM: it applies a set of algorithms to cool each home prior to the DR event. This type of pre-cooling minimizes uncomfortable temperature increases in the home, helping encourage greater participation in the DR program.
- HVAC performance monitoring: HVAC identifies lapses in HVAC performance and notify consumers as soon as a problem is detected.

When the customer signs up for Rush Hour Rewards [55], the energy company will pay him to help reduce the load on the electrical grid during rush hours (times when demand for energy is high). The Nest thermostat will turning down heating or cooling to help save more energy while still keeping the house comfortable.

An exception of the business model, described above, is the "behavioural model", which sells the services directly to the regulated utility, not engaging the customer outside of the behavioural program [59]. The revenue is typically based on subscription fees and shared savings charged to the utility. Opower [56] and Tendril [57] are the typical example of this business model.

Opower is a great example of the use of ongoing individualized feedback and prompts, coupled with norm appeals. Opower helps individual utility companies to send customized home energy use feedback reports to their residential utility customers. A full-colour reports include a comparison with other similar households, offer tips and strategies to reduce energy use, and provide seasonal energy consumption information. A web portal offers personalized insights and tips, and tools for choosing an optimal energy rate plan. In addition, Opower offers utilities the opportunity to send text messages directly to customers to alert them when their energy consumption is high and offer ways to reduce it.

The Tendril Platform ingests numerous data types from an array of sources, becoming a central repository for pertinent customer and home information. Examples of data types include:

- Home Characteristics (age, size, material, HVAC type, etc.)
- Occupant Demographics
- Utility (consumption, billing, etc.)

- Partnership (marketplace data, device data, etc.)
- Weather

Personalized insights are delivered through multiple channels, including HERs, High Bill Alerts, a Web Portal, Challenge Emails and the MyHome mobile application. Examples of insights include:

- Notification of high usage
- In-HER advertisement for product or service
- Energy saving tips and recommendations
- Utility program promotions (DR, Lighting, etc.)
- Energy use by appliance
- Weekly Challenges

Actions taken by customers or automatically initiated by the platform (once pre-authorized) ensure grid reliability and reduce the need for costly infrastructure. Examples of actions include:

- Customer buys a smart thermostat or upgrades an appliance
- Tendril Platform auto-adjusts thermostats to maximize EE savings
- Customer downloads a mobile app
- Tendril Platform optimizes water heaters to run during periods of excess renewable generation

4. DR PROGRAMS IN EU AND WW

4.1 OVERVIEW OF DR IN EU

Demand response programs have been playing an important role throughout the European Union in recent years, either better integrating the network due to new renewable technologies or reducing consumption in residences at peak times. Some countries, such as Belgium, Finland, France, Ireland, Switzerland and UK present a more advanced framework, making them an attractive environment for new projects and investments [44]. However, even for these countries, DR is still a new concept and there are areas for improvement, such as a standardization of the responsibilities of all participants involved (consumers, aggregators, suppliers), new regulations and interoperability issues [44]. It is also important to highlight the development of demand response in countries that historically had few or no openness to these types of programs, such as Estonia, Italy and Spain, which are working on new regulations and studying their potential for future applications through public and private partnerships [44]. Figure 13 shows the map of incentive-based demand response development in Europe.

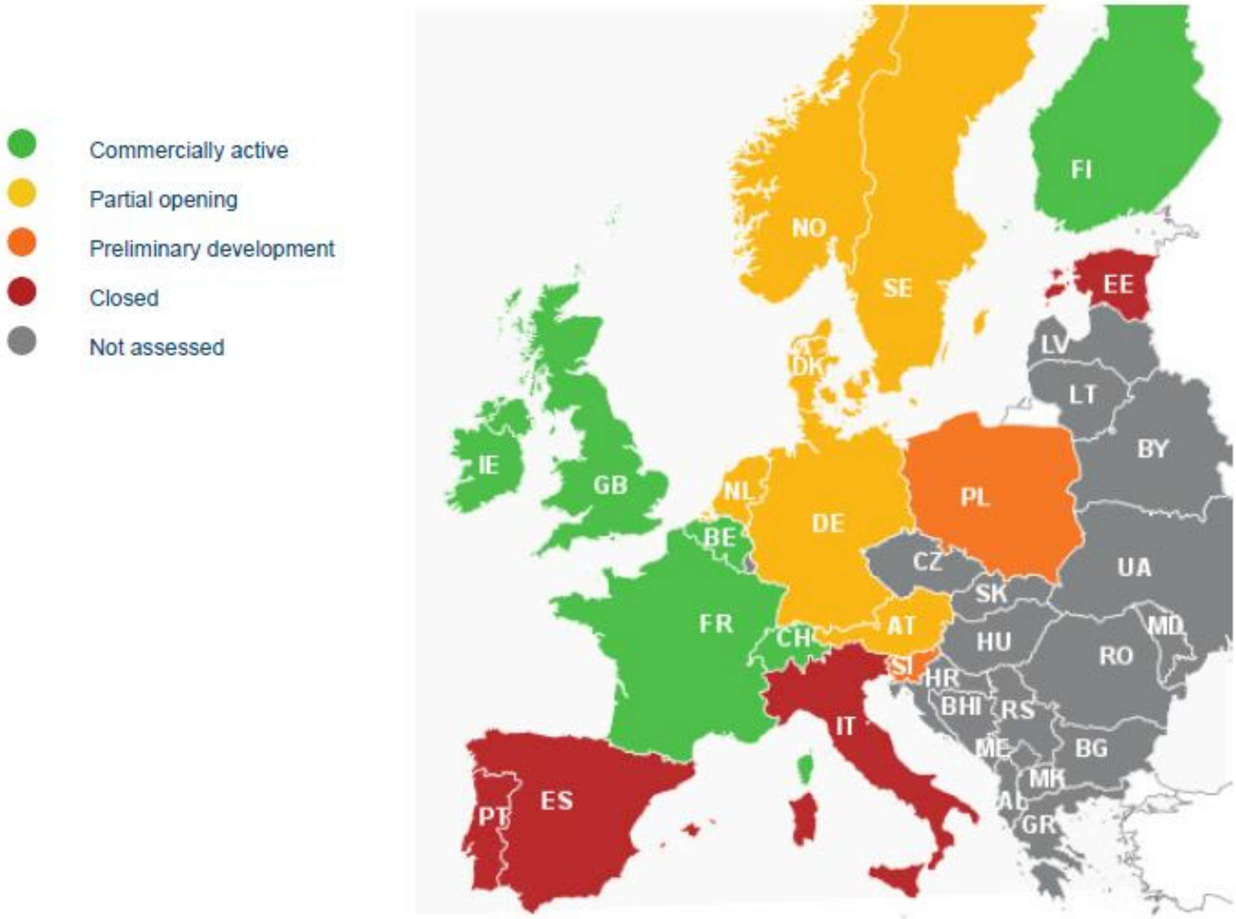

Figure 13 - Map of incentive-based demand response development in Europe. [44]

As can be seen in the map presented, the three countries where RESPOND pilots will be deployed are at different stages of DR development, a positive fact that will give a good view of its applicability throughout the European Union. Despite presenting the most critical picture when compared to other countries, Spain on the other hand presents good initial opportunities in DR, being encouraged mainly by government initiatives. Currently, the main barrier to be overcome is relating to demand-side flexibility and aggregators, which are not allowed under current legislation, similar situation is happening in countries such as Portugal and Estonia [44].

Denmark is yellow marked, which means there are several initiatives and discussions in progress and some DR modalities are already allowed, although an improvement in the definition of rules and roles of those involved in the system. Together with Germany, Austria and other Nordic countries, Denmark is part of the group of countries that have started the process of standardization for independent aggregators, which can bring integration and flexibility opportunities between them as a single energy market [44].

Ireland currently has a presence in some DR sectors. In order to foster greater applicability and also to standardize the roles of participating agents, the new "Integrated Single Electricity Market" will be implemented in 2018 and together with the DS3 (Delivering a Secure, Sustainable Electricity System) program it will bring improvements to balancing market, wholesale market, and as well as a newly designed Capacity Mechanism [44]. UK has a similar framework, an active open DR market which is already working, however some regulation and role definition are still needed for a better dissemination all over the countries.

4.1.1 DR PROGRAMS IN EU

<u>Belgium: LINEAR - Local Intelligent Networks for Energy Active Regions (2009-2014)</u> [60]

For a long time the generation of energy in Belgium was planned according to the demand required by the consumers. However, due to a modernization of the electric system, old low-efficiency plants are being shut down and there is also a considerable reduction in the use of nuclear power plants, giving way to the use of renewable energy-based plants such as solar and windfarms. However, this change in the energy matrix directly influences the concept of how the electric system works, now the generation depends on weather conditions, not being possible to manage only from the point of view of the user's demand.

To manage this new scenario, the LINEAR project had two different compensation models and four business models, finding the best way to balance the energy network according to the consumer's needs and also the energy generators capacity. The main concept of the project was to stimulate users to change their consumption patterns through a financial incentive (rate control) or by operating their equipment automatically (automated control), rewarding the households according to the level of flexibility of this control.

The focus of LINEAR project was residential demand response, its platform was built for multi stakeholder smart grid approach, with the objective of increasing the share of renewable energy resources, taking into account the reduction of investments in fossil fuel plants. A significant increase in average household consumption and demand peak was also considered in their studies due to the replacement of old fossil-fuel equipment for electrical equipment.

Most of the current applications of demand response are in the industrial sector, however to explore the potential of DR in residences it is necessary to consider different criteria of those normally applied, such as a different standard of consumption and level of comfort, essential components to guarantee the engagement of program participants.

LINEAR has implemented two types of smart appliances that offer a lot of flexibility for control and load reduction with little impact on user comfort. The first group takes into consideration equipment that can usually work at different times without major impact on user's life, such as dishwashers, washing machines and tumble dryers. In this project 445 of these kinds of equipment were automated. The second type of appliance were the buffered devices, such as smart domestic hot water buffers (15) and electrical vehicles (7). Additionally, 110 families were equipped with smart meters, approximately 2000 sub-metering points were installed and 94 houses had photo-voltaic panels, representing a total of 400 kWp.

As a project's result (Figure 14), in general automated demand response yielded larger and more predictable demand shifts compared to manual demand response. Consumption also shifted deeper into the night. For white goods appliances, the performance was good, however the performance for the buffers was lower, although consumption during the evening peak was lowered and postponed into the night, peak time consumption remained significant. White goods appliances outperformed the domestic hot water buffers (DHW) in relative savings, but the energy consumed by DHW buffers was much higher than that for white goods appliances.

Profit dynamic tariffs vs. flat tariff[1]	Profit (%) (average for white goods, absolute for Domestic Hot Water (DHW) buffers)	Standard deviation (%)
Dishwashers	18.33%	18.76%
Tumble dryers	8.92%	20.16%
Washing machines	10.97%	18.51%
DHW buffer 1	8.93%	/
DHW buffer 2	5.05%	/
DHW buffer 3	1.97%	/
DHW buffer 4	1.71%	/

Figure 14 - Average profit for white goods and DHW [60]

<u>France: NICE GRID the French Demonstrator of GRID4EU (2011-2016)</u> [61] [62]

The NICE GRID project consists of a smart electricity distribution grid that harmoniously integrates a high proportion of solar panels, energy storage (electrical and thermal), load management devices and smart meters installed in the homes of volunteer participants. The project is designed to address potential network constraints that could be caused by a massive integration of photovoltaic (PV) generation into a low voltage network, with the help of flexibilities connected to the grid.

The objective of this program was to study a grid model composed of photovoltaic panels and batteries, to create a self-sufficient neighbourhood in cases of power faults. To achieve this, it was necessary to work on the integration of solar energy generation with the distribution network, in addition to engaging users to change their consumption habits reducing demand at peak times.

The architecture of the project consisted in the deployment of an AMI (advanced metering infrastructure) network and the use of intelligent energy meters. This method allows 2-ways communication: equipment can send and receive data to and from the system through its own network, it is an efficient and accurate mode that doesn't need any other internet communication method to work. Consumers and aggregators can monitor and control devices such as heating, it is also possible to consult the household demand, the PV energy generation and the current battery load. All of these afore mentioned tools create a robust management environment which allows a quick response if any intervention is needed.

The success of consumer engagement contributed very positively to the results, during the analysed period more than 60% presented changes in consumption patterns, reaching up to 77% in certain cases. Consumers were financially rewarded with values ranging from EUR 20 to EUR 40, according to the effort made.

Another approach of GRID4EU was to engage the customers to shift their electricity consumption during “Solar Hours”, the volunteers were communicated via text and/or email when some action from them was needed. As a result, during the summer the encouragement to postpone some daily household tasks to solar hours proved fruitful. Efforts addressed essentially the use of household appliances (dishwasher, washing machine, etc.) and to a lesser extent ovens, vacuum cleaners, irons and swimming pool filtration systems. At the end of each summer, the customer was awarded with a gift-voucher for a tariff equivalent to the off-peak tariff for their power consumption during Solar Hours. The Figure 15 shows the average profile before and after GRID4EU deployment.

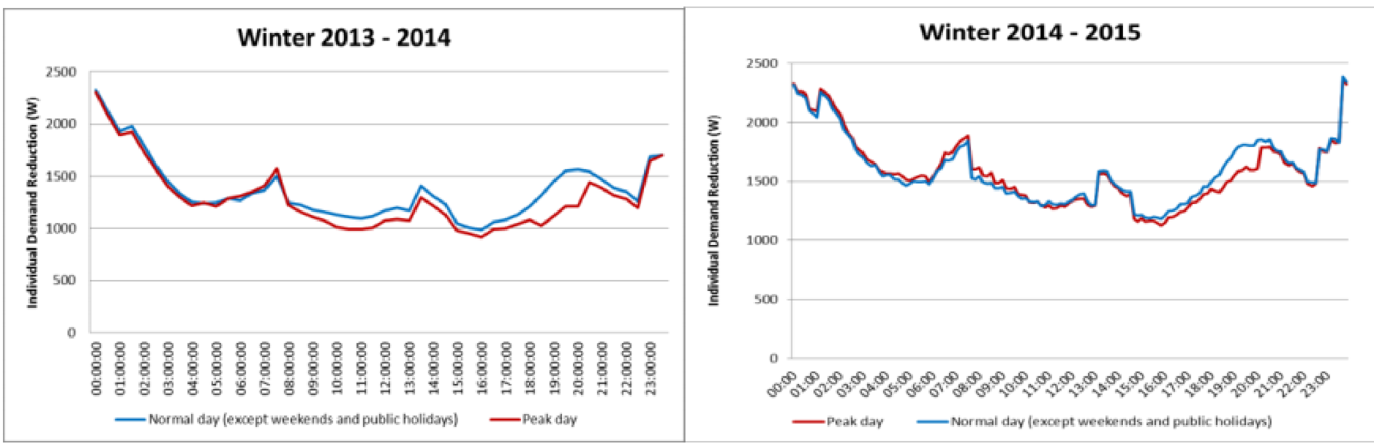

Figure 15 - Profile of all participants for winter 2013-2014 (left) and winter 2014-2015 (right) [61] [62]

According to GRID4EU results, the mean individual load reduction during the first winter was approximately 300W per participant, compared to 190W per participant the year after, which corresponds to a 37% decrease. Considering only the "voluntary savings" participants this reduction drops only 12% in power usage. Regarding heating, "Controlled heating" participants had just a 7% of energy saving, while the consumers who did the manual control presented 20% of energy reduction. It would seem that the controlled participants did not make any special voluntary effort (although they also received an SMS the evening before load shedding).

Netherlands: PowerMatching City (2007-2014) [63]

PowerMatching City is a project that demonstrates an energy system in an existing neighbourhood in Groningen, Netherlands, outfitted with a variety of Smart Grid appliances. Gas-fueled appliances ensure the integration of gas and electricity on the household level, creating flexibility for peak loads in electricity demand. This market-based Smart Grid implementation allows end-users to trade energy on a local market level.

Similar to the other DR programs, mentioned before, this project aimed to solve the intermittency challenges caused by the utilization of renewable energy technologies, specifically wind and solar. To avoid fluctuations in power supply, a smart grid was deployed given flexibility to maintain the power balance. Thereby, consumers could benefit from the program through greater control of their consumption pattern and also save energy.

The deployment considered two different models. 12 houses were equipped with hybrid heat pumps with heat buffers while ten houses had decentralized generation capabilities using micro-CHP. Twenty-four smart appliances and two electric vehicles with demand response capabilities were installed and all houses were connected to PV panels and smart meters. The city has a 2.5MW wind turbine that can support the energy balance if needed. Although there are no concrete numbers, PowerMatching City has been considered a success case for the deployment of a smart grid, using technologies that make network generation/demand flexible without general impacts to the user and its comfort, besides being interoperable allowing future growth.

Results from the PowerMatching City were compared with a similar Smart Grid project called Pecan Street in Austin Texas [64]. The comparison revealed that Households in PawerMatching City have reached a great balance between electricity demand and supply, the electricity consumption from the grid were largely reduces with a sufficient increment of self-generation. Looking the project performance between the 2013-2014, the average generation of electricity increase by 10%, while the consumption decrease by 6% and the average usage from the grid decrease by 18% [64]. The user experiences revealed that they preferred technologies that automatically shift their energy use, since it requires minimal effort for them. The study [64] also concluded that the patter of household electricity generation and consumption and their contribution to peak load balancing in the electricity network is largely influenced by existing Smart Grid set-ups, local climate and related needs for heating and cooling, the average capacity of installed energy generating technologies and the prevailing energy behaviour.

<u>EcoGrid: Consumer engagement in the future power system (2011-2015)</u> [33][34]

The EcoGrid EU project was a research and demonstration project that aimed to demonstrate the operation of a power system with high penetration of renewable and variable energy resources. The purpose was in large-scale to test how much every tenth electricity consumers on the Danish island Bornholm could contribute with flexible consumption and how test participants equipped with demand response devices with smart controllers and smart meters would respond to real-time prices based on their pre-programmed demand-response preferences. The Figure 16 presents the concept of EcoGrid project.

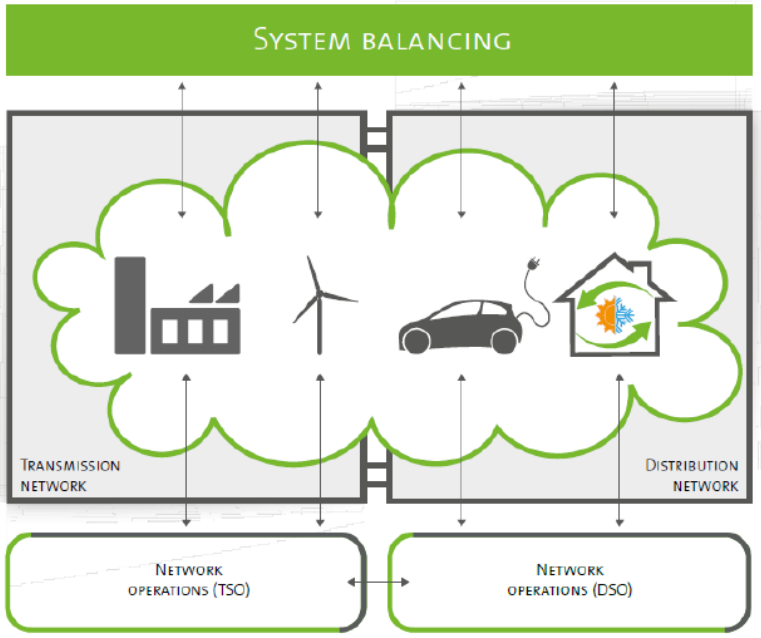

Figure 16 - EcoGrid demand-side participation [33]

The aggregated demand response to real-time prices and day-ahead forecasts was tested for approximately 1,900 private households with a peak load of 5 MW, and for 18 industry/commercial customers. The time resolution of the real-time price is 5 minutes, and all participating customers got Automated Metering Readers (AMR) meters with the same time resolution for evaluation and settlement. A majority of the household participants have heat pumps or an electric heating system and were equipped with a smart meter and other automation devices in order to adapt consumption to prices and price forecasts. About 500 households were manually controlled, only having access to price information (none of their electric household devices were automatically controlled). In summary, the four test groups chosen by EcoGrid were:

- The manual control group (price-based) (500 residential consumers);
- The automatic control group (price-based/semi-automated) (700 residential consumers);
- The automatic control group (incentive-based/fully autom.) (500 residential consumers);
- The group of industry/commercial buildings (direct control) (20 companies).

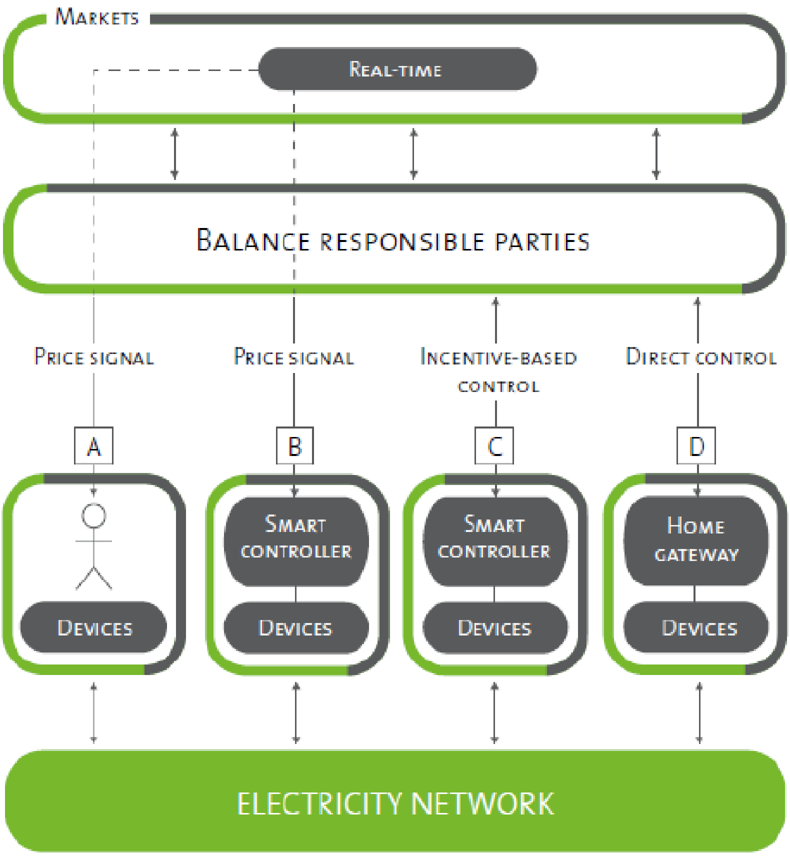

Figure 17 - EcoGrid consumer groups [33]

Overall, the EcoGrid project performed well and reductions were seen across all consumer test groups. The residences participating in the semi-automated and fully automated programs had a peak demand reduction of approximately 35% higher than expected, resulting in 236 kW and 347 kW respectively. The group of industries also showed a better reduction in the peak load when compared to the expected value of 50 kW, reaching a total of 61 kW. Only the group that performed the manual demand control achieved a below-expected performance with a reduction of only 29 kW, slightly away from the 60 kW target.

However, considering the project as a whole, the result was very positive, reaching a 1.2% reduction in peak demand, exceeding the 1% target, besides having a positive acceptance of 70% by consumers.

EirGrid: Power Off & Save - Residential Consumer Demand Response Project (2016) [65]

In Ireland, state-owned electricity company EirGrid in partnership with Electric Ireland launched in 2016 the Power Off & Save pilot project, which is investigating the impact of residential demand reduction in the grid during peak times, through inputs sent by EirGrid. Electric Ireland has recruited more than 1400 consumers who took part in 10 Power Off & Save events. During each event, a text was sent to participants asking them to reduce their usage for the following 30 minutes. The change in usage will be recorded and analysed.

The programme target is a minimum of 2MW and a maximum of 5KW demand response. Some participants received smart control technology, enabling them to control certain appliances remotely, while others are only able to reduce usage manually. Participants are divided into three main groups:

- Smart Energy Controller (SEC) Group - participants in the SEC group are using Smart Energy Controllers to help them reduce usage. The package includes three Smart Plugs to install on energy intensive appliances such as tumble dryers, dishwashers and washing machines.
- Smarter Pay As You Go (SPAYG) Group - this group was recruited from the existing Electric Ireland Smarter Pay as You Go customer base, they didn't receive any additional smart control technology;
- Smart Hot Water Group - a group of participants that are testing smart hot water cylinders.

The workflow in the Figure 18 shows the interaction between EirGrid and consumers.

Figure 18 - EirGrid process workflow [65]

This project is in its last stages, scheduled for the first half of 2018. However, EirGrid released last year a report with the partial results achieved so far. After two Power off and Save events, the analysis of the results for both shows that 50% of all participants reduced their consumption when compared to the 30 minutes period before the event. The Figure 19 shows the consumers time reaction in there events.

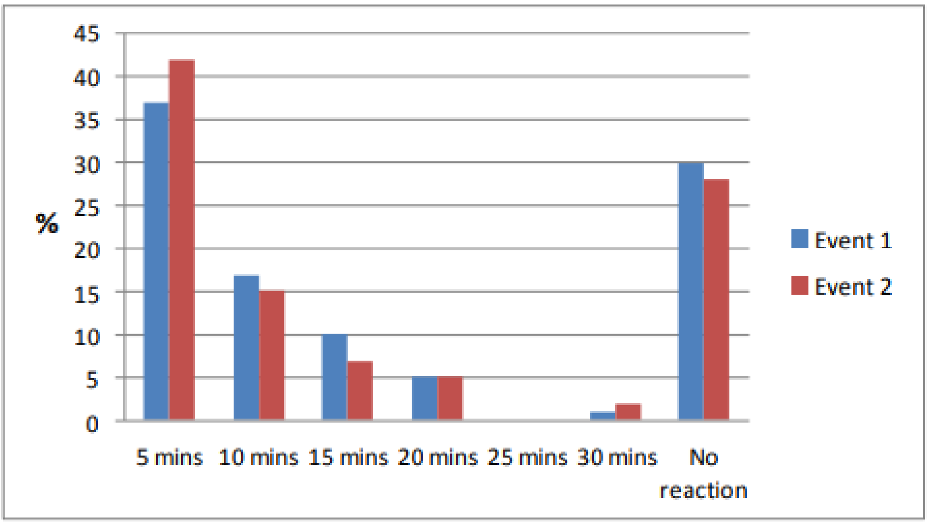

Figure 19 - Consumers reaction in EcoGrid [65]

Looking at the level of usage reduction, the data analysis shows that the available load is considerably lower than the original estimate. Usage reduction levels are being captured for future events and the cumulative data will be analysed at the end of the project, the first results showed a total reduction of approximately 290 kW.

NOBEL GRID: New Cost Efficient Business Models for Flexible Smart Grids (2015-2018) [66]

The NOBEL GRID project aims to provide advanced tools and ICT services to all actors in the Smart Grid system and retail electricity market, in order to create benefits from cheaper prices, more secure and stable grids, and cleaner electricity generation. These tools and services enable active consumer involvement, new business models for new energy actors and the integration of distributed renewable energy production.

The main impact expected is regarding changing the electricity market concept, fostering an active participation of prosumers and new actors in energy markets, such as aggregators and Energy Service Companies, besides opening new markets for advanced Smart Grid and smart metering technologies to stimulate European competitiveness in the sector.

The NOBEL GRID expected results are the following:

- the development of a Smart Low-cost Advanced Meter based on Unbundled Smart Meter (USM) concept, which will provide extended functionalities to all stakeholders within the Smart Grid energy system.
- Grid Management and Maintenance Master Framework (G3M), the access point for Distribution System Operator (DSO) into the advanced functionalities and services, providing electricity network monitoring and control functionalities.
- Demand Response Flexibility Market (DRFM) cockpit is a decision support system for Aggregators, Retailers and ESCOs to manage their flexibility assets while supporting grid operators to ensure network stability and security.
- Energy Monitoring and Analytics Application (EMA App) provides domestic and industrial prosumers with real time data visualizations and targeted user profile recommendations to improve energy efficiency, maximize use of renewables and minimize energy bills, giving them control and protection.

This pilot is being carried out in Bilbao area in the North of Spain in the distribution grid operated by Iberdrola Distribución. Figure 20 presents the stakeholders affected by NOBEL GRID.

The demonstrator area is characterised by 1.075 Secondary and more than 190.000 customers will be involved. The massive Advance Metering Infrastructure (AMI) deployment in the area was completed before. This project is mainly focused on monitoring and control of LV network and network management methodologies for network operations, although it must be underlined the selection of two sub-functionalities related to novel approaches to asset management.

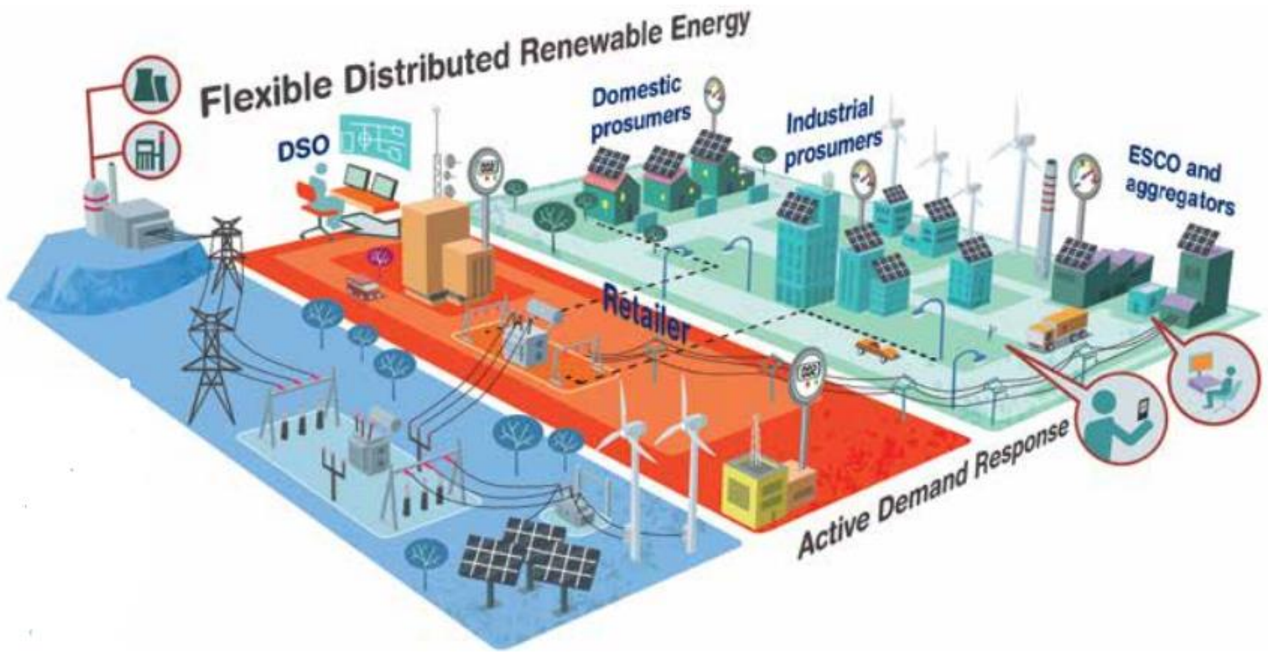

Figure 20 - NOBEL GRID project stakeholders [66]

4.2 OVERVIEW OF DR PROGRAMS IN WW

The International Energy Agency (IEA), composed by 29 countries from North America, Europe and Asia, produced a report in 2016 on energy market trends in the coming years. Among the topics covered, there is a specific chapter about demand response, which presents the current framework, good practices and also the challenges for a good future dissemination. It is a common sense that a major challenge for regulators in the successful transformation of the electricity sector is the integration of new technologies into the power system [67]. This is not only about electricity generation, but also about new technologies that change the way we consume electricity.

To date, demand response has been widely applied in industries, however the development of new technologies and smart appliances in the residential area has shown the importance of this new market, empowering and raising the user's awareness for a new green life-style, helping to better manage their energy demand, reducing their costs and also contributing positively to the environment. According to [67], while many smart technologies already exist, four principal challenges remain:

- the need to build consumer engagement;
- the lack of a supportive regulatory framework in many markets;
- privacy and cyber security issues that can be a major constraint unless factored in the design of demand response arrangements;
- the large number of fragmented stakeholders involved in restructured electricity markets, which introduces added complexity.

4.2.1 DR PROGRAMS IN WW

Japan: Share – Innovative Community and Energy System (2010-2014) [68]

Demand response has been widely applied in industries, however the development of new technologies and smart appliances in the residential area has shown the importance and potential of this new market, empowering and raising the user's awareness for a new green life-style, helping to better manage their energy demand, reducing their costs and also contributing positively to the environment. The integrated local management uses smart meters as the gateway for exchanging data between the smart appliances and the EMS (energy management system), making its integration to storage batteries and renewable energy generation.

There is a heightened worry about the stable and continuous supply of electricity, new decentralized models of generation through renewables are replacing the old plants that still use the concept of management of generation view only. Foster demand side management through DR programs has become a key element of this new concept, encouraging consumption reduction through both dynamic prices and incentive programs. This practical reduces the duty of electric companies to control power generation to respond to changes in power demand, which will also lead to a reduction in power plant capacity. The reduction of electricity bills is an economic benefit for consumers that practice demand response activities.

The project also confirms the participation of residential customers using methods that differ from business ones. Information exchange sessions and workshops are held a number of times each year in order to increase people's understanding of the project and as a result consent forms were received from 195 out of 225 households. In order to encourage participation by consumers, it is important for both power suppliers and consumers to share information on energy. In this project, a smart meter and information terminal that displays information from the smart meter is installed in each household and office, which allows information to be shared between the power suppliers and consumers through CEMS.

Regarding the models offered to the consumers, the dynamic pricing system consisted in creating a model which the unit price for electric power rates fluctuates in response to demand for electric power supply in the area for energy management.

The incentive program has also developed a mechanism that aims to maintain and increase the motivation of consumers to save electricity, and encourage changes in consumers' demand for power, without being dependent on changes in electricity bills. Overall, through these aforementioned actions, the project confirmed an approximate 20% peak reduction in the summer and winter of 2012, and the summer of 2013.

U.S.A.: Entergy New Orleans "SmartView" AMI Pilot (2010-2013) [70]

Entergy New Orleans (ENO) developed and implemented the Smart Grid pilot program to test low-income customer response to certain DR programs enabled by AMI technology, to evaluate customer behaviours and the impacts of peak time rebates, air conditioning load controls, and other enabling technologies. The pilot provided the company with valuable information regarding customer acceptance of AMI technologies.

The pilot program's measurement period began in June 2011 and ended in September 2012, with approximately 4700 participants, or about 10% of the target demographic population. The program offerings consisted of 1) monetary incentives and 2) a set of one or more technologies to enable interval metering, provision of enhanced customer information about electricity consumption and month-end bill estimates, and (for some participants) automated load response. The users were distributed according to the following groups:

- A/C Load Management (ACLM): A/C is cycled off in ten-minute increments twice per hour during the event hours (1-4 p.m. on event days). No prior notification of events; Desired behaviour: No adjustment to A/C during event; general increase in energy-saving habits.
- Peak Time Rebate (PTR): Participants are incentivized to reduce energy usage during the hours of 1-6 p.m. on PTR event days. Notification by 5 p.m. on the day prior to event. Desired behaviour: Shift energy use to off-peak period; general increase in energy-saving habits.
- IHD: Access to current consumption, estimated current bill, projected month-end bill via the IHD. Usage numbers are real-time and bill estimate updates once at end of day.
- Desired behaviour: General increase in energy-saving habits.
- Web Portal: Access to their detailed usage data and energy-saving information via web portal. Usage numbers update 4x/day and bill estimate updates once at end of day. Desired behaviour: General increase in energy-saving habits.

Although energy savings varied among the treatment groups, 78% to 90% of participants believed they saved money as a result of the program, and the data indicates that 58% to 67% of customers actually saved energy. Post-pilot surveys found that participants had a very positive experience during the SmartView pilot. Almost all respondents (99%) felt that customer service representatives were "Very Helpful" or "Somewhat Helpful," with the majority of every treatment group responding "Very Helpful".

The most effective result was a peak event load reduction of 11-16 % through ACLM and PTR.

U.S.A.: Borrego Springs Microgrid Demonstration (2012-2014) [71] [72]

The Microgrid Borrego Springs Demonstration focused on the design, installation, and operation of a community scale "proof-of-concept" Microgrid. The site of the Microgrid was an existing utility circuit that had a peak load of 4.6 MW serving 615 customers in a remote area of the service territory. The key aspects of the Microgrid Demonstration were the integration and operation of the of distributed generation, advanced energy storage, price-driven load management and fault location.

Regard demand response, the overall objectives of this demonstrator were to achieve a 15% or greater reduction in feeder peak load, to develop a strategy the integration of the Automated

Metering Infrastructure (Smart Meters) system into Microgrid operations and to demonstrate the capability to use automated distribution control to intentionally island customers in response to system problems.

Approximately 60 residential and small commercial customers were provided home-area-network energy management systems to display real-time energy use and pricing information and provided education and training to use the convenient options to manage energy use remotely. These customers were provided incentives for participating and actively managing their energy usage to moderate heavy electrical use during peak demand periods to prevent electrical supply emergencies during the operation of the Microgrid. Figure 21 shows the key elements of the project.

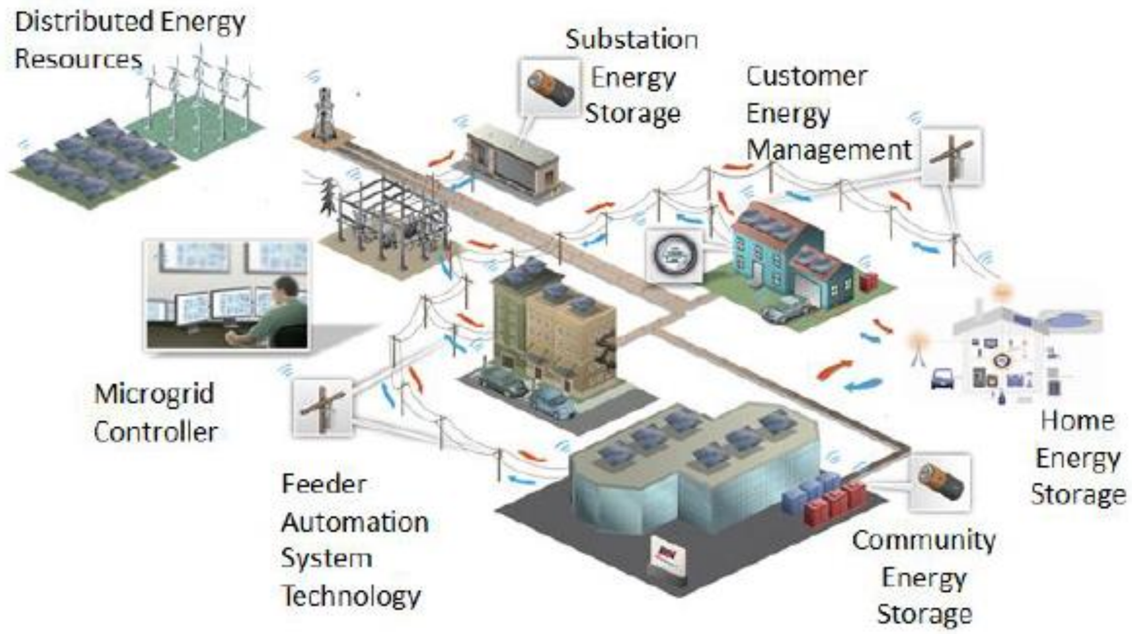

Figure 21 - Borrego Springs Project overview [68]

This project designed and demonstrated a utility operated microgrid that incorporates sophisticated sensors, communications, and controls to explore microgrid islanding (temporarily disconnecting from the grid) of multiple customers along an entire distribution feeder. The Borrego Springs Microgrid Demonstration successfully incorporated customer participation into the operations of the electrical delivery system by enabling coordinated demand response concurrent with Microgrid operations. In addition, the Microgrid integrated and controlled multiple distributed generation and electrical energy storage devices to operate the grid in the most cost-effective and reliable manner, benefiting customers by reducing overall outage time during very adverse conditions. Overall, the Borrego Springs microgrid achieved a greater than 15 % reduction in feeder peak load and improved system reliability.

4.3 EFFICIENT DR PROGRAMS

Residential DR programs can be challenging to implement successfully due to different aspects as limited responsiveness of customers, equity considerations between them and high cost of the ICT infrastructure [69]. How to define a DR program successful? The existent studies collected on this document underlines the fact that there are so many different aspects that can influence the implementation of a DR program.

[46] conducted a meta-analysis, using logistic regression approach, on 32 residential electricity demand response programs, to determine whether their likelihood of success were correlated with the structures of and contexts surrounding the programs. The analysis found that the success appears to be correlated with the extent of urbanization in the region where the DR program is implemented, the renewable energy policy and targets, and the annual economic growth rates.

The study offers the following guidance to increase the effectiveness of future DR programs:

- Deploy DR programs in urban areas, particularly in faster-growing cities that are likely to have greater infrastructure spending;
- Complement DR and electricity policy with supportive renewable energy policies;
- Couple electricity policy with wider economic policies and urban development planning, in order to also place it within the context of broader sustainable urban development.

5. DR STATUS IN PILOT COUNTRIES

5.1 DENMARK

Within the countries of the European Union Denmark stands out for having a balanced electricity market, its electricity production is enough to meet the demand needed even at peak times. Consequently, demand response programs are still very limited because there is no demand for flexibility either by the transmission or distribution operators. However, with the increasing amount of variable resources (wind and solar power), investments today need to take flexibility needs into account to prepare for a future where the challenge of balancing production-side and demand-side will increase [44].

Consumers are allowed to participate in all the ancillary services in Denmark. However, due to a weak business case as well as a regulatory environment which makes it difficult for independent aggregators to develop innovative Demand Response businesses in the market, Demand Response participation within the markets remains limited [44]. The lacks in the regulatory environment have affected the aggregation, which is legal in Denmark but the responsibilities are not well-defined, creating a barrier to independent aggregators.

Although demand response programs can participate in the wholesale market, regulation's improvement should be made in this topic as well to make this feasible. As an example, some markets have a volume demand of 10MW which makes it impossible for smaller pools of flexibility like heat pumps and vehicles to enter the market unless they have for example 5000 heat pumps [44]. Additionally, payments in the wholesale market are too low to make a positive business case.

Regarding distribution network services, demand-side flexibility could represent an important tool for local congestion management. Several demonstration projects have been run by utilities focusing on the integration of intermittent energy into the grid. However, as commented previously, there is almost no pressure to purchase flexibility [44]. There are a number of relevant projects in Denmark currently analysing the effective use of flexibility by distributor system operator including EcoGrid, which will be detailed later.

A new network tariff regime is currently being discussed and amended both at the TSO and DSO level. Both projects are in the exploratory phase but one of many special attention points is the need of active Demand Response. For this market to grow, these customers would need to be specifically enabled through low entry barriers and upfront costs [44]. The DR potential penetration on the Danish market are summarized in Table 5.

Table 5 – DR potential in Denmark

Country	Denmark
DR Potential	0.35 GW
% peak load	7.5%
Main Enablers	1) Ancillary services are open to Demand Response; 2) Prequalification is made at the aggregated pool level; 3) Demand Response can participate in the wholesale market.
Main Barriers	1) Payments in the wholesale market are too low to make a positive business case; 2) Product requirements are still largely generation-oriented and block demand-side resources; 3) Some markets have a volume demand of 10MW which makes it impossible for smaller pools of flexibility to enter the market.
Demand Response Access to Markets	Consumers can trade their flexibility into the common Nordic wholesale markets. However, the traded volume is very limited, mainly due to low prices.
Service Provider Access	The current market definition requires that independent / third-party aggregators must bilaterally contract with the consumer's BRP and retailer (if they only wish to sell flexibility and not energy) to provide Demand Response services.
Product Requirements	For incentive-based DR, some markets require online measurement and 24 hr service.
Verification and Penalties	There are no specific penalties that discourage those from participating on either the balancing or wholesale market apart from the imbalance settlement procedures.

5.2 IRELAND

In Ireland, demand response participation has increased in recent years mainly because the regulation changes after the phase out of its previous DR scheme in early 2013. The electricity market rules were changed by Ireland's TSO Eirgrid, now Demand Response providers can enrol as Demand Side Units (DSU) in the Single Electricity Market (SEM). These regulatory changes combined with the rapid expansion of wind energy and a target of 40% renewable energy in electricity generation by 2020, will be an important driver for DR programs, as the system's need for flexibility is set to increase [44].

The opening of the balancing markets for DSUs in 2018 and with the launch of the Integrated Single Electricity Market (I-SEM) in 2018, which intend to integrate the whole island's electricity market with European electricity markets enabling the free flow of energy across borders, will bring new business opportunities, besides delivering increased levels of competition which should reduce the prices as well as improving security of supply and transparency [44].

Regarding aggregators, they are allowed in Ireland but the minimum size of DSUs is 4 MW. The reduction of this value to 1 MW would encourage greater participation and competition in this area, since currently many loads shall be grouped to achieve this minimum 4 MW. Aggregators do not have to ask for permission or inform the retailer or BRP prior to load management. They can aggregate load from anywhere in the country. Neither the BRP nor the aggregator is charged for the imbalances caused by the load management.

Demand Response programs can participate in the wholesale electricity market from the point of view of bidding and dispatch, however Demand Response providers do not earn an energy payment for this. Demand-side flexibility could represent an important tool for local congestion management, there is no much development from the distributor operator at this time, but it should change in a near future because the application of renewable sources in the system will change the way energy should be consumed.

The tariff scheme in Ireland is close to flat and does not reflect congestion or real time need, even industrial tariffs do not have a significant effect on demand-side response activities. An ex-post pricing mechanism prevents the involvement of implicit demand-side measures given the lack of actionable price signals. Lack of different market products limits the level of participation.

For balancing market, all the individual units of each pool of loads must fulfil all technical and prequalification requirements. This prequalification is complex and very costly and might even get worse in the years to come, with the opening of the balancing market programs to Demand Response. Prequalification should be carried out at the pooled level to avoid this issue [44].

The DR potential penetration on the Irish market are summarized in Table 6.

Table 6 – DR potential in Ireland

Country	Ireland
DR Potential	0.40 GW
% peak load	7.5%
Main Enablers	1) Aggregation is allowed and the minimum bid size is 4 MW for DSUs. 2) The new "Integrated Single Electricity Market" to be implemented in 2018, together with the DS3 programme, will open a range of markets for demand-side response, specifically the balancing market, and the wholesale market, as well a newly designed Capacity Mechanism.
Main Barriers	1) An ex-post pricing mechanism prevents the involvement of price-based demand-side measures given the lack of actionable price signals. Lack of different market products limits the level of participation.
Demand Response Access to Markets	Individual Demand Response sites may be aggregated in order to be operated as a single demand side unity (DSU). Demand Response participates in the wholesale electricity market from the point of view of bidding and dispatch, however Demand Respond

Service Provider Access	In the balancing market, a medium to large electricity users (> 4 MW) can participate in a Demand Side Unit (DSU) or an Aggregated Generating Unit (AGU). The aggregator does not require BRP's agreement prior to load management
Product Requirements	For incentive-based DR, demand sites typically use on-site generation, plant shutdown, or storage technology to deliver the demand reduction.
Verification and Penalties	In case of repeated under-performance or non-delivery, a Demand Response aggregator faces license restrictions from the Commission for Energy Regulation (CER) and/or Utility Regulator of Northern Ireland.

5.3 SPAIN

Spain is the first country in the world where the default price for households is based on hourly spot prices, which is an important drive for price-based demand response programs. Consumers are already encouraged to participate in Time-of-Use (ToU) contracts, that give them the possibility to shift consumption patterns in response to signals given, thus saving energy and network resources [44]. The contracts are flexible and can have time of use differentiation up to 3 periods for households and up to 6 periods for large consumers .

On the other hand, even though some pilot projects being deployed in this area, the development of incentive-based demand response are still limited to industrial consumers. Nowadays Spain depends on hydro and gas generation to cover the flexibility needs, but the recent renewable energy generation growth and the development of microgrids are changing the framework, then changes in the network management and regulations should be made to balance the energy systems and support future applications [44].

The Interruptible Load programme is the only one incentive-based demand response program, which is reserved exclusively for large industrial consumers. Aggregation is still not legal in the Spanish electricity system, however some non-recognized representatives exists and sell energy in the name of their prosumers, besides building balancing perimeters. Since 2016, decentralised and renewable energy resources (specially wind generators) have been able to prequalify and participate in the balancing market (tertiary reserve), this could significate a good step in new regulations for aggregators [44].

From the point of view of distribution network, demand-side flexibility can play an important role for local congestion management. If needed, the distributor system operator can coordinate with the transmission operator the use of the interruptibility service or as for redispatching and curtailmaint of generators. Some pilot projects are on-going at city level, such as "Smart City Project" in Malaga, and the "Barcelona Smart City" [44].

The DR potential penetration on the Danish market are summarized in Table 7.

Table 7 – DR potential in Spain

Country	Spain
DR Potential	4.80 GW
% peak load	10%
Main Enablers	1) Spain is the first country in the world where default price for households is based hourly spot prices, which is an important driver for price-based demand response programs. 2) All consumers are able to take advantage of Time-of-Use (ToU) contracts.
Main Barriers	1) Aggregation is not legal; 2) There is only one scheme allowing incentive-based demand response: The interruption load program, reserved only for large industrial consumers.
Demand Response Access to Markets	While some of the markets are open for Demand Response in principle, in practice this applies only for large industrial consumers. Aggregated Demand Response is allowed only for Tertiary Control.
Service Provider Access	Overall, there is no possibility for aggregated demand-side resources to take part in the Spanish electricity market. Only consumers with contracted power above 5 MW have access to interruptible demand service managed by the TSO.
Product Requirements	Smart meters deployment at advanced stage.
Verification and Penalties	For the Interruptible Contracts, the new scheme has defined stricter conditions in case of non-fulfilment of the project requirements. A penalty of up to 120% of the availability price applies for the first failure, and exclusion from the tender applies for a second failure.

6. DISCUSSION

Chapter 5 describes the DR status on the RESPOND pilot countries.

The main features of the DR programs analysed in Chapter 4, are summarized in Table 8.

Table 8 – Main features of the analysed DR programs

DR project	Country	Sample size	DR type	Tariff type	Active control	Smart meters	Smart appliances	Renewables
Linear	Belgium	240	Price Based	RTP	Manual + Automated	Yes	Yes	PV
Nice Grid	France	2300	Incentive Based	Flat	Manual + Automated	Yes	Yes	PV
Power Matching City	Netherlands	22	Incentive Based	ToU	Automated	Yes	Yes	PV + Wind turbine
Share	Japan	195	Price & Incentive Based	RTP	Manual	Yes	No	PV + Wind turbine
Smart View	USA	4700	Price Based	ToU	Manual + Automated	Yes	Yes	No
Borrego Springs	USA	600	Price Based	RTP	Manual + Automated	Yes	Yes	PV
EcoGrid	Denmark	1900	Price & Incentive Based	RTP	Manual + Automated	Yes	Yes	PV + Wind turbine
EirGrid Power Off & Save	Ireland	1400	Price Based	CPP/ToU	Manual + Automated	Yes	Yes	No
Nobel GRid	Spain	6000	Incentive Based	ToU	Manual	Yes	No	PV + Wind turbine

Taking into account the RESPOND aim and the potential status of DR in pilot countries, the analysed DR programs are defined high, medium or low (Table 9) congruent with RESPOND project, from the ICT and Business model point of view.

Table 9 – DR projects relevance to RESPOND from ICT and Business point of view

DR project assessed	Country	Description	Relevance to RESPOND	Comments
Linear	Belgium	LINEAR focus is the automation of smart appliances that offered a lot of flexibility for control and load reduction with little impact on user comfort.	**Business: High** **ICT: High**	Compared to RESPOND, LINEAR project presents a similar general concept, aiming to automate residential loads and to integrate renewable energy sources, reacting to utility signal prices.
Nice Grid	France	NICE GRID consists of a smart electricity distribution grid that integrates a high proportion of solar panels, energy storage (electrical and thermal), load management devices and smart meters.	Business: High ICT: Medium	This project is a good example about consumer engagement. Smart meters are used for demand monitoring and renewables generation, however just few loads (heaters) were automated.
Power Matching City	Netherlands	PowerMatching project demonstrates an energy system in an existing neighbourhood outfitted with a variety of Smart Grid appliances.	**Business: High** **ICT: High**	Houses were equipped with automated smart appliances for load control, integrated to solar panels and wind turbine. The technologies applied have considered interoperability for future growth.
Share	Japan	Share project consists of a smart electricity distribution grid that integrates a high proportion of solar panels, wind power generator and energy storage and smart meters.	Business: High ICT: Low	This project is a good example about consumer engagement. Smart meters are used for demand monitoring and renewables generation, however the load control is manual.
Smart View	USA	Smart Grid pilot program to test low-income customer response to certain DR programs, to evaluate customer behaviours and the impacts to the network.	**Business: High** **ICT: High**	This pilot has high relevance because assessed 4 different of DR programs, from only price incentivated to fully automated ones.
Borrego Springs	USA	The Microgrid Borrego Springs Demonstration focused on the design, installation, and operation of a community scale “proof-of-concept” Microgrid.	Business: Medium ICT: Medium	The DR objective in this project was to reduce the energy demand through a smart meter that displays pricing information in real-time. Education and training were the customer's engagement driver.
EcoGrid	Denmark	Project that aimed to demonstrate the operation of a power system with high penetration of renewable and variable energy resources.	**Business: High** **ICT: High**	This pilot has high relevance because assessed 4 different of DR programs, from only price incentivated to fully automated ones.
EirGrid Power Off & Save	Ireland	"Power off and Save" is investigating the impact of residential demand reduction in the grid during peak times.	**Business: High** **ICT: High**	This project is a good example about consumer engagement. Some groups participate just in the price-incentive program.

Nobel GRid	Spain	The NOBEL GRID project aims to provide advanced tools and ICT services to all actors in the Smart Grid system and retail electricity market.	Business: Medium ICT: Medium	DR enabling is just part of the Nobel Grid. Its focus is on incentive-based programs.

Looking at Table 9, "LINEAR, PowerMatching City, SmartView, EcoGrid and EirGrid Power Off and Save" resulted the most relevant DR programs for RESPOND aim. The ICT and Business solutions developed by these projects could be used as guidelines for RESPOND to optimal design the DR programs on the pilot countries.

7. CONCLUSIONS AND RECOMMENDATIONS

This document analysed DR programs applied to EU and Worldwide. The methodology employed to address the DR programs overview, it was mainly based on desk research techniques via literature review. 72 documents between relevant journal papers, reports and web pages were analysed. The authors found the DR literature quite fragmented, since many contemporary DR programs do not reveal completely the solutions developed and the published results does not cover all the aspects needed to properly characterize the program itself.

The document reports an overview of 11 contemporary successful DR programs, implemented at European and Worldwide levels. "LINEAR, PowerMatching City, SmartView, EcoGrid and EirGrid Power Off and Save" projects resulted the most relevant DR programs for RESPOND (Table 9). The document includes also other two studies [40] and [46] which analysed a total number of 43 DR programs. General recommendation for successful implementation of the DR schemes on pilots can be retrieved on section 3.4.1 and 3.4.2, describing general barriers and drivers for DR implementation.

The following paragraphs summarize the main findings and lesson learned from the ICT, business model and customer engagement points of view, individually linked with the project pilots. The analysis will be at disposal to other task in WP1, in particular T1.4 specifying strategies and actions for project pilots.

ICT

The fundamental aspects of DR programs for the ICT point of view were presented in section 3.2. The basis of metering and control technologies and communication infrastructure/protocols were introduced in sections 3.2.1 and 3.2.2. Relevant real market ICT software and hardware products are reported in section 3.2.3. Chapter 5 reports DR potential in the pilot countries (Table 5, Table 6, Table 7). As results, the comparison between the successful DR programs and DR potentials leading to defines the most suitable DR schemes and ICT scenarios for each pilot sites (Table 10).

Table 10 – DR programme type and control scenarios suggestion for RESPOND pilots

Pilot	DR programme type	ICT (control scenario)
Aarhus	Price-based (RTP/TOU)	Local loads: - Smart thermostats for heating systems; - Load control switches for smart appliances; - Smart meter for different tariffs and consumption information; - Smart load shift control for solar photovoltaic; - Mobile/PC application for system management and remote load control. District loads: - Smart thermostats for heating systems; - Smart load shift control for energy storage (hot water tank); - Load control switches for common areas (e.g. public illumination). - Mobile/PC application for system management and remote load control.
Aran Island	Price-based (RTP/TOU) Incentive-based	Local loads: - Smart thermostats for heating systems; - Load control switches for smart appliances; - Smart meter for different tariffs and consumption information; - Smart load shift control for solar photovoltaic; - Mobile/PC application for system management and remote load control. District loads: - Smart thermostats for heating systems; - Smart load shift control for energy storage (hot water tank and electric vehicle); - Load control switches for common areas (e.g. public illumination). - Mobile/PC application for system management and remote load control.
Madrid	Price-based (RTP/TOU)	Local loads: - Smart thermostats for cooling and heating systems; - Load control switches for smart appliances; - Smart meter for different tariffs and consumption information; - Mobile/PC application for system management and remote load control. District loads: - Smart thermostats for cooling and heating systems; - Smart load shift control for energy storage (hot water tank); - Load control switches for common areas (e.g. public illumination). - Mobile/PC application for system management and remote load control.

BUSINESS MODELS

Section 3.4.4 reports a study where 147 business models were analysed. It defines as most common business models for DR, two archetypes: one is market based, the other is utility based. The Danish and Spanish pilots fit better the utility based one, while the market based business model can be implemented in Ireland pilot.

CUSTOMERS ENGAGEMENT

The key success of residential DR programs is the motivation and consumers engagement, through incentives offered by the utilities. DR schemes must increase the customer awareness of the benefits of DR to adopt or change their electricity usage. The major reasons for encouraging customers to participate in the DR schemes are including cost saving, blackout prevention, or responsibility sensing. Also the study reported in [40] underlines as DR schema tariffs should be simple to understand for the end users and an important condition to make dynamic tariffs work is that the end users should be engaged with them.

The study [46] underlines that to increase the effectiveness of a DR program, it should deployed in urban areas, particularly in faster-growing cities, that are likely to have greater infrastructure spending. There might be a reason for this: the higher densities of populations in urban areas may create economies of scale and reduce the costs of such programs. So, Aran Island customers engagement process could be more difficult, so the authors advise to the RESPOND consortium to take into account of this lesson learn. A possible solution could be the organization of dedicated workshops and others local initiative to monitor and encourage the customers participation, evaluating the effectiveness multiple engagement approaches.

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Annex I.

The methodology employed to address the DR programs overview, reported in the main document, is mainly based on desk research techniques via literature review. The research was performed using a Web of science research tool [18].

In particular, Table 11 shows 72 relevant documents between journal papers (J), reports (R) and web pages (W), selected by the authors to perform the DR overview. The Table 11 describes how the different documents covers different aspects of DR (X mark on the table): type of programs, ICT, business models (including also drivers, barriers, customer engagement) and DR programs example at European and Worldwide levels.

Table 11 – Documents classification on different aspects of DR

REF	J/R/W	YEAR	TYPE	ICT	BUSINESS	DR EU/WW
[1]	J	2016	X	X		
[2]	J	2016	X	X		
[3]	J	2016	X			
[4]	J	2016	X		X	X
[5]	R	2017	X			
[6]	R	2007			X	
[7]	R	2014			X	
[8]	J	2017	X	X	X	
[9]	W	2016			X	
[10]	J	2014	X		X	
[11]	J	2009	X		X	
[12]	J	2017		X	X	
[13]	J	2017			X	X
[14]	J	2017	X	X	X	X
[15]	J	2016			X	
[16]	J	2015	X		X	
[17]	J	2016	X		X	
[18]	W	2012				
[19]	J	2014	X	X	X	
[20]	R	2011	X	X	X	X
[21]	J	2014	X		X	
[22]	J	2010	X		X	
[23]	J	2008	X		X	
[24]	J	2012	X			

[25]	J	2013			X	X
[26]	J	2010			X	X
[27]	R	2013	X	X	X	
[28]	J	2011	X	X		
[29]	R	2017	X	X	X	X
[30]	J	2010	X		X	
[31]	J	2016		X		
[32]	W	2018		X	X	X
[33]	R	2013		X	X	X
[34]	R	2016		X	X	X
[35]	J	2011		X		
[36]	R	2014			X	
[37]	J	2014	X		X	
[38]	J	2005	X		X	
[39]	J	2009	X		X	X
[40]	J	2016	X		X	X
[41]	W	2017			X	
[42]	J	2016			X	
[43]	J	2014	X		X	
[44]	R	2017	X		X	X
[45]	J	2017	X			
[46]	J	2018			X	X
[47]	R	2015	X	X	X	X
[48]	R	2016			X	
[49]	J	2017	X		X	
[50]	J	2015	X		X	
[51]	W	2017			X	
[52]	R	2014			X	
[53]	W	2017			X	
[54]	W	2017			X	
[55]	W	2017			X	
[56]	W	2017			X	
[57]	W	2017			X	
[58]	J	2012			X	
[59]	J	2014			X	
[60]	R	2014	X	X	X	X
[61]	R	2016	X	X	X	X

[62]	R	2016			X	X
[63]	R	2014		X	X	X
[64]	J	2017			X	X
[65]	R	2016	X	X	X	X
[66]	W	2016				X
[67]	R	2016	X		X	X
[68]	R	2017		X	X	X
[69]	J	2013	X		X	
[70]	R	2013		X	X	X
[71]	R	2013			X	X
[72]	R	2014		X	X	X
[73]	J	2011	X		X	