EcoGrid EU – A Prototype for European Smart Grids

Deliverable D7.4
EcoGrid EU Replication Roadmap

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Project full title: Large-Scale Smart Grids Demonstration of Real Time Market-based Integration of DER and DR
EU Project no: 268199
Instrument: Collaborative project
Thematic Priority: ENERGY

Approved (EB/Coordinator) 2016-01-27
Dissemination level Public
Project Information

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<td>Deliverable title:</td>
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<td>Work package title:</td>
<td>WP 7: [Framework condition, deployment, replication and international collaboration]</td>
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Version Control

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<tr>
<td>1</td>
<td>2015-08-12</td>
<td>Georgios Giannopoulos</td>
<td>Initial version</td>
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<td>2</td>
<td>2016-01-27</td>
<td>Georgios Giannopoulos</td>
<td>Revised version</td>
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Quality Assurance

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<td>Action</td>
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<td>Verified (WP-leader)</td>
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Abstract

It is no secret that the power system of today is completely different than in the past. The production mix has changed to a large extend introducing new challenges in system operation, electricity market design and infrastructure needs. The fluctuating nature of renewables has increased the need for interconnections and cross border collaboration between countries in order to be able to exchange energy and reserves. In addition to this, new means of flexibility are necessary to be utilized like storage, demand and renewables. In order to harvest the maximum potential, a well thought plan for integrating these new sources of flexibility in the power system needs to be followed from the beginning.

The change of production mix and the challenges that the power systems are facing today, create the need for new ways of maintaining the balance of the system. Flexibility resources in the transmission grid are diminishing due to the replacement of large production units with decentralized renewables. As a result, it becomes more and more important to explore the distribution lower voltage levels of the grid in order to get more sources for ancillary services.

The aforementioned change will have a direct impact on the operation of the system, as the energy resources and loads that are physically situated in lower voltage levels are more difficult to control. EcoGrid EU is working towards this direction, having as an objective the proper integration of load from residential sector and small industries in the balancing market. In addition to this, EcoGrid EU takes into account the fact that the capacity of the distribution grid can be a limiting factor in some cases due to security constrains.

In addition to this, in order to have the most efficient system operation possible, cross border collaboration should be envisaged. Currently the European TSOs are working towards cross boarder exchange of ancillary services and any new efforts of integrating flexibility to the system should take this into account.

However, not all power systems are the same or face the same challenges. The particularities of every country/region should be investigated in order to identify the sources of flexibility and the specificities of the market design in each case. Of course this does not prevent the drafting of general rules and guidelines applicable to most of the cases. Aspects like the flexibility of the retail pricing schemes or the publication of sufficient balancing information in order to trigger a reaction by the market actors or end users are some examples of general guidelines. As far as the technological aspect is concerned, widely accepted standards should be developed to insure interoperability of the devices and trigger competition between flexibility service suppliers. What is more, the customer aspect should not be neglected and the technology should be adapted to their needs offering the necessary comfort levels and being as much user friendly as possible. Finally, when approaching the end consumers, the motivating factors should be carefully investigated and not be restricted to financial incentives. Alternative motivations like environmental awareness are strongly affecting the approach of residential users.
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1 Introduction to EcoGrid EU

This report aims at studying a possible replication of EcoGrid EU in Europe. To do this, different barriers that could hinder such a replication will be identified and recommendations to overcome them will be given. Different aspects of the replication are analysed separately in order to make sure that an exhaustive elaboration is achieved.

Before going to the replication study, a short description of the EcoGrid EU concept is given to help the reader understand better the analysis.

1.1 Motivation and objectives

Motivation

The share of renewable generation from wind and solar in the energy mix of Europe is growing and is expected to keep on doing so. However, unlike conventional generation, high penetration levels of renewable sources (e.g. wind and solar generation) are a challenge for real-time power system balancing due to the highly variable and difficult-to-forecast nature of the resource. Accordingly, there will be a higher need for fast balancing power in the future. In the traditional centralized power system, demand is passive and uncontrollable and makes no active contribution to the operation of the system, e.g. to balancing. The main motivation for the EcoGrid EU project is to activate electricity demand and to let electricity consumers participate into the market thereby creating additional capacities to balance the power system in a secure and economic way.

The overall objective

The objective of the EcoGrid EU project is to develop and demonstrate in large-scale a generally applicable real-time market concept for smart electricity distribution networks with high penetration of renewable energy sources and active user participation. The concept is based on small and medium-size distributed energy resources (DER) and flexible demand response to real-time price signals. The EcoGrid EU project aims to focus on market-based, cost efficient and standardised solutions.

This will contribute to the integration of additional renewable energy sources to the power system in a secure and cost efficient way having as a direct impact the reduction of CO₂ emissions. In addition, the EcoGrid EU project will work towards a reduction of peak load on Bornholm and raise of awareness of customers regarding the challenges of power system.

Key tasks of the project

Several interlinking topics have been covered in the project period:

- Development and implementation of the EcoGrid EU concept covering all aspects from ICT, control systems and market design and business cases.
- Preparation for the demonstration by getting acceptance from all involved parties, recruiting and training participants and installing and testing equipment.
- Demonstration of the concept in large-scale with about 1900 participants.
- Contribution to the standardization process of architectures and interfaces for DER integration by drawing on results from the implementation and demonstration.
- Suggesting strategy/roadmap for replicating the results from the specific demonstration site to other regions.
- Broad and consistent dissemination of major project results to stakeholders and decision makers, both in the involved regions and on a Pan-European level.
1.2 **Concept and demonstration**

1.2.1 **General concept and architecture**

The EcoGrid concept provides a market framework that allows small-scale customers and distributed resources to participate in power system balancing, by supplementing present markets for energy and balancing.

The real-time market has a high time resolution of five minutes, which improves the capabilities to manage high amounts of rapidly fluctuating renewable energy sources. Moreover, the concept removes fundamental barriers under the market framework that today prevents small-scale customers and power generation from supplying balancing services.

### Efficient balancing and operation of the future power system

Development of a real-time market could be considered one of the ways to meet the challenges in operating a power system with increasing shares of renewable sources, e.g.:

- The market price is set in the very last minute, meaning that very accurate forecasts of wind power and demand can be utilised when determining the market price. It means that problems with forecasting errors, inherently present in conventional markets, are minimised.
- Increased demand-side market participation reduces the need for costly flexibility on the production side and/or compensates for traditional balancing power and services from conventional generation displaced by generation based on renewable energy sources.
- The EcoGrid EU real-time market will improve the utilisation of the inherent (free) flexibility in e.g. thermal loads (load-shifting potential).
- Activation of a large number of customers will improve the function and competition in the power market through increased market participation and by connecting the wholesale market with the retail market (increase retail competition).
- The real-time market enables locational pricing for congesting management. This will result in better use of grid capacity, reducing and deferring costs for reinforcements of the distribution network.

#### The TSO sets the price signal

As illustrated in Figure 1 the main principle of the EcoGrid EU market concept is to let the TSO or a real-time market operator issue a real-time price signal, to which flexible resources like electric heating and heat pumps can respond.

The TSO creates the real-time price signal, by continuously monitoring the power system and adjusting the price signal to correct the balance of the system. To do so, it is necessary to create reliable forecasts of the expected demand response to price changes.

This forecast will be used when computing the marginal price change required to trigger a response of the right size, leading to a proper rebalancing of the system.

#### EcoGrid EU increases the functionality of the existing power market(s)

The TSO ensures coordination between the regulating power market and the new real-time market. Small-scale customers and power generation units can subscribe to real-time prices from either the real-time market or the retailers. Likewise, virtual power plant concepts can potentially participate in the present markets as well as in the new real-time market. This market structure provides high flexibility to all market participants and encourages competition, and the EcoGrid EU market is not designed to limit any existing market functionality, but only adds new opportunities.
The concept will remove the barriers that DERs have previously been facing to enter the present market structure, e.g. requirements on size and online monitoring, and a significant administrative burden including bidding in the markets, complying with schedules, and financial obligations.

**Congestion management**

In the basic concept of the EcoGrid EU project, control of active power is generally done by leveraging the global real-time market price and its corresponding forecast. Based thereon, price deviations for each of the local areas can be computed in order to relief active power issues within that area. The influence on local active power is for instance needed in order to prevent imminent overloads, e.g. on connection lines. If no local price adaption is required, the local price is equal to the global real-time market price.

** Approaches to realize the real-time price response**

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Three main approaches are used to realise the demand response of the EcoGrid customers:

1. Manual control - participants only have access to real-time price information, i.e. none of their electric household devices are automatically controlled
2. Automatic control of individual electric devices/resources
3. Aggregated control of a portfolio of electric devices/resources

1.2.2 What was demonstrated?

EcoGrid is a large-scale demonstration, involving every tenth electricity customer on the Danish island of Bornholm. The aggregated demand response to real-time prices and day-ahead forecasts was tested for approx. 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, etc., i.e. none of their electric household devices were automatically controlled. A control/reference group got the 5 minute meters for monitoring but did not get access to any price information.

All participants except for the control/reference group were given access to the customer feedback system “My EcoGrid” which provides information about consumption patterns, real-time prices and forecasts as well as an overview of bonus payment. Moreover, approx. 600 households took part in training group sessions held by Østkraft in Villa Smart (the EcoGrid EU demonstration house), while the industry/business participants received individual consultancy/advice from the industry experts (the EcoGrid EU suppliers/developers of automation equipment).

The industrial customers include:
- 13 industry fork lift chargers
- Three manure mixers
- 1 commercial battery storage charger
- 1 commercial building automation system (Bornholm ferry terminal)

**The EcoGrid market demonstration: a virtual reality of the future**

The development of the EcoGrid concept implies the creation of a virtual reality that reflects how the market concept – given optimal framework conditions – is expected to function in the future.

This abstraction is useful in order to fully understand the EcoGrid concept by focusing on future possibilities rather than the current barriers for replication.

The next step was to demonstrate the concept on Bornholm in the context of the present Nordic power market, while adapting the field test conditions as close as it was possible, to the “virtual reality” of tomorrow’s EcoGrid real-time market.

**Adaption of the EcoGrid concept to the demonstration**

The very fundamental idea of the EcoGrid EU market concept is to balance the power system by repeatedly issuing a price signal for flexible resources to respond to. The price signal will be continuously updated in order to keep the power system balanced, by increasing the price when there is a power deficit in the system, and vice versa.

In the demonstration, the TSO is not issuing the price as it would be the case in the real world. The price is distributed by a “price engine” that computes an artificial price which is sent directly to the customer equipment and aggregators. The artificial price and forecast used for the demon-
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The EcoGrid concept (and the future replication hereof) implies that the current regulating market will come into play in the case of imbalances, along with the response from the flexible customers. Consequently, the regulating market price and the real-time price are calculated as an integrated whole, based on the optimal distribution in the two markets. This interaction was emulated as part of the EcoGrid real-time price calculation, with a parallel regulating market running inside the price calculation engine.

The fundamental principle of operating the balancing system as a so-called “closed-loop control system” is the same: Based on the forecast of demand response, real-time prices are calculated and broadcasted to the market in order to obtain the amount of balancing resources required by the system operator. [1]

**The EcoGrid impact on the system balance**

A very important question to answer for the demonstration was whether it was possible to balance the power system, using prices as the primary control signal, and the system balance as feedback?

Evidently, a demonstration restricted to 1,900 households on Bornholm would not be able to give the full answer to this question as the impact of the demonstration activities on the overall system balance (in the Nordics) will be negligible. The first feasible adaptation would be to define a smaller system to balance rather than the entire power system. It was decided that the evaluation of the impact on power system balancing should be based on wind power in the Bornholm power system. The price generation was still based on the fundamental closed-loop principle, and by measuring the feedback on a reasonable system it was possible to demonstrate the feasibility of balancing a system by means of a real-time price signal.

To have a first view on the effect of EcoGrid EU on the power system of a whole country, a rough estimation has been performed in order to assess the potential in the Danish power system. If aiming to get 100MW balancing power in similar conditions, this would then require nearly 2 mill. households. Following official statistics, Denmark has app. 2.6 mill. households. In view of experience gained during the project based on analysing the data from the experiments, it is believed that 1/3 to 1/2 of the households were truly responsive only. Similarly, control was quite primitive and with limited information. [1] It is estimated that at a more mature stage of employing demand response in a similar framework, the number of households needed to provide the same demand response could be divided by at least 2 and up to 10. This means that, going from pessimistic to optimistic scaling, 100MW balancing may require anything between 2 mill. and 200.000 households. Special attention should be given to the fact that these results concern the case of Denmark and they are not fully indicative for other countries with different loads.

1.3 **Replication context – Development of the European power market**

It will certainly not be possible to implement a single-standard EcoGrid EU real-time market concept all over Europe without changes to the current regulation framework situation(s). In a replication scenario it is important that the implementation of the real-time market mechanisms also considers the harmonisation process of the electricity markets in Europe, e.g. a process of providing framework guidelines for demand side interaction in power markets, the extensive roll out of smart meters and network codes aiming at harmonised rules for cross-border exchanges of electricity.

To what extent the concept will be replicable to other market across Europe, depends on several factors, e.g.

- The current differences in balancing market setups
The systems capabilities to manage increasing (local) congestion challenges
- Adaptation of the concept to the appropriate sampling frequency of meter data
- The consumer’s readiness for smart grid – and vice versa.

1.3.1 *Differences in balancing market setup*

An example of the main differences in market design is related to the different frequency control philosophy of the separate synchronous systems in Europe: E.g. Area control error (ACE) minimisation in Central Europe, and balancing referring to the frequency deviation for the whole Nordic system based on a common merit order list of control objects. The benefit of adding balancing resources by end user response to the running marginal price will help both setups. The availability of the real-time price information in the future balancing markets is a pre-requisite for the EcoGrid EU concept. Chapter 2.2 discusses in more detail the implications due to differences in market design.

1.3.2 *The compatibility of the congestion management approaches*

Using DR for balancing could be proven very beneficial as long as it is less costly than the traditional balancing means and keeps the same level of network security. In the case of EcoGridEU, flexibility from the lower voltage levels is targeted which may have a direct impact on the security of the distribution grid. As a result, the grid limitations should be taken into account firstly.

There are two different functionalities that EcoGrid EU could offer for congestion management:
- Avoid possible congestions that could have been caused by activation of flexibility from distribution grid for different reasons
- Avoid possible congestions that could have been caused irrespective of activation of flexibility

Provided that the necessary input from the distribution grid is available at the right timing, EcoGrid EU could serve both functionalities is regulation would allow different prices in different locations. This demonstration project did not demonstrate a real case of congestions management and for this reason, a simulated case was proposed. [1]

1.3.3 *The customer and the smart technology*

The perspective for wider replication of EcoGrid EU also depends on the consumer’s readiness for smart grids. One of the largest tasks, preceding the EcoGrid EU demonstration has primarily been to establish a broad understanding of the Smart Grid vision behind EcoGrid EU and the concept of “flexible consumption”. Having strong community-oriented customers on Bornholm was the key to success for the EcoGrid EU project. The socio-economic context of replication will certainly be very different from region to region. Therefore the communication means must be adapted to each specific case taking into account the need of customer involvement.

From EcoGrid EU field test we experienced that many customers were not familiar with smart technology, e.g. before EcoGrid started up, no smart meter was installed in the homes of residential customers and very few people knew something about the “concept” of home energy automation equipment (see chapter 3).

Efficient demand response depends on technology and equipment enabling automatic processing of data and calculation of the most economic viable response. Hence, new and improved data will also be needed to enable demand response in real-time, and interval meters, in addition to simple access to price signals, is a prerequisite to give the consumer price incentives to respond to variations in real-time prices. Moreover, to enable load changes as deliveries of system services, the response signal must be sent in a safe manner, and real-time consumption data must be available directly from the smart meters (see chapter 4)

Therefore the status and success of smart meter roll out will have a large influence on the conditions for EcoGrid replication.
1.3.4 The Replication Roadmap

Taking into account the individual aspects of the EcoGrid EU concept replication, a roadmap has been created that shows the necessary steps to be taken in order to achieve a full implementation of real time demand response. Figure 3 gives a graphical illustration of these steps and further details can be found in chapter 6.

Figure 3 Replication Roadmap for EcoGrid EU

1.4 Document structure

The Replication Roadmap document is meant to show the way towards a possible roll out of EcoGrid EU in Denmark and other European countries. To do this, the aspects that could influence a possible deployment of the concept have been divided in four categories: customer, technological, market and regulatory. Each aspect is elaborated separately with the aim of aggregating the identified points into a chapter that will serve as recommendation to policy makers.

In order to be easier and clearer for the reader to understand the messages, all of the four aspects are analysed in the same way. First some of the key findings of the demonstration are presented. Afterwards, a replicability study is performed looking also in a possible application in different European countries. Finally, after processing this information, several recommendations are given. It needs to be noted that in the recommendation part, there are also additional ones included from the overall demonstration experience that do not necessarily come out of the two previous chapters.

In order to have a more thorough analysis of the replicability of EcoGrid EU, each aspect is examined from two points of view: replicability and scalability. It is important to give the definition of the two concepts to avoid confusion.

Scalability can be defined as the ability of a system to change its scale in order to meet growing volumes of demand. A system is understood as a set of interacting elements with similar boundary conditions. By contrast, replicability denotes the property of a system that allows it to be dupli-
cated at another location or time. Scalability and replicability are the preliminary requisite to per-
form scaling-up and replication successfully.
2 Market aspect

2.1 Findings from demo

This chapter gives a high level summary of the findings coming from demo related to the impact the EcoGrid EU concept had on the power system and market. Since it is not the purpose of this document to present analytically what was done in the EcoGrid EU project, only the main findings related to this chapter are treated in order to provide the ground for the replication study.

2.1.1 Demonstration of DR

One of the main findings from the demonstration is that DR was achieved via a real time signal for balancing. The real time market simulator was calculating a 5 min signal that was sent to the end consumers who responded via the automatic equipment.

Figure 4 shows the change in DR requested on the x axis, and the change in load observed on the y axis. There is a clear correlation between market request and the DR observed. As a result, it can be said that the activated DR was in the correct direction according to the request.

![Figure 4 Results of different levels of DR activation. The red line in the middle of the boxes shows the average while the upper and lower limits of the boxes show the 25% of the data greater and lower than these values consequently [1].](image)

2.1.2 EcoGrid EU as a supplementary balancing source

Although from Figure 4, an obvious correlation between DR and market request can be seen, the variability of the service delivered is still considerable. This would not give comfort to the system operator to completely substitute conventional units by DR. EcoGrid EU can provide additional flexibility for balancing but it is clear that conventional balancing mechanisms will still be needed. EcoGrid EU does not attempt to replace them, but to complement them.

For the aforementioned figure it can be seen that for lower DR activations, the effect can be negative. However, it has to be underlined that in a possible roll out, the variability is expected to be different. This study was not in the scope of the project so no clear opinion can be expressed.

2.1.3 Wind power curtailment reduction

One of the problems of the power systems with high penetration of renewable sources of energy is that there are cases where the production from RES in addition to the non-flexible conventional generation is higher than the demand. This could lead in a situation of spillage of renewable energy (in this case wind energy).

On the other hand, by incentivizing the demand to participate in balancing, the curtailment of wind energy can be reduced as it was demonstrated in EcoGrid EU. Figure 5 shows the benefits in wind
curtailment resulted from this project (virtual calculation of wind curtailment using a market model).

![Graph](image)

*Figure 5 Cumulative sum of the wind power curtailment with the baseline market and real time market*

### 2.1.4 Reduction of activation of conventional energy

The previous section addressed the issue of increase of consumption to avoid spilling wind energy. However, DR could be activated in the opposite direction (reduction of consumption) in order to balance the system as illustrated in Figure 4. This could reduce the activation of conventional spinning reserves as it was demonstrated by the market simulations of the project. A direct result would be a reduction in balancing costs as balancing from DR is expected to be cheaper than the conventional units.

### 2.1.5 Need to redesign the market mechanism

In the EcoGrid EU project, a market mechanism that was simulating the balancing market in Denmark was developed taking into account the DA market and the intra hour deviations occurred from change in the wind forecasts. This was a traditional regulation loop where flexibility from DR following a forecasted price elasticity was integrated.

However, through the project is was found out that the market scheduled an oscillating response from supply and demand and such volatility let to higher costs to stabilize the market that in a case with no DR. As a result, the market design that has been used in EcoGrid EU demonstration should be improved in case of a real life implementation.

### 2.1.6 Economic consideration of the demo inspired on the methodology for analysing Smart Grid projects developed by JRC

After analysing the main findings from the demonstration from a system point of view, an economical consideration is performed that gives a high level idea of the different kinds of benefits identified. It should be noted that this is a qualitative study of the demonstration only and is not considering a roll out (this is performed in chapter 2.2.3).

In addition to the costs, some of the benefits are analysed to allow the reader have a more complete idea of the value of the demonstration. However, the whole exercise still remains high level and qualitative as the purpose of the project has been to improve the balancing from residential sector concept and not achieve the most competitive, cost oriented solution.

The cost benefit analysis method proposed by European Commission Joint Research Centre was used modified for the needs and available data of the project. However, as mentioned before, the analysis is not exhaustive and no sensitivity analysis was performed. Some of the main benefits
and costs are given below, but a more detailed and complete description of the methodology and its outcomes can be found in Appendix C.

Benefits
- Reduction of ancillary services costs
- Defer generation investments
- Defer distribution capacity investments
- Reduction of electricity costs for LV and MV customers
- Reduction of emissions
- Reduction of wind energy spillage

Costs
- Equipment
- Development of intelligence
- Maintenance

2.2 Replication study

A big part of the assessment of the future potential of EcoGrid EU concept is the analysis of the existing ground for adoption on different market designs and the flexibility potential from the residential sector that exists in different countries of Europe. This subsection will first give a description of the currently existing balancing market designs in Europe in order to be able to perform a comparison regarding the replicability of the concept. This, combined with the flexibility potential in each country, will give a more complete view of the “Ecogridability” of each system. Finally, the different aspects that could affect the roll out of EcoGrid EU will be analysed in order to be able to conclude on recommendations in chapter 6.

2.2.1 Different balancing market designs in Europe

The impact of EcoGrid EU on the power systems is highly depending on the way the balancing mechanisms are designed in different countries. As a result, the different market designs that exist in Europe should be studied separately first in order to be able to perform a comparison and assess the “Ecogridability” of each one.

- Pro-active balancing markets: In these markets TSOs are balancing the system based on the forecast of the system imbalance. The balancing objective is to optimise the activation of balancing products from different merit order lists with as aim to reduce the average activation price of flexibility used. Typically these markets are having an imbalance settlement period larger than 15 min and are using slower replacement reserves as well. The optimisation of such a system is only efficient in case the forecasted imbalance used for optimisation is adequate. Therefore, BRPs are incentivised to not deviate from their generation and/or load schedules. Examples of countries are France, Spain, UK, Nordic countries.

- Re-active balancing markets: In these markets, TSOs are only resolving the residual imbalance of the market parties after real-time. Balancing responsible parties are incentivised to take actions until close to real-time to restore the system imbalance. Typically these markets are having an imbalance settlement period equal to 15 minutes and are using mainly fast reserves (aFRR and ad hoc mFRR). The balancing objective of such a market is to keep the residual imbalance to be resolved by the TSO as small as possible. There are 2 kind of re-active balancing market designs:
  - Markets where BRPs are incentivised until close to real time to balance themselves;
  - Markets where BRPs are incentivised to even help to restore the system imbalance. Examples of countries are Belgium, the Netherlands.

- Central dispatch markets: These electricity markets are closing the market functioning (after the closure of day ahead markets). After this closure the TSO will activate energy from load & production in order to perform the congestion and balancing management in a combined way. That energy is bought in an ex-ante purchasing process. Examples of countries are Po-
land, Ireland and Italy. This third balancing market design will not be further investigated as no participating country of EcoGrid EU is using this balancing market design.

In general TSOs in Europe are neither fully proactive nor fully reactive, but operate somewhere on the spectrum between those extremes. The distinction between self-dispatch and central dispatch markets is neither straightforward. Some of the so-called self-dispatch systems are having a lot of features which are similar to central dispatch systems.

For comparison reasons, two representative countries will be used for the aforementioned systems, Denmark and Belgium. Below, there are some important aspects described that characterize the two balancing markets. As these parameters influence each other, they should be investigated together and in order to be exhaustive, they will be linked with the guidelines of the network codes¹ that are currently being drafted. The parameters that are going to be analysed are:

- i. Imbalance settlement Period (ISP)
- ii. Imbalance pricing methodology
- iii. Volume calculation
- iv. Reserve product prioritisation
- v. Imbalance price and other imbalance information publication

A detailed description of these parameters can be found in Appendix D.

**Re-active market design (p.ex. Belgium)**

The main goal of a reactive balancing design is to encourage BRPs to react to market signals until close to real-time in order to minimize the system imbalance and consequently the activated balancing energy. Therefore, it’s important to ensure that BRPs have the flexibility to adjust their schedules or even allow them to deviate from their scheduled values². This mechanism is supported by proper financial incentives and a close-to-real time publication of the balancing information. Subsequently, the TSO will normally react by activating reserves in real-time unless there is a specific event expected. A reaction close to real time requires fast reserves.

A single portfolio calculation is used as BRPs are settled according to their total position in order to increase their balancing means. The generation and demand portfolio are treated in the same way and reaction of load or production are not treated individually.

In order to achieve an efficient re-active operation, the imbalance settlement period should be small. In Belgium, the imbalance settlement period is equal to 15 minutes.

The objectives of a re-active balancing market design are supported by a single price model. It can trigger load and production close to real time to react on price signals. BRPs are always financially incentivized to help the system no matter the direction of their imbalance.

In a re-active balancing market design, the TSO only knows the residual imbalance in real-time and respond then ex-post with fast and automatic reserves (aFRR) to restore the imbalance. In case of a persistent imbalance, he will subsequently activate manual reserves (mFRR). In the Belgian system, market parties fulfil the replacement role and accordingly the TSO does not contract RR.

**Proactive market design (p.ex. Denmark, Spain)**

The goal of this model is to prevent BRPs to deviate from their scheduled production program. The only way to perform balancing is to send a new schedule. Depending on the gate closure time to send a new schedule, this might limit their possibilities to balance close to real time.

² The deviation from the scheduled values is subject to conditions. A dispatcher can always ask a BRP for security reasons to go back to their scheduled values.
These electricity markets are closing the open market functioning after the closing of intraday market. After gate closure, the TSOs will perform the balancing, using centrally managed balancing markets. Pro-active balancing markets are typically using a lot of comparably slow reserves which might be activated up till 1 hour before delivery time (and after the closing of intra-day market). The BRPs are not allowed to deviate from their production schedules and the TSO takes control of the balancing task by forecasting the system’s imbalance and proactively activating balancing power (slow reserves) before real time. The imbalance pricing methodology that supports this design is the dual price model, which implicitly penalizes the imbalances.

The activation of reserves before real-time is done in a manual way and the residual imbalance in real time is picked by the automatic reserves. Such a scheme is reducing the flexibility for BRPs to balance themselves one hour before real time as the TSO takes control.

However, the balancing market design for load is different. In order to give different balancing incentives to load and generation, a two portfolio calculation is necessary. These different portfolios in combination with different imbalance pricing schemes on generation and load could offer the possibility to trigger market reaction from one side. It needs to be underlined that a BRP having different portfolios for consumption and production cannot net the imbalances.

In contrast to generation, BRPs of load are subject to single imbalance pricing in order not to penalize imbalances more than the marginal cost of balancing energy. One of the conditions to effectuate a reaction close-to-real-time is the implementation of a single imbalance pricing methodology.

2.2.2 Replicability of EcoGrid EU

As mentioned before, the study of the replicability of EcoGrid EU regarding the market and economic aspect will include both the market design issue and the flexibility potential that can be found in a country.

Comparison of two market designs regarding EcoGrid EU adoption

The task of identifying which power system could be more favourable for the adoption of EcoGrid EU is complicated as the quantification of the advantages and disadvantages of each case is not obvious. However, the following section tries to list some characteristics that could have an impact on a possible implementation of the concept.

Reactive balancing market

In this paragraph, some aspects are analysed that already exist in a reactive balancing market and could be favourable for the integration of EcoGrid EU concept.

- Publishing of balancing information:
  Balancing information is already published close to real time and end users can react to this. This is already in line with the EcoGrid EU concept with the difference that EcoGrid EU requests a price to be published short before real time, while in a reactive system they are published right after and as a consequence there is no guarantee on what the price will be in advance.

  Important notice: When flexibility providers deliver DR activations, it is important that the concerned BRP is informed properly to avoid counter-balancing reactions, evening out the effect of DR activations on the system.

- Single imbalance pricing:
  In case residential production is expected also to participate, then a single imbalance pricing methodology is required. Re-active markets already use this kind of pricing methodology. Price signal to be sent to consumers need to be equal to the imbalance price. An intermediary role of BSPs/Aggregators is possible.
Proactive balancing market

Regarding the aspects related to a proactive market, the following points have been identified:

- **Lower possibility of overreaction to the price signal**
  As the market is "frozen" by the TSO one hour before real time, the TSO can better forecast the reaction of the system to a price signal because the BRPs are not allowed to deviate from their schedules any more. This way, a possible overreaction could be easier avoided.

- **Easier setting of EcoGrid EU price**
  Only the load is allowed to deviate and as a result, the TSO can forecast the price he should send more accurately depending on the response he wants.

- **Accurate forecasting of load response is crucial**
  In pro-active balancing markets, the TSO is activating slow reserves based on a forecast of the imbalance. As the BRP’s should stick to their generation portfolio, the expected reaction of demand response should be very accurately predicted in order to activate the proper amount of reserves ex-ante.

Final comparison

It can be seen from the analysis above that the current balancing market designs will need several adaptations in order to implement EcoGrid EU. However, with the current reactive balancing design, a response close to real time exists, which already resembles EcoGrid EU.

For the replication of the EcoGrid EU concept, aspects of both systems need to be integrated. However, the future NC on EB will require the harmonization of the balancing market design and in the latest version of the NC on EB there is a clear tendency to go to a reactive balancing market, single imbalance pricing settlement and an ISP of 15 minutes.

Table 1 summarizes the differences between the two different market designs and identifies some prerequisites for the replication of EcoGrid EU. From the table and the analysis, it can be concluded that the concept could not be replicated as such on one of the two systems, but some modifications will be required.

**Table 1: Comparison of different balancing market designs**

<table>
<thead>
<tr>
<th></th>
<th>Proactive</th>
<th>Reactive</th>
<th>BE</th>
<th>DK</th>
<th>EcoGrid EU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imbalance settlement period</td>
<td>Not relative</td>
<td>Small</td>
<td>15 minutes</td>
<td>1 hour</td>
<td>5 and possible 15min</td>
</tr>
</tbody>
</table>
| Imbalance pricing methodology | Dual     | Single   | Single | - Load: Single pricing  
                                                      - Generation: Dual pricing | Single             |
| Volume calculation (portfolio) | Not important | Single | Single | Double        | Single             |
| Reserve products activation prioritization | Manual | Automatic (fast reserves) | Manual (slow reserves) | Not important |
| Imbalance price & volume publication | Further away after real time | Close after real time | Close after real time (2-3 min) | Almost 30min after real time | Real time |
**Demand flexibility**

Influence on demand flexibility: Technical aspects
As described in chapter 1, the EcoGrid EU is meant to assist the system operators in balancing their area. To do this, a proper balancing market design is a precondition, but also the flexibility potential of each country should not be overlooked as not all loads are suitable for balancing.

The overall flexibility potential in residential sector is investigated by looking at the installed power of the most relevant devices. These devices are the following:

**Interruptible devices**

These are flexible devices whose energy consumption can be controlled fast enough and many times within a day. Some of them, like in the case of hot water buffers, have a thermal energy storage and can decouple heat demand from electric power demand. Moreover, in many cases, the potential of decreasing or increasing consumption is not always symmetric.

- Electric hot water buffer
- Direct heating
- Heat pumps
- Air conditioning systems
- Electric vehicles

**Devices that can be flexibly scheduled**

**White goods** (dishwasher, washing machine, clothes dryer, ...): It can delay starting as long as it finishes its cycle before a predefined deadline. The flexibility potential is asymmetrical: at any given moment during the day, more devices can potentially be switched on than maximally delayed. Moreover, the load shifting is more dependent on the end user. Hence, the flexibility potential is generally higher during weekend days than during weekdays. The highest potential can be found during evening and night-time hours, especially during weekend days.

The flexibility potential of Spain and Belgium are analysed in order to have a first qualitative assessment of the balancing possibility from residential loads.

After examining the installed capacity of flexible devices in the two different countries (Spain and Belgium), the whole sale market should be investigated in order to identify if there is a business opportunity for EcoGrid EU.

**Market profitability study**

After the analysis of balancing design and flexibility potential in two countries, a study on the possible profitability of the use of residential DR for balancing is performed in Spain and Belgium. It has to be noted that in this chapter, only the final results are presented and more information can be found in Appendix F.

**Spain**

In order to analyse the market opportunities of demand response for balancing, the (amount of energy traded), the price and the price variability of balancing market are examined.

The Spanish case identifies the number of periods during a year in which intraday and balancing markets have a relevant impact in the price of energy in order to be able to simulate the reaction of the demand [2].

An hour by hour data is processed to compare the day-ahead market price and the imbalances market price. Instead of taking every different market operated by the TSO, the overall deviations price is taken for simplicity purposes (this price reflects the results of all the balancing markets). Additionally, the traded energy is accounted to evaluate the potential market size.
Belgium

ELIA has performed an investigation on the balancing savings from using DR instead of conventional units for balancing. In this analysis, a substitution of the non-contracted mFRR (also called “free bids” - manual Frequency Restoration Reserve) by residential DR is proposed. In Belgium the residual imbalance is first picked up by aFRR and if the imbalance is persistent, the dispatchers activate the free bids. These bids have a higher price than the spot price because they are the bids that were too expensive to be selected in the DA wholesale market.

Given the installed capacity of hot water buffers in Belgium, the total annual, balancing savings for the TSO could be estimated around 2M€ which corresponds to a reduction of 23% in the total activated free mFRR bids. This analysis has been performed according to the following assumptions [3]:

- Only use of hot water buffers in Belgium
- 18% of households have a HWB and 10% of them would use it for DR

(The reader needs to keep in mind that this is a rough estimation and all the assumptions can be found in [2])

Conclusion from Spain and Belgium

As a conclusion, it is important to underline that all the above three aspects should be taken into account when assessing a country regarding the possibility of implementing the EcoGrid EU solution. The balancing market design, the flexibility potential and the market profitability study should be analysed in every case.

Table 2: Comparison of two indicative countries with different balancing designs regarding potential replication

<table>
<thead>
<tr>
<th></th>
<th>Belgium</th>
<th>Spain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balancing market design</td>
<td>Possible replicability with required changes</td>
<td>Possible replicability with required changes</td>
</tr>
<tr>
<td>Flexibility potential</td>
<td>Present: electric boilers Future: Heat pumps, EVs</td>
<td>Present: air conditioning, electric heating, electric boilers Future: Heat pumps, EVs</td>
</tr>
<tr>
<td>Market profitability</td>
<td>2M€/y reduction of balancing costs</td>
<td>Low profitability due to small price difference between DA and balancing</td>
</tr>
</tbody>
</table>

The macro-economic factors are a key factor for replication because they indicate the flexibility in the regulating market and highlight the benefits achieved by following the EcoGrid EU approach. The benefits obtained should be described by calculating the reduction in regulating power costs achieved by the EcoGrid solutions and by calculating the benefit obtained by the participating customers, which should be higher than the cost of automating the reaction to real-time prices of their devices.

The analysis performed indicates that a detailed economic analysis has to be performed to guarantee the replicability of the EcoGrid EU solution to every different country.

At this point of the analysis, it worth mentioning that there are different ways of stimulating demand response. The price incentive mechanism that EcoGrid EU proposes is one of them and a high level presentation of alternative methods is presented in Appendix G.

2.2.3 Scalability of EcoGrid EU

In this subsection we are looking at the economic scalability of the EcoGrid solution, which is going to be analysed from the point of view of an Economy of scale and Cost/Benefit ration evolution.
This analysis expands the financial consideration performed in Chapter 2.1 to large number of customers.

Economies of scale

The economies of scale of the EcoGrid solution try to determine the impact that an increased number of EcoGrid EU customers will have on the cost of the solution. An exponential increase of the cost would imply that the EcoGrid EU solution is not scalable. Oppositely, the solution is scalable with a cost increase less than linear proportional with the number of participants. This analysis assumes that the current reduced demonstration of the project is profitable. In the following paragraphs, the impact of the increase in customers’ participation upon the system costs is analysed.

The EcoGrid EU demonstration has involved the participation of around 1,900 customers. The communication with the end consumers and accordingly the required software/hardware components can be divided into two groups: The first group has to react manually to price signals and the second one has an automated system to react. In this report, the impact of cost on the scalability is investigated for the last group, which most likely will be implemented in the future for balancing. It needs to be noted that the results from the demonstration showed that not much reaction should be expected from the manual response. This is also one of the reasons that the following analysis will focus only on the automatic response.

To analyse the impact of an increasing number of EcoGrid EU participants on the costs of the solution, the required hardware and software components should be investigated, together with the evolvement of custom developed equipment to mass production and single-vendor to multi-vendor markets.

The equipment required by the EcoGrid Real Time Market participants consists of smart meters with 5 minutes resolution, home energy management systems, and their feedback system. The mass production of this kind of equipment should have an increase in cost less than linear proportional to the number of equipment built. Moreover, going from a single-vendor to a multi-vendor situation would increase the competition and reduce the prices per unit. Then, it can be concluded that due to economies of scale, the costs for the EcoGrid EU solution will decrease significantly. From the above, it also becomes obvious that standardization and interoperability of equipment are key aspects for the profitability of such a smart grid solution.

The equipment required by the EMS (Energy Management System) consists of software packages to forecast the price response of the EcoGrid customers and to calculate the real time price in correlation with the regulating power market. The costs of these components should not scale up with the number of participants and therefore the benefits will increase.

On the other hand, the required communications’ bandwidth can be an important issue to examine. The required characteristics of the communication system are the following:

- The 5 minutes real time price sent to the customers: It is characterized by a periodic multicast one way transmission, which requires a 5 minutes frequency, low bandwidth and fast transmission.
- The customer reaction registered in the smart meter: It is characterized by a periodic one way transmission for settling and billing, which requires a low frequency (once a week/month), low-medium bandwidth (not much data but many customers involved) and low transmission speed (not relevant reaction time). In a reapplication case, the Area Control Error (ACE) will be used by the TSO as a feedback regarding the reaction of customers. As a result, no real time communication of consumption is needed.

Accordingly, we could say that the increase of the number of customers will increase the costs less than linear proportional.

Congestion management

Same considerations could be made for the case in which the EcoGrid EU solution is used for congestions’ avoidance by the DSO. Therefore, the necessary equipment required by the BRP/retailer consists of the software for settling and billing calculation, which does not have a proportional increase with the number of participants. EcoGrid EU demonstration has shown that technically it is possible to distribute different prices for consumers in order to avoid congestions.
In addition to this, the distribution grid operators need to be able to monitor the grid and forecast in short time the expected congestions. This functionality should not be considered as a given the distribution grids and it is a prerequisite for the EcoGrid EU solution.

Taking into account these considerations, it can be said that an increase of EcoGrid EU participants will not endanger the economic profitability of the solution, but that it would rather increase it.

**Cost/Benefit ratio evolution resulting from the increase in EcoGrid participants**

From the point of view of the electricity system, an increase of EcoGrid EU participants in the provision of regulating resources implies:

- An additional competition for the provision of balancing means that more providers will participate in the market. This increase in market competition between demand side competitors should lead to a reduction of the service prices.
- The provision of demand resources should be cheaper than the resources provided by the conventional power plants. A massive penetration of demand response resources will produce a displacement of the resources provided by fast and expensive power plants. As a consequence, this means a cost reduction of the service or an increase in benefits.
- Renewable energy sources will very likely further increase in the near future. This increase in the participation of renewable resources will produce an increase in supply fluctuations that can endanger the network security. The fluctuations can be avoided by the use of fast acting power plants or the use of demand response. Therefore, the EcoGrid EU solution would increase the participation of renewables by providing fast acting balancing power to balance the whole system, thus reducing the energy cost and the cost to operate the system.

By scaling up the EcoGrid EU solution by increasing the number of participants, the system cost will increase less than proportional with the increment of the number of participants, as it has been explained in the economy of scale analysis. At the same time, this solution reduces the operational cost of the system by providing cheaper resources than those provided by conventional power plants and it’s a resource that can mitigate the fluctuations of renewables in the future, fostering their penetration.

Simulations conducted during the project conclude that for a wind generation of 50% in Denmark, the participation of EcoGrid EU customers would reduce the up-regulating power with 7% and the down-regulating power with 3%. At this point, the reader needs to bear in mind that important assumptions have been done during this study that can be found in the aforementioned deliverable.

From this analysis of scalability, it can be concluded that a scaled up deployment of the EcoGrid EU solution would lead to an increase in profitability with respect to the currently limited demonstration. The current profitability of the solution can be inferred from the demonstration implemented in Bornholm.

### 2.3 Recommendations

With the EcoGrid EU concept, Demand Response is achieved via a real time price signal for balancing. The real time market simulator is calculating a signal every 5 minutes. This signal is sent to the end consumers who will respond via their automatic equipment. According to the findings of EcoGrid EU, there is a clear correlation between the market request and the response. However, the variability of the delivered services is still considerable. **In order to guarantee the Security of Supply, TSOs should take their responsibility to open up the market to DR on a non-discriminatory basis regarding production and consumption.**

**With the current results, DR can complement the conventional generators for balancing and should thereby be principally run on a voluntary basis.** EcoGrid EU could attract additional flexibility and increase the efficiency of the market.

**Before regarding the replication in a specific country, a detailed economic analysis has to be performed to investigate the business opportunity for every different country.** This...
economic analysis should include aspects like the investigation of the balancing market design, the flexibility potential, the current costs for ancillary services, the possible profitability from price differences etc.

**Balancing market design**

The impact of EcoGrid EU on the power systems is highly depending on the way the balancing mechanisms are designed in different countries. *In general TSOs in Europe are neither fully proactive nor fully reactive, but operate somewhere in the spectrum between those extremes.*

One of the conditions to effectuate a reaction close-to-real-time is to make sure that there is a proper remuneration of the reaction that would help the system in both sides (downwards and upwards regulation). Imbalances that are against the system needs should be charged based on the marginal cost of balancing energy. On the other hand, BRPs should be financially incentivized to diminish the real-time system imbalance by deviating from their initial position in order to help the system. Therefore, **liabilities of BRPs should be removed which impose them to exactly balance their proper portfolio regardless the global system imbalance.** They should only face imbalance payments. In addition, BRPs should be properly informed to avoid counter actions in case there is DR activation in their perimeter.

**In order to avoid overreaction of other means of flexibility to the EcoGrid EU signal, the reaction of the entire system should be appropriately forecasted.** It’s important to avoid an oscillating response from supply and demand as it could lead to counter balancing costs.

**In proactive market designs, a lower possibility of overreaction to the price signal exists:** The TSO can better forecast the reaction of the system to a price signal because the BRPs are not allowed to deviate from their schedules close to real time. However, in this balancing market design, an **accurate forecasting of load response is crucial** as the TSO is activating slow reserves based on a forecast of the imbalance. Moreover, also the BRP/Supplier needs to be able to correctly interpret the behaviour of his customers: in that respect it is important to know whether a reduction of consumption is the result of an DR-activation or not as if the reduction is caused by an DR-activation, the BRP can anticipate a possible ramp-up and rebound as soon as the DR-activation ends. To that extent, a certain degree of aggregation for the real-time information needs to be communicated towards the BRP on a lower voltage level could be accepted.

The future NC on EB will require the **harmonization of the balancing market design** in order to ensure a correct framework for developing cross border balancing markets. This potential can enhance security of supply and reduce costs. In the latest version of the NC on EB there is a clear tendency to go to a single imbalance pricing settlement and a shorter ISP. This would be in favour of EcoGrid EU as harmonisation of EcoGrid EU price and ISP is needed (a possible compromise could be 15 minutes).

To be in line with the Transparency Directive, a **clear and transparent publication of balancing information close to real time** is required. It is of major importance to treat DR in a non-discriminatory basis from day-ahead to balancing, including ancillary services. Although prices are published ex-post, the publication time is close to real time (a few minutes after) which serves as an incentive for market actors to react on the imbalance of the system. This, combined with **single billing** - where retail supplier, network charges and new DSR payments are all on one bill - offers them the possibility to modulate consumption without receiving penalties and the raise consumer acceptance.

Furthermore, in order to exploit the full potential of load and also help the system in the best way, DR should be incentivised to participate in Day Ahead and Intra Day markets as well before being offered to balancing.

**Market profitability study**

A second major impact on the detailed economic analysis for a country consists of the assessment of the **flexibility potential** of the residential sector (and possibly other sectors). If the flexibility
potential is sufficient, a detailed study on the profitability of DR should be performed by examining market opportunities for DR in different markets (DA, ID, balancing).

In the residential sector, the flexibility potential should focus on automatic response of devices as little reaction is observed from manual response during the EcoGrid EU demonstration phase.

A detailed cost benefit analysis should further investigate and prove the business case for a specific country or region. An important assumption in this business case will be the installation and implementation cost for equipment to enable DR.

From a scalability point of view, it can be concluded that a scaled up deployment of the EcoGrid EU solution would lead – due to economies of scale – to a relative increase in profitability with respect to the currently limited demonstration of EcoGrid EU. However, the cost of the equipment is always an issue for the roll out of the EcoGrid EU concept, as customers are only willing to invest a small amount of money and the financial incentives are rather limited.

In the longer term, this increase in market competition between demand side competitors should lead to a reduction of the ancillary services prices and can mitigate fluctuations caused by renewables resources, fostering their penetration.

All in all, the real time market for balancing is an interesting concept that would be suitable for residential DR and is generally in line with the currently drafted network codes. Currently observed trends on market designed in combination with each county’s specificities should be investigated further for a potential roll out of the concept.
3 Customer aspect

In this chapter, the main findings from the demonstration are described in order to be able to perform a replicability and scalability study later in subsection 3.2. Finally, based on these findings, several recommendations where extracted and are written in chapter 3.3.

3.1 Findings from demo

This section includes key findings and lessons learned from the EcoGrid demonstration. The purpose is to summarize the most relevant results for replication and deployment. To do this in the most comprehensible way possible, the results have been categorized in three time periods as shown in Figure 6.

![Figure 6 Customer findings from demo](image)

First, involving the participants was key to the success of the EcoGrid EU project. It took a large communication effort to fulfil the ambitious target of attracting almost 10% of all residential electricity customers on Bornholm. In a later stage, it was a big challenge to keep the participants involved. At the third stage, evaluation of the customers’ acceptance and response to the EcoGrid EU concept is based on customer surveys and statistical analysis ([1]).

3.1.1 Customers’ characteristics and recruitment

Who are the EcoGrid EU participants?

More than 2200 customers on Bornholm have been recruited to EcoGrid EU, while the objective was to recruit 1,900 households. However about 400 participants have withdrawn from the project, of which 200 because they were not qualified for participation.

At the end of the demonstration project (Spring 2015) 1840 private customers were still participating. Of all participants, 1019 customers have energy management/home automation equipment installed, i.e. automatic control of heat pumps (260) and electric heating (759).

Beside the households, the EcoGrid EU project included 17 industrial installations and 1 commercial building. This number is a bit lower than expected as the original goal was to recruit up to 100 industrial installations and commercial buildings. This was due to limited industrial processes.

The reader is advices to read Appendix A as the sample of the customers was not homogenous and different groups exist with different characteristics. These characteristics include the house types, heating devices, age of residents, consumption profiles but also types of control used to achieve Demand Response.

Baseline

Different base lines were evaluated to analyze the flexibility potential of the participating groups: reference group, historical metering data of the participants, standard profile and a statistical model. The reference group could not be used as a baseline as the characteristics of the groups were quite different. As a result, for the evaluation of the flexibility and the market potential a statistical model was used (see [1]for more details).

For the assessment of the flexibility potential a lot of data are necessary as for example separate meter data for the heat pump, knowledge about the customer settings, etc. together with the baseline these data should be defined early in the project.

Socio-economic characteristics of the participants
The participants do not represent fully the average population on Bornholm: Customer surveys indicate that the EcoGrid EU participants are over represented by high (er) income households, single houses, owner of their houses, two-person households and elderly people. Therefore, the future smart grid customers will certainly differ from the EcoGrid EU participants on Bornholm.

Table 3: Customer statistics of EcoGrid compared to Bornholm and Denmark³

<table>
<thead>
<tr>
<th></th>
<th>EcoGrid Customers</th>
<th>Bornholm Total</th>
<th>Denmark Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average age</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 70 year</td>
<td>59 year</td>
<td>46 years</td>
<td>40,9</td>
</tr>
<tr>
<td>20%</td>
<td></td>
<td>16%</td>
<td>12%</td>
</tr>
<tr>
<td><strong>Live in apartment</strong></td>
<td>2%</td>
<td>10%</td>
<td>39%</td>
</tr>
<tr>
<td><strong>Household Income</strong></td>
<td>&gt; 500 000*</td>
<td>405 480</td>
<td>474 321</td>
</tr>
<tr>
<td>(DKK)</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**Energy behaviour and consciousness**

Among the 900 EcoGrid EU households participating in a customer survey, 87% are at home on weekdays in the evening and at night and 73% during the weekends. Almost half of the participants are at home during regular working hours, which may be explained by a high participation of retired people. Of these respondents, almost 90% uses electricity for cooking.

Respondents indicate that they have some basic knowledge of their consumption and the cost of electricity. Approximately one third of the respondents know the cost of a kWh of electricity and their electricity usage last month. Nevertheless, most of the participants are unfamiliar with concepts such as “baseload” and “demand response”. Therefore, benefits for participants must be clearly communicated and understood.

However, the respondents said they are willing to change the time of use of their dishwasher, washing machine, dryer and electric heating. On the contrary, TV and PC are pointed out to be less flexible in time of use. Experience from the recruitment of the EcoGrid EU participants point out that communication and participant involvement from a very early phase of the EcoGrid EU project is key to success.

Besides automated control of their heating, approximately 65% is interested in automatically controlling their washing machine and dishwasher as well. Less interest exists to automatically control refrigerators and freezers. Similar preferences exist for remote control of their appliances.

**Motivating factors**

Although the importance of financial incentives for the EcoGrid EU participants is clearly evident, a considerable percentage of respondents rated environmental aspects very high. The most important factors convincing people to participate in the project are listed in Figure 7.

3.1.2 Customer involvement and response

**Creation of smart grid awareness**

In an initial phase of this Smart Grid rollout large demonstration projects, a greater awareness and understanding of the societal needs related to the rollout helps to compensate for the fact that the individual economic benefits of smart grid are still not so obvious. Therefore, Østkraft launched from the very beginning of the project – and even before the start of the official recruitment – communication initiatives to raise a general understanding and awareness of smart grids.

According to social science terminology these general information activities can be defined as the “core communication” that comprises the information supply to end-users, which establishes the...
bridge between the smart grid technology and the behaviour of end users. Adequate core communication contributes to optimal interaction between individuals and technology.

Figure 7: Motivating factors to participate in the EcoGrid EU project (Results of 1,609 participants; November 2013 [4]

Benefits communicated to the customers [4], [5]

It was decided early on in the project that communication with the public should focus on social values and environmental aspects rather than individual financial benefit. Further, participants were guaranteed not to ‘lose money’ by participating in EcoGrid EU and that they would receive the equipment for free which also played a significant role as motivation. Thus, the participants will never pay more for the electricity compared to what they otherwise would have paid according to their normal contract. The fact that no financial benefits can be guaranteed to the participants was a challenge. However, the financial risk - in a real smart grid environment – for end customers related to their integration into a real-time market has to be rendered acceptable without minimizing the incentives to actually respond to variable prices.

The recruitment target of 1,900 households made it necessary to also recruit people who were not particularly, or sufficiently interested in the “social and environmental” values of the EcoGrid EU project.

In a direct-mail campaign targeted towards recruiting the remaining 200-300 customers, Østkraft emphasized that EcoGrid EU participants could not lose money, but probably gain a financial bonus in addition to the free installation of the new equipment. Østkraft also stated that they would achieve individual advice and support during the entire demonstration period. Finally, Østkraft made phone calls to the customers who did not respond to direct mails. Importance of direct and personal contact with the customers should therefore not be underestimated.

Establishment of a Strong communication platform [4], [5]

Østkraft has been the main messenger of information about EcoGrid EU, but local ambassadors (e.g. Regional municipality mayor) and other well-known people have been active in the promotion of EcoGrid EU.

Additional, partners in a Danish Smart Grid communication project and the EcoGrid EU dissemination group have supported Østkraft in the development of communication tools (e.g. electronic newsletters, EcoGrid magazines, leaflets and pamphlets, videos, interactive EcoGrid EU Lego model, direct mails etc.).

The communication platform and activities:

- www.EcoGridBornholm.dk: Electronic news and information;
- Establishment of a smart grid demonstration house ‘Villa Smart’ in Roenne;
- Active use of public events to create awareness and information about the EcoGrid EU Project;
Moreover, the EcoGrid EU is mentioned on several occasions in the local media especially since the project was among the nominees to win the “Sustania Prize” and awarded with the silver medal “the honorable mentioned award”;

**Supportive communication, consultancy and training** [4], [5]

During the EcoGrid EU demonstration, there was a strong focus on informing and training especially regarding the functionality of home automation: “We have learned that all participants are manual customers until they know how the home automation system works.” (Martin Sjøberg, Siemens) [6].

Applying active regulation in winter times results in highly increased number of requests for technical support: Most requests were caused by minor technical issues, although there were also some more severe requests (e.g. heat pumps not satisfying the comfort requirement of the customer). During the course of the project, continuous training possibilities are necessary to react quickly on participant’s needs:

“For many customers there is a need for re-training after a while and training works best when it is personal. People don’t read what it says, but what they think it says and people get quickly impatient if things are not working properly or if they don’t understand how things work.” (Maja Bendtsen, Østkraft) [6]

Plenty of support – and certainly even more than during the EcoGrid EU project – is needed in the initial phase of the roll out of smart grid home automation solutions and the project has shown that the best advice to customers is delivered through personal contact. Therefore, a personalized customer service is advised to the extent that it is possible regarding man effort and costs, in particular during the initial phase of a wider smart grid roll-out. The following communication tools were provided to EcoGrid EU participants:

- Website (FAQ, user guides, news and newsletter, feedback systems);
- Help desk (by phone);
- Training session at Villa smart (targeted/adapted to different test groups);
- User guides/training videos;
- Home visits of electricians.

In EcoGrid EU, the so-called research communication activities (i.e. customer surveys/focus group interviews) is part of the communication plan that involves participants in the feedback of the project and informs them about their important role in the project. In a future smart grid, including active participation of end-users, research communication activities such as customer surveys, can be used in a proactive way to meet customers’ needs. Thereby, the continuously changing customer needs should be included.

**The challenge of keeping the customers involved**

The experience is that most EcoGrid EU participants have been extraordinary “patient”. However, by the end of the demonstration project about 400 participants have withdrawn from the project mainly because of the reasons shown in Figure 8. Many of them have mentioned (in focus interview/customer survey) that it took too much time to get the project going or to confirm participation in the project.

**“Honourable Mention” ISGAN and GSGF prize** (http://www.eu-ecogrid.net/events-and-news?start=5)

**“EEGI label”** (http://www.eu-ecogrid.net/events-and-news?start=10)

EcoGrid EU being among the 10 shortlisted finalists for 2012 “Sustania Prize” (http://www.eu-ecogrid.net/events-and-news?start=15)

A majority of the 200 participants who signed out by own request (>90 %) belong to the most recently recruited participants in the automatic control group. Their primary motivation for participating was the prospect of saving money (all). About 1/3 of the customers who have signed out
are within a group of “privileged” summer house owners (137) to whom the innovative aspect were priority no 2.

Participants of the manual control group were obviously not signing out of the project because they are unhappy or they have lost their interest in the project. They rather stay inactive or resign. In general, this group thought the project was less helpful to gain insight in consumption than in the automated response groups, which is interesting since manual response would require more insight than automatic response to adequately change consumption to respond to price signals.

Figure 8: Motivation of participations for signing out of the project [4]

Actual response from manual customers

The feedback systems were not used by many customers regularly and the logs showed less response than the customers reported. Hence, the customers that actively used the feedback system were analysed separately. These active manual customers did not shift their load significantly, but they increased their consumption during very low price periods. For example during the manual test they received information how to decrease their load in high-price periods.

The manual response to prices is a challenge by itself, especially in the long-run, as the customers have to actively and continuously set actions to shift their loads. Also in the German E-Energy projects it was shown that the customers adapt easier to fixed high and low price periods than to constant changing prices and periods. Especially real-time prices with high time resolution that change close to real-time are challenging to handle manually. The time resolution of the real-time prices with 5 minutes is a challenge for the manual customers.

Actual response from customers with automation

The actual responses from the different groups in EcoGrid with automation are shown in Table 4. These flexibility potential shows the best and average load shifting for one hour normalized per customers of the groups. To draw also conclusions for longer periods than for the 5 minute periods only these periods were considered where prices showed in the same direction for at least 12 5-minute periods. The values in kW are divided by the average load (over the whole evaluation period) of these groups to get a better feeling for the amount of the load shifting Table 5.

Table 4: Demand response potential in EcoGrid project normalized to group size [kW]

<table>
<thead>
<tr>
<th>Groups</th>
<th>Increasing RTP [kW]</th>
<th>Decreasing RTP [kW]</th>
<th>Increasing DA [kW]</th>
<th>Decreasing DA [kW]</th>
</tr>
</thead>
</table>

4 This test took place during four weeks at the end of the demonstration and it was specially designed for the manual customers with very high and low prices during times where the participants had reported to be often at home. Additionally to the feedback system the participants were informed via e-mail about these prices and got special information about load shifting and manual possibilities for load-shifting.
This project has received funding from the European Union ‘s Seventh Framework Programme for research, technological development and demonstration under grant agreement No 268199. The European Commission is not responsible for information presented in this report, nor does it represent the official EC policy and viewpoints.

The flexibility potential from the different groups depends amongst others on the optimization algorithms, the heating devices and on the characteristics of the households as for example if the house is a holiday house or an all-year residence.

The optimizing algorithm of the groups 1A-1C concentrates mainly on reducing the consumption during the highest prices of the day without performing any scheduling (the prices are an indicator for the peak). On the other hand, the optimizing algorithm of group 2 performs load shifting taking into account the forecasts of prices. When comparing the results of the two groups 1B and 2 with electric boilers the difference of these algorithms can be seen. The overall load shifting has a higher effect on the load flexibility than peak shaving – this can be very easily being seen in Table 5.

When comparing the results of the heat pump group 1A and the electric heating group 1B with the same optimization algorithm, the heat pump group has a higher flexibility potential – except for the average reaction to the DA-price. Both groups react on average similar to the day-ahead prices. The load shifting potential from the different heating devices as electric boilers and heat pumps could be further elaborated in a further demo project. For this in a future project a group focused on heat pumps with the optimizing algorithm of group 2 would be very interesting.

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**Table 5: Demand response potential in EcoGrid project normalized to group size [%]**

<table>
<thead>
<tr>
<th>Groups</th>
<th>Increasing RTP [%]</th>
<th>Decreasing RTP [%]</th>
<th>Increasing DA [%]</th>
<th>Decreasing DA [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semi-automated heat pumps (1A)</td>
<td>-0.3368</td>
<td>0.0240</td>
<td>0.3364</td>
<td>0.0239</td>
</tr>
<tr>
<td>Semi-automated electric heating (1B)</td>
<td>-0.1497</td>
<td>-0.0086</td>
<td>0.1154</td>
<td>0.0086</td>
</tr>
<tr>
<td>Semi-automated heating with aggregation (1C)</td>
<td>-0.0898</td>
<td>-0.0051</td>
<td>0.0947</td>
<td>0.0051</td>
</tr>
<tr>
<td>Fully automated electric heating (2)</td>
<td>-0.3177</td>
<td>-0.0147</td>
<td>0.2101</td>
<td>0.0147</td>
</tr>
<tr>
<td>Manual</td>
<td>-0.0166</td>
<td>-0.0013</td>
<td>0.0170</td>
<td>0.0013</td>
</tr>
</tbody>
</table>

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Figure 9: The response from manual customers using actively the feedback system to very low prices from 6 – 8 p.m. The non-reactive customers received no signal for demand response but their consumption was measured.

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When comparing the results of the heat pump group 1A and the electric heating group 1B with the same optimization algorithm, the heat pump group has a higher flexibility potential – except for the average reaction to the DA-price. Both groups react on average similar to the day-ahead prices. The load shifting potential from the different heating devices as electric boilers and heat pumps could be further elaborated in a further demo project. For this in a future project a group focused on heat pumps with the optimizing algorithm of group 2 would be very interesting.
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The results shown in Table 4 and Table 5 can be characterised as “conservative” because in this demonstration project the priority was to be confident that the changes observed in the consumption were due to price changes and not external factors like temperature, time of day etc. As a result, only the statistically significant results were reported. This means that different factors like temperature, time of day etc were filtered out in order to get the correct amount of flexibility that is related to DR. Having a criterion of 97% to be statistically significant, some results were excluded which could have been due to DR. In addition, the calculations were done using all households in the respective groups, without taking into account knowledge of how well the individual houses responded (see below for the different groups).

Another reason for the low DR observed is the fact that the control algorithms were repeatedly tuned over time, leading to changes in the behavior of the groups. This in turn resulted in less DR being identified by statistical models, as the emerging patterns of the behavior with respect to time of day, outdoor conditions and price changed with the change in control algorithms. These changes did not allow the statistical models to identify a repeating pattern with the desired characteristics and as result were excluded as being non statistically significant.

Another reason for low DR in fully automated electrical heated houses (Siemens) was that the flexibility in heating could not be fully utilized. In these houses a control algorithm (price agent) was used, that influences the temperature by setting a higher and lower limit. The limits could be set independent for every heating zone (room). To satisfy the customer demands, every customer was able to modify these values on their own. The standard range was preconfigured to +2 and -2 degrees to the required temperature. There were customers with a big response based on that controller and configuration, but on the other hand, there were also customers, which gave no or only very limited response. We assume that this is because of the following reasons:

- A lot of houses used other heating sources extensively which were not under Ecogrid EU control (e.g. wood stoves or Air/Air heat pumps).
- A group of recruited houses were summer houses, which were not responsive in the heating period, as the set-point was set to ‘winter protection’ mode (4°C) when unoccupied which does not allow for demand response.
- Even it has not been observed it in the project, there is a theoretical possibility, that the customer manually reduced the flexibility to 0.

The control of heating systems using the IBM and TNO price agents was faced with a number of limitations, which reduced the demand response volume from the real-time market in practice compared to the theoretically possible numbers. First, due to the focus on keeping in-house hardware costs low it was not possible with such an installation to increase indoor temperature above the set maximum temperature of the heating systems (heat-pump and radiators or direct electric heating panels). Pre-heating during low price periods was therefore technically not possible.

Secondly, the reaction time from the existing heat-pumps from a throttling command to a stop is about 5-20 minutes (1-4 price intervals of 5min) which is quite long. In addition, during the pro-
ject there were technical difficulties with a larger number of indoor temperature sensors, which could not be completely eliminated even by involving the manufacturer of the temperature sensor and the technical support of the Green Wave Reality (GWR) HEMS manufacturer. In the periods where houses did not provide proper indoor temperatures the demand response potential of such a house was limited to not jeopardize the users comfort and demotivate the users.

Next to the technical limitations also non-technical limitations limited the exploitation of the demand response potential. One non-technical limitation in the direct electric heating group was that many of the direct electric heating panels were set to a very low temperature and were almost never used for heating during the demonstration period.

Another issue with direct electric heating panels was the audible noise from switching the panels on and off. Even though an electric heating panel is an ohmic resistance with no ramp-up or ramp-down time and ideal for providing demand response in the five minute market, users complained about the noise and rather high switching frequency. To not demotivate the users the IBM agent limited the switching frequency which came at the cost of also limiting demand response potential. In a production installation this problem could be mitigated using different components like electric relays instead of mechanical, different placing or acoustic damping all at the expense of higher installation costs.

Moreover, some users set the interruption temperature, i.e., the indoor temperature that should not be undercut, relatively high compared to indoor target temperature. This combined with a low thermal inertia limited the exploitable demand response potential.

Through the EcoGrid EU project, important conclusions were extracted regarding the reasons for low demand response estimation. After identifying the reasons for low demand response, the evaluation teams of the consortium assessed them towards a future roll out in order to give a first estimation on the total potential of Denmark. Taking several assumptions, it was estimated that if 2 million households participated in real time demand response in Denmark, 100MW to 1GW of balancing power could be obtained. In addition to the Danish case, a Belgian case has been studied that showed 2M€ costs savings for the TSO per year by the use of hot water boilers. More information can be found in chapter 2.2.2.

The EcoGrid EU market concept is technology neutral. However, the residential DR potential differs from country to country. In an area where electricity is used for heating in general and for water, floor heating etc. with a short term thermal storage capability, the load shifting potential is much higher than shown in this project. The availability of the running balancing price information during operation, which presently is published in Belgium and the Netherlands, will make "close to real time" price distribution more realistic and cost efficient.

**Influence on energy efficiency**

The total energy consumption of the automated groups (group 2) was slightly reduced compared to before; the groups 1A-1C did not show a change in their energy consumption for both electrical and thermal usage. The energy efficiency of the manual and the reference group did not change.

3.1.3 Results from customer surveys

In general the customers were more positive to the project in the final survey than half-way the project.

In the final customer survey about 70% of the respondents answered positively on the overall EcoGrid project, e.g:  

- They perceive it as a positive experience;  
- They would like to participate in a project such as EcoGrid EU again;  
- And they say that it is likely that they would recommend others to participate as well.

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The results provided in this section are primarily based on evaluation by consulting the customers in two online customer surveys (the half-way survey and end survey) participants unless otherwise is mentioned. The results are based on the self-reported answers from the respondents (about 50% of all household participants contributed to the surveys). The EcoGrid customers who decide to sign out are not included in the survey.
It is interesting that overall scores on **expectation and ability to obtain goals** are higher compared to the half-way project survey, which indicates that customers might feel more enabled to reach goals in general. However, over time it seems that customers became less positive about the potential to save money or reduce consumption, but focussed more on social goals (e.g. doing something good for the environment and contributed positively to the image of the island).

**Appliance use.** At the end of the project, more than half of the respondents indicated that they have changed something in the way they used appliances. Similar to previous surveys the participants prefer to change the time they turn on their appliances in response to price changes (43%) over changing the frequency of use (7%).

Changes in frequency only increased when prices were low. This might indicate that **it is easier for customers to increase the frequency of which they use appliances than it is to decrease it.** Customers who did not change anything in the way they used their appliances said the most important reasons were that it was impossible to change anything and **that the incentive was too small.** Thus, in order to realise demand response by manual response to price signals, it is important to make sure that customers know what to change and that they have sufficient incentives to change their consumption.

**People were satisfied with automatic control**

The final survey results with regard to convenience, noticeability, and changes in comfort of the automatic control were similar to the results of the half-way survey. Automatic control was perceived as moderately convenient, not noticeable, and led to a slight increase of comfort. In the fully automated group, a larger increase in comfort was observed. This might have been caused by the additional means of this group to adjust temperature settings. Overall, 63.5% of the 664 respondents think automatic control is convenient.

**Feedback system**

"My EcoGrid" online feedback system provides information on electricity prices and gives insight in consumption. In the final survey 23% of the respondents visits "My EcoGrid" regularly. At the end of the project, the website use was increased slightly to 29%.

For the manual response group, the feedback system is of great importance, as it is necessary to adequately respond to price signals. The manual response were significantly more active towards the end of the project (33%) than in the halfway survey (14%) This increase might be caused by the load shifting experiment for the manual response group where customers were informed by emails that price spikes were expected. In the experiment the participants received an e-mail with a warning message in advance of (expected) very high or low price periods. The e-mail also linked to the feedback system and gave information about ways to change energy usage.

**Information and communication**

Half-way the project, customers were asked to evaluate how they perceived the information and communication so far:

- They were satisfied with the frequency and amount of information;
- They were also positive about the communication and service of Østkraft.
- As already mentioned, they indicate that the period between the subscription and the real start was too long.

With regard to the equipment and the installation process respondents were moderately positive. By the end of the project, frequency and amount of information was perceived as ‘just right’ or slightly too little. Customers were even more pleased with the service and communication of Østkraft than they were half-way project, and were also happier with the installation process. Also in the load shifting experiment, the information and timing of emails was positively evaluated by respondents.

**Critical lessons learned**

In the start-up phase of the project, existing hardware solutions had to be modified and new software had to be developed. During this phase, several issues were encountered that delayed the
rollout of equipment to customers. An important lesson was that it is crucial to reserve sufficient time to develop and test hardware and software, even before involving customers.

Furthermore, once customers have signed up for a project, they should continuously be updated on any development in the project. In this way, they are kept involved and interested.

Østkraft invested a lot of time and resources to solve the start-up issues that were encountered, often by having personal contact with customers or sending installers to the homes to help customers solve issues. This has resulted in a positive evaluation of their communication and services. However, for future projects, it is important to realise this kind of customer support requires a lot of effort.

The response from the manual customer was very limited and they showed mainly a higher consumption when the prices were very low. The actual flexibility potential depends on the automated heating devices, the control algorithm and the characteristics of the households. The optimizing algorithm that focused on load shifting including scheduling achieved higher flexibility potential than the one that was acting only on real time prices without any other information. The load shifting response to the real-time prices is for all automated groups higher than the response to the day-ahead prices.

### 3.2 Replication study

In general, it could be argued that since this experiment was a large scale demonstration including automation technology, it will not be very difficult to go towards a roll out. Although this is not far from reality, there are several aspects that deserve more detailed study. The replication chapter will be focused on the missing parts that were identified from the demonstration in order to securely move to deployment.

The conditions on Bornholm are optimal for a roll-out of smart grids: Over 25% of Bornholm’s total energy consumption - and more than half of the electricity consumption is covered by renewable energy. Bornholm is branded internationally as "Bright Green Island" and "energy laboratory" for innovative projects. Therefore, innovative energy projects have generally been met with wide acceptance on Bornholm. When recruiting for EcoGrid EU, several private households on the island were (or had been) involved in small energy pilot tests on the island - or they had heard of someone who had participated.

From the above, it gets obvious that these favourable conditions will not necessarily be found in case of a roll out of the concept to the whole Denmark or other countries of Europe. For this reason, it is necessary to analyse what would be different in case we would like to proceed from a large demonstration to a real roll out. To do this, both the aspects of Replicability and Scalability should be assessed (an explanation of the two concepts can be found in chapter 1).

#### 3.2.1 Replicability

**Characteristics of participating households**

The participants of EcoGrid EU belong to a higher income group that the average population and have a high focus on energy efficiency measures. On average, the participants were older than the Danish population. Hence, the results might not be representative for whole Denmark and even less for other European countries. However, a high percentage of the Bornholm population (5%) was involved in the project; Hence, the participants were not only early-adopters.

**General mind-set regarding sustainability, renewable energies and new technologies**

The participants were generally open-minded about sustainability, renewable energies and new technologies. 50% of the participating households consciously carried out energy saving measures in order to increase energy efficiency in their households. Relative to this, the specificities of the Bornholm inhabitants should not be overlooked and the general mind-set of a society should be investigated before replication.

**Keeping customers involved**

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It was found from the demonstration that luckily the customers were patient enough and did not get demotivated by the different challenges the project faced. On the other hand, this should not be taken for granted for the entire population. Consequently, it becomes very important to perform several tests and move to a smart grid deployment only when enough certainty of the targeted solution is achieved.

**Customers’ goals**

Another aspect that could be differentiated is the goals of the customers. In this project their main goals were related to innovation, environmental consciousness, community feeling etc. Again, it should not be neglected that this may be a very specific characteristic of the Bornholm inhabitants.

3.2.2 **Scalability**

In addition to investigating the differences between the residents of Bornholm and the other places, the aspect of rolling out the smart grid also deserves a discussion.

**Recruitment process and incentive for participation**

The success of EcoGrid EU was highly dependent on the participation of residential electricity customers. In order to get a high participation rate, participant’s involvement was key. Therefore, a large communication effort was necessary in the initial phase of a project, especially regarding the problematic, the benefits and risks. A proper estimation of resources and timing for an efficient recruiting approach will be necessary in order to scale up this concept. The recruitment process of EcoGrid EU can be seen as the best practice approach for other demo projects, but also for a wider roll-out.

**Communication during the project**

A thorough understanding of the functioning of smart meters and their advantage is of major importance for a future replication of demand response for residential customers. It must be assumed that in the initial phase of a wider roll-out the need for information and communication, personal training, etc. would be very high. In the long-term, this need will become comparable to other technical equipment.

One of the big challenges for demonstrations projects like EcoGrid EU— or for a wider roll-out of the EcoGrid EU market concept is to design solutions in a way that attract a diverse group of participants:

“From other tests, it is known that the conditions for field-tests are particularly well suited for island communities: People want a positive image of their island. This creates greater personal involvement in for example environmental issues. In large cities, the set of motivating factors are typically much more complex, and you must expect large variations in the different factors motivating urban people.” (Interview with Jessane Mastop, ECN). [6]

**After sale support**

One of the key messages from the previous chapter is the importance of “after sale” support for the EcoGrid EU or smart grid customers. It is understandable that more support will be needed at the initial phase of the smart grid development, but what about a longer perspective? Will this be possible in case of a roll out?

“I do not think there is a need for more information about the use of automation equipment than is required for the installation and use of an alarm system. It’s similar to the development of other technologies: When the internet came there was a great need for information
about how to use it. Today, manuals, web and phone support are sufficient.” (Martin Søbjerg, Siemens) [6]

3.3 Recommendations

It is without doubt that one main outcomes of this project is that the customer aspect is crucial and the consumer’s comfort and needs should be one of the restrictions or even drivers of the whole smart grid deployment.

Alternative ways of motivating customers

Before going towards a roll out of a demand response solution, the business case and possible benefits for the consumers should be carefully analysed and communicated to them. On the other hand, financial incentive is not the only way to attract participants.

Alternative ways of motivation should be targeted like social, environmental or innovation goals. Furthermore, regarding commercial customers, their participation can be used as part of their marketing strategy.

Acceptable comfort level should be ensured

It is clear that the comfort level influences the decision making of the end consumers: In case the comfort level is similar or better, the recruitment is easier and the drop-out rate will be lower. Moreover, the drop-out rate can be reduced by optimized technical equipment and lower waiting times for the installation of the equipment.

“Smartness from a consumer point of view is certainly not about kWh, but rather about convenience or comfort.” (Interview Jacob Østergaard, CET-DTU)

Customers don’t like major temperature variations. Østkraft experienced that two degrees temperature variation was not criticized by customers, but higher deviations were not acceptable.

Target a diverse mix of participants

In case of a big roll-out a diverse mix of participants could be attracted to take part in load shifting – also the ones with less energy efficient equipment. By doing this the load shifting potential could be increased compared to the EcoGrid EU demo.

Adequate information and visualisation towards customers

In many projects, participants highly appreciated that they received insight in metered consumption data, price curves and the visualization of the energy costs. The general acceptance of dynamic tariffs varies according to their complexity and transparency. Price information to consumers should be kept simple, understandable, and easy to respond to.

In case of manual response, special attention should be given to the feedback system. From EcoGrid EU it was found that the web-based feedback system was randomly used and was not enough. An external display or mobile application could have brought better results. The usage of the feedback system could be further increased by integrating new possibilities (e.g. change temperature settings) for the participants to influence their comfort settings.

People get quickly impatient

Experiences from similar demonstration projects shows, how important it is that the participants have their equipment installed relatively short time after signing up to the project. From the outset this was also the aim of Østkraft and the project in general. In reality the recruitment for the demonstration project has taken place at a faster pace than the installation of the equipment. For the participants, waiting seems to take a while. For this reason, it is very important that the participants are continuously updated and informed about the project.

Proper training of participants
By communicating with and engaging the participants in the project it may be possible to influence the consumer behaviour of the participants. Even automated customers are “manual” customers before they know how to use their home automation system.

**Customer approach and reliability**

People skills are equally important to technical skills. Installers, electricians and technical “experts” should be chosen carefully. It’s important that they have both technical and communication skills. Additional training should be given if one of the skills is underdeveloped.

**Acceptance of automation**

In this project, a high acceptance of automation was noticed. Respondents, who were aware of their automatic control of heating, were positive. They indicated it was convenient, not very noticeable, and there was a slight increase in comfort as compared to no automatic control of heating. Overall, the EcoGrid EU automation equipment was perceived as neutral to moderately positive.

The acceptance of automation is highly dependent on:

- High comfort levels;
- Possibility to change customer settings (especially in winter times the automation was overruled by EcoGrid participants);
- Personal trainings and installation with technically and socially skilled staff;
- Re-training for customers after a while is needed in order to guarantee the acceptance of automation;
- Existence of comprehensible manuals;
- Sophisticated technical equipment (technical issues such as malfunctioning, the installation process and the time it took the project running were named to be the main reason for people to drop-out of the project).

Especially for real-time prices automation is very important as the active participation of the manual group can be described to be quite low.

**Load shifting potential and fatigue effect**

Keeping the participants’ highly motivated during the whole project period is essential for the success of the project. Several actions could be taken to prevent user fatigue:

- On the one hand, the ICT infrastructure should provide a reliable, stable and user-friendly platform. Communication problems and malfunctions of devices should be solved very quickly if they appear. Several additional actions are key for success; E.g. software updates should be done remotely, web portals should be kept very simple, ...
- On the other hand, other than monetary incentives can increase people’s awareness and maintain their interests. E. g. Non-monetary incentives, gamification, competition and social comparison and goal setting components) should be investigated to motivate and reward smart grid customers.

From several projects, it can be concluded that customers reacting via manual response are more likely to adapt their behavioural routines to simple, easy to comprehend pricing schemes than to complex and frequently changing price signals. However, if more complex and dynamic signals are to be used, they should be combined with equipment that offers capability for automatic reaction.

Once customers have signed up for a project, they should continuously be updated on any development regarding the project.

**Data security and protection, privacy and intrusion**

Due to the processing of personal data and integration of ICT on a significant scale, data protection, privacy and security become major concerns. A functional and clear privacy and security poli-
cy must be put in place. This requires definition of roles and responsibilities regarding data management.

**Technical and infrastructural challenges**

The EcoGrid EU concept with 5 minute real-time prices focuses highly on devices that can react automatically on prices (e.g. devices with a high inertia as electric heating). In terms of replicability the demand flexibility should be investigated in advance, together with the technical feasibility of these devices.

About 200 participants of EcoGrid (9%) had to withdraw from the project because it was not technically possible to install the required equipment. Others needed to be excluded from the project due to the lack of flexibility or the existence of tailored solutions which were inappropriate or incompatible.

**Home visits must be kept on a minimum level**

EcoGrid EU has provided valuable insight into the difficulties that arise when targeting a large group of participants. For example, the problems that were encountered with equipment and installation in the beginning of the project were tough to tackle as it required so many house visits. For a larger roll-out this would imply high costs and human effort. A smaller scale test-setup of equipment would be advised, although such a test group should be diverse enough to make sure that all possible difficulties are encountered.
4 Technological aspect

During the EcoGrid EU project, different technologies were tested in order to allow different kinds of demand response. As described in the introduction chapter, both manual and automatic DR were tested by dividing the participants in different groups. Different providers have offered their technology and the results showed noticeable demand response. Interesting findings were identified during the four years of the project and important recommendations have been extracted related to technological issues.

4.1 Findings from demo

4.1.1 Unexpected problems identified

Being the actor with direct contact to end consumers, Østkraft has been giving valuable feedback on technological findings related to the technology used. To be clearer, these findings have been separated in situations where (i) the installations had to be abandoned and (ii) unexpected failures/malfunctions in the installations have been occurred.

Situations where the installations had to be abandoned

In some cases, despite the willingness of end users to participate in this effort, there were technical limitations that did not allow them to provide DR and the installations had to be cancelled. In retrospect the partners should have spent more time on making a clear definition of minimum technical qualification criteria prior to project initiation in order to avoid visits to non-technically capable houses. However, a technical assessment must be made by an electrician before the installation could start as alternative ways for installation would be forbidden by law.

Example of technical challenges and limitations, and where the installation had to be abandoned:

- Some of the home energy management system could not be installed as heating system was not separated by its own fuse in the electric wiring of the home;
- Most air-to-air heat pumps did not have the capabilities to be automatically controlled;
- No space/room for the equipment.

Unexpected failures/malfunctions with the installations

In addition to the non-technically compatible houses, cases with unforeseen technical malfunctions have been experienced. For the equipment to function, it was required to have stable cable internet connection at every customer. For the subset of customers who had no cable internet, mobile components were added. However, the software in the equipment was not designed to manage situations, for example when “machine-to-machine” communications goes down from 3G to 2G.

In order to mitigate the negative impact from unstable network connections a timer was installed. The timer ensures that the router/home plugs once a day is turned off, so the equipment has to restart communication.

The AMR meters in the experiment have failed periodically. Although Østkraft has a server that stores all metered data, many customers feel insecure when they either see no numbers on the display or alternatively an error message with digits that can be confused with very high power consumption.

Examples of other unexpected issues/malfunctions with the installations include:

- Insufficient battery capacity of the temperature sensor installed in 600 EcoGrid houses with automatic control of heat pumps;
- Errors were detected in a part of the contactors from about 500 participants with automatic control of electric heating;
- Missing information at the user web portal;
- The equipment was noisy;
- The electricity consumption of the equipment was unacceptable high.
Some of the issues mentioned above may seem insignificant and trivial. However, small technical errors and vulnerabilities in the EcoGrid installations caused additional workload for Østkraft, including more visits from electricians than expected. In the worst cases the customers felt so uncomfortable that they opted out of the project.

4.1.2 Direct EcoGrid Exploitable Results

Within the EcoGrid EU project a large technological step has been made from the basic concept of EcoGrid EU (Figure 10, left) via decomposition in roles and functionalities (Figure 10, right) to a comprehensive deployment of software and hardware. Naturally, Information and Communication Technology (ICT) is the key enabler for both demonstration and replication of the concept. For the ICT architecture of EcoGrid, the first level decomposition shown in Figure 10 has been further decomposed into multiple layers of software and hardware, together forming the ICT Architecture of the project.

![Figure 10: From the EcoGrid Basic Concept (left) to First-level Decomposition (right).](image)

The EcoGrid EU field deployment consists of a mix of existing off-the-shelf products, enhancements of existing products and newly developed modules. The project’s ICT innovations include new methods, tools, software and hardware products developed for EcoGrid EU and available for use beyond the project. Additionally, a number of pre-existing products and tools were used in a new way or novel context.

In this way, EcoGrid EU led or will lead to new product features in existing control products and (open source) software, as reported by Landis and Gyr, Siemens and TNO. Further, EcoGrid EU led to new research tooling available to or already exploited in further R&D projects, as reported by IBM, Siemens and TNO. See the [7] for more information.

4.2 Replication Study

When it comes to the questions of replicability of the technology it makes little sense to try to compare different countries since the implementation of a new technology does not depend on the location. Nevertheless, it would be quite interesting to analyse the replicability between a demonstration project and a real implementation to a power system.

4.2.1 Stages of Smart Grid Technology Development

The “smartening” of the electricity system is neither a one-time event nor a linear pathway. Instead, it is an evolutionary process that moves along different axes and through different overlapping stages. Later on in this chapter, we sketch the EcoGrid EU ICT Roadmap. We do that against
the background of a more general Smart Grids Roadmap, based on two existing roadmaps combined with insights from the authors. The existing roadmaps used are [8] and [9].

Two important developmental axes are the **richness of smart grids functionality** and the **increasing reach throughout the electricity system** of these functionalities. The latter is depicted in Figure 11: When the electricity system gets “smarter”, the reach of Information and Communication Technology is enlarged from the transmission system, through the distribution system to the connected customers.

Figure 11: Smarter Electricity Systems: increasing reach of ICT throughout the electricity system [8].

While the reach of smart grid technology increases, its functionality evolves as well. Focussing on customer integration, the richness of smart grid functionality is recognised to develop through four stages (adapted from [9]):

- **Foundation:** In this stage, important prerequisites to customer integration are being realized. There is, however, limited interaction with the customer itself. Typical developments: introduction of smart metering, increasing distribution-grid monitoring and automation, introduction of whole-sale and transmission-level markets, demand response as a point solution (e.g. remote switching of heating and/or cooling systems during peak times).

- **Inform & Automate:** The customer becomes connected with the electricity system coordination, albeit through one-way communication. Customer-level ICT is introduced to react to these outside signals, mainly to inform the customer. Grid monitoring and automation becomes mature on the mid-voltage levels and is introduced in the low-voltage grid. Typical developments are: short-cycle billing (e.g. once a month), feedback display systems, demand response through price signals (time-of-use pricing, critical-peak pricing, dynamic pricing).

- **Interactive Grid:** Two-way communication with customers and their automated systems is introduced. Automation is present across the entire energy value chain and increases value/decreases cost for all parties involved. Increase in sensing and control systems in the network and at customer premises. Next generation computing enables analytics and control that increases the value generated by smart grid technology.

- **Transactive Grid:** Full convergence of energy and information systems. Throughout the value chain, control actions are made based on value transactions. This leads to a network of subsystems that automatically negotiate about their actions, not only regarding the ‘electricity commodity’, but also regarding local and global ancillary services. Wide implementation of distributed computing systems leads to shorter response times and more localised control.

Figure 12 shows these four stages against the two developmental axes defined: richness of smart grids functionality; Increasing reach through the electricity system.
4.2.2 Mapping the EcoGrid EU demonstration phases to Smart Grid Stages

The aforementioned sectioned gave an overview of the stages for a full implementation of smart grid solutions in a real grid. As a result, it would be interesting to map the different phases of the demonstration on the same roadmap in order to identify where EcoGrid EU is standing and how far it is from an implemented smart grid solution.

- **Foundation**: Some of the elements of the foundation that were a prerequisite for the demonstration were already existing (p.ex. whole-sale market on transmission level). Since EcoGrid EU was a project to demonstrate a specific solution and technology, it was not necessary to fully realize the foundation level in order to move forward.

- **Inform & Automate**: As described in the introduction, the first stage was an open loop test, where the EcoGrid real-time price was communicated to the participant’s premises while the resulting demand response was not measured in real time. In this test phase, the resulting demand response was determined in a later moment in time, based on the metering data. This phase belongs to the “Inform & Automate” stage of smart grids development: the customer, and the automation system at the premises of the customer, is informed of the real-time price and an (automated) reaction follows.

- **Interactive Grid**: In a mass roll-out situation, however, the triggered demand response would have a direct influence on the system-wide balance. This influence would become apparent by monitoring the system frequency and/or the power flows at the boundaries of the transmission-level control zone in question. In such a situation, a closed-loop control would be possible, where the real-time price can directly be adjusted in order to minimize the total imbalance in the control zone. As this method interacts directly with the grid, it can be seen as an early form of the “Interactive Grid” stage in Figure 12. Although EcoGrid was a large-scale demonstration, the amount of load influenced is still small as compared to the total load in a transmission control zone. Hence, during the EcoGrid demonstration this type of closed loop operation was performed based on a fast automatic meter reading process collecting five-minutes metering data of the participants in near-real time. In the last part of the demonstration, distribution-level congestion management was performed using a subset of the houses in the demonstration. A feeder connecting 26 houses was receiving a locational price when the power load on the network segment reached a certain capacity limit. In these cases, the real-time price for this subgroup was differentiated from those of the rest of the EcoGrid EU participants in order to steer away from the overload situation. When this type of congestion management is performed on a larger scale, i.e. involving a high number of potential congestion points, the smart grid operation can be said to be part of the "Interactive grid".

- **Transactive Grid**: Although EcoGrid EU was a large scale demonstration, it still remained to an experimental level. As a result, it cannot be argued that a transactive grid stage was achieved, but the project set important foundations to show the way towards it.
4.2.3 Enabling Large-scale Deployment in the Last Mile

In order to replicate the EcoGrid EU concept on a large scale successfully, the approach to the last mile is of paramount importance. To roll out to multimillions of small and medium-sized customers, the Cost to Connect should be low, while the Ease to Connect, must be high. For both of these aspects interoperability is key: in any value chain, cost for hard- and software goes down when proper interoperability standards are in place. These standards need to ensure a seamless connection between different layers in the value chain and between systems manufactured by different vendors.

Lower Cost to Connect: In order to reach a low connection cost, it is recommended to standardise the gateway software platform such that:

- Customers are not forced to invest in new gateway hardware when he/she switches to another energy provider. Dedicated software that might be provided by the new energy supplier should run on the existing gateway hardware.
- The software platform runs on generic non-proprietary hardware, so it can be integrated in a multi-functional hardware platform. In that way, the smart grid gateway software runs on existing hardware such as the internet router or a general home-automation platform. Then, there is no gateway hardware cost to connect a small-customer to the smart grid.

Increase Ease to Connect: To connect a small customer to the smart grid, gateway software, and possibly hardware, needs to be installed and connected to the devices and installations at the customer premises. Performing these installation tasks can either be done through self-installation by the customer or by trained staff. In either case the installation must be as simple and straightforward as possible. Therefore standardization must allow the following:

- Plug & Play connectivity on all levels: from energy-responsive devices to the gateway and onwards to the outside systems that form the smart grid'. Therefore, standard protocols for discovery, Provision and Reconfiguration need to be in place:
  - Discovery: A customer buys and installs a new device (white goods, heat pump heating, electrical car, etc.). How does the new object find the right energy gateway? And not that of the customer’s neighbour.
  - Provision: How are software updates distributed to the gateway platform and the connected devices? This may happen for various reasons, such as protocol updates. Also when the customer changes energy provider and the new provider uses different response software than the predecessor.
  - Interoperability between hardware/software providers and between value chain parties. It is very important that the customers do not need to change their hardware each time they want to switch suppliers.

Resource Abstraction protocol for energy capabilities of connected devices. Through such protocol energy flexible devices communicate their available energy flexibility in a way that shields off the specific operational details of the device, comparable to the way a USB device communicates with a computer it is connected to.

4.2.4 Scalability of technology

The EcoGrid ICT architecture is well scalable. The only (near-) real-time communication necessary is the one-way broadcasted price. Generally, one-way signalling of low-bandwidth information can be done very efficiently and scales well with the number of listeners to the broadcast. The largest change from the state-of-the-art triggered by a roll-out of the EcoGrid concept is the higher resolution of the automatic metering. The common practice in automatic meter reading implementation is a metering interval between 15 minutes and an hour. The EcoGrid concept takes this down to 5 minutes, which increases the amount of data that needs to be collected, communicated, stored and processed into billing information. For an EcoGrid roll-out, however, this is not time-critical information, as the metering data is solely used for billing purposes.

4.2.5 Cost of equipment evolution
In order to assess the profitability of the EcoGrid EU concept, a view on the equipment cost has to be given. At this point it is necessary to underline that the equipment used for this demonstration project was a modification of existing equipment and the costs should not be indicative for future roll out. However, a rough estimation of the costs in a future case where the economies of scale will bring the prices down is provided below. The assumptions taken for the cost estimation are described in detail later in this chapter.

As far as the current and future equipment costs of EcoGrid are concerned, they can be categorized in three main groups:

- Cost of house equipment
- Installation cost of house equipment
- Cost of market platform

At this point, it is important to mention that EcoGrid EU is a demonstration project where a market concept was demonstrated. The main purpose of the project was not to develop new hardware that will be used for demand response, but to demonstrate demand response via real time pricing. To do this, existing hardware was modified to fit the needs of the demonstration and as a result, the cost and performance of the hardware used during the tests should not be taken as a benchmark for future studies. It can be expected that when the needs are known, more advanced equipment will be designed for this exact purpose. However, for reasons of completeness, an indication of prices is given below.

**Cost of house equipment**

Before start describing the cost of the equipment and giving rough estimations on its future evolution, special attention should be given to the fact that in the future it is highly probable that each home appliance is connected to the internet of things by communication interface that is integrated by the manufacturer by default. In such a case, the number of additional devices needed for demand response will decrease significantly and could even reach the point where only the optimisation intelligence is required as an add on.

IBM used the technology developed by Greenwave for the EcoGrid EU project as it is not in the business of developing, manufacturing or selling home energy management systems. As a result, the numbers given below regarding the future evolution of costs should be regarded as rough estimations.

The HEMS in-house hardware costs for the GreenWave equipped semi-automated households controlled by IBM in EcoGrid EU were about 250 - 350 Euro per household depending on household layout and needed material not including license costs for the needed cloud services. A productive installation of this type would be cheaper by 50-70 € as some of the components where used for development purposes and wouldn’t be necessary in a productive setup. The components used for the semi-automated households in EcoGrid EU where mostly off the shelf standard products that are already in mass-production hence no big price drops on the components should be expected.

Said the above the hardware for a scenario with the same framework conditions as the semi-automated households in EcoGrid EU with one temperature sensors per household, a HEMS gateway and one actuator for the heating system throttling, but excluding the development hardware used in EcoGrid EU in form of a clamp and pulse reader, would currently cost between 150 and 300 Euro. This price for one installation is based on a web search for current low- to mid-price aftermarket home automation components from different venders and HEMS systems types and assumes an internet connection available free of charge in the participants households.

For a rollout scenario with 50000 participants in 5 years a share of 10% already cloud connected heating system installation where no further in-house hardware is necessary is assumed. For the 90% legacy houses where additional hardware is needed the average price for the additional hardware is expected to be 160 Euro after a quantity discount of 20%. This leads to total hardware costs of 8m Euro for all 50000 participants.

SIEMENS also thinks that there could be other options to connect appliances in the future integrated in the home appliances (like Danfoss online or Smart meter gateway) in the future. In these cases the costs for installation and equipment could be very low or nearly zero.
In the Pilot project Siemens has chosen to control the applications with existing equipment. This equipment was chosen with the aim to use as much as possible already existing equipment. Beside the project, products have improved with new functionality. That new functionalities would already today reduce implementation costs.

For the project, Siemens has chosen the own product series ‘Syncho Living’ and a prototype for a Grid gateway. For the installation in houses an average of 6 Syncho Living components (Sensors, Controllers, User Interfaces, Web Server) and 5 Contactors and the Grid gateway have been deployed. With the new version of the ‘Syncho Living’ firmware, the ‘Grid gateway’ could already be replaced today. This would reduce the costs today from ~1400€ in the project to ~1000€. We assume, that an additional reduction by ~30% could be reached, if a mass rollout of the components is issued.

**Installation cost of equipment**

With regards to installations, 3-7 hours per installation with HEMS have been used. The time used depends on the complexity of the house, electric wiring and the equipment itself. The Siemens equipment was more complex to install than IBM/GWR. This was caused by more possibilities to parameterize the Siemens equipment and the possibility to divide the house into more heating zones.

When doing the installation the electrician shall not only do the technical part of mounting contactors and relays. His first task when entering the house is to “read” the house and its use to optimize the installation he is about to do. First then he can set out and explore whether it is also technically possible to do an installation, and then the actual installation can begin. Before leaving the house the electrician will do settings in the system together with the customer.

In future, when many appliances are already connected to the internet (IOT appliances) the installation process will be dramatically reduced and can perhaps even disappear completely, as the appliances are already connected. It is difficult to exactly predict, when IOT appliances will be generally distributed, but it expected that the installation process will be unnecessary within the next 15 years as appliances are exchanged. On a 5 years horizon it is however expected that an installation time of 2-5 hours is still needed, as the installations will still to a high degree be retrofitting.

With the Smart thermostat the installation time would be reduced to 1-4 hours (depending on application), compared 3-7 hours for Ecogrid Project

**Cost of market platform**

Being a research project, EcoGrid EU had special needs regarding data logging in order to have sufficient information for the analysis of the results. To have a more realistic point of view, one should remove these extra functionalities and limit the use to a productive environment without all the extra logging specifications. In such case, the hardware costs would be at around 7500-15000 € for two servers in two different locations to provide a failover possibility. A yearly expense of 500-1000 Euros is also needed for energy, cooling, backup and so on. Both numbers expect this servers are placed in a already existing data centre with and existing infrastructure.

Regarding the scaling of the market place, no additional hardware will be needed for the central price calculation. The question is more on the price distribution. Different possible solutions would exist like the IP Multicast network infrastructures available in many countries operated by internet providers, the infrastructure of VOIP or attaching it onto the data channel of a radio signal. Scaling wouldn’t be a problem as it is a network built to scale. However, to get to the service costs one would need to enter negotiations with the operators which was something outside the scope of the project and as a result no cost estimation can be given for this part.

**Table 6 Indicative estimation for future cost of equipment**

<table>
<thead>
<tr>
<th>IBM</th>
<th>Application</th>
<th>Hardware</th>
<th>Business case 1</th>
<th>Business case 2</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Hardware</td>
<td>Hardware cost 1 home</td>
<td>Hardware cost for 1m homes where a percentage already has a cloud energy</td>
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<tr>
<td></td>
<td></td>
<td>Hardware cost 100k homes/home</td>
<td>Hardware cost 1m homes/home</td>
<td>Hardware cost for 1m homes where a percentage already has a cloud energy</td>
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This project has received funding from the European Union’s Seventh Framework Programme for research, technological development and demonstration under grant agreement No 268199. The European Commission is not responsible for information presented in this report, nor does it represent the official EC policy and viewpoints.
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### 4.3 Recommendations

One of the findings of the EcoGrid EU project is that a robust and effective ICT technology is a major aspect for a successful smart grid roll out. Despite the fast technological advancements that have taken place the last years, this issue should not be underestimated and only properly tested solutions that fit in customer’s flexibility needs should be implemented. The following recommendations can be proposed for a successful implementation:

**Use of “off the shelve” solutions**

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This estimation is only indicative and is given under several assumptions:

- IBM is not producing this hardware and also Greenwave (hardware provider for IBM) is out of business. As a result, the figures given are rough estimates after a market research.
- The hardware & solution used for the Ecogrid Project was not cost-optimised; a future solution could be based on the new Siemens Smart Thermostat.
- The price examples depend on which heating application is used: we take typical examples of electric radiator; electric heat pump; electric domestic hot water.
- The examples for the SIEMENS equipment include the simplest case, single zone heating control; and 3-zone control (living, bathroom, bedrooms).
- The Siemens Smart thermostat may require adaptation, depending upon which (high volume) applications are required.
- Decision to adapt will usually be based on a volume commitment by the customer.
- Two basic Business Cases are assumed by SIEMENS: 1. Supply of control hardware only; 2: Supply of control hardware and cloud-based energy management.
- Business Case 2 – Cloud-based Energy Management, can have various elements, e.g.: peak load shifting; energy saving; customer loyalty programme.
- Depending on content of Cloud Energy Management business model, a monthly fee ranging between 1 and 10€/month/home is assumed.
- Depending on the business case, the hardware cost may even be reduced to zero when supplied with Cloud-based Energy Management.

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<table>
<thead>
<tr>
<th></th>
<th>Meters</th>
<th>Consumption measurement</th>
<th>Landys +Gyr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric radiator heat and heatpump households</td>
<td>Temperature sensor, Actuator, HEMS Gateway</td>
<td>~250 Euro</td>
<td>~160 Euro</td>
</tr>
</tbody>
</table>
In this demonstration project, the technical solutions that have been used were based on existing equipment that was adjusted for the needs of the project. This equipment was not initially designed for using DR from end consumers to balance the grid and had to be modified at the beginning of the project to perform the demonstration. In addition to this, during the course of the demonstration, the need of further modifications was identified to reach a successful result.

As a consequence, several problems occurred which impacted the demonstration and subsequently the consumers. For this reason, it is proposed that technological improvements should be performed via smaller scale experiments. When the size of the demonstration is large or in case of a roll out, “off the shelf” solutions should be deployed that are designed and tested for the specific reasons of each project.

Finally, clear responsibilities should be defined in training of using the equipment and after sale support. The end user should have one contact entity for all these issues that will give clear guidelines from the beginning of its involvement in the program.

**Ease to connect**

Another interesting finding of the project is that technology used to enable demand response for residential consumers should be as simple as possible and require minimum effort from the users to set up and operate. Interoperability is a prerequisite which should result in the customer being able to switch service providers without having to perform complicated changes in his equipment. The target should be to have close to “plug and play” functionalities of the equipment where a customer just installs the equipment and it starts working.

**Technology adapted to extract flexibility**

As mentioned before, the devices used to enable DR should be robust and user friendly enough to attract and gain the trust of end consumers, who are not necessarily primarily interested in the challenges of the power systems.

Furthermore, they need to be properly designed in order to be adapted to end user’s needs and as a result be able to extract the maximum flexibility possible (p.ex. possibility to handle multiple heating zones in one house). Technical specificities of the houses and appliances to be controlled should be carefully considered when selecting a technical solution. However, this does not mean that the technology should be customized for every consumer differently. A uniform solution is desirable but focused towards flexibility.

**Data handling and remote controllability**

Having the data security and customer comfort as priorities, another important lesson from this project is the ability of efficient and reliable data handling. Adequate storage of data should be foreseen in case of a real life implementation that will ensure minimum effort to recover any lost information and limited need for personal visits to customers’ houses. In addition to this, remote access of the equipment from the contact entity of the customers should be foreseen to avoid on-site visits every time a problem occurs.

Moreover, knowing that DR from residential sector included numerous contact points, a great deal of data is expected to be generated. This data will be used for flexibility estimation, settlement, service improvement assurance of customer comfort etc. As a result, big data handling capability is one of the most important aspects of success.
5 Regulatory aspect

The analysis of the possible replication of EcoGrid EU would not be complete without investigating the existing regulatory barriers and formulate possible recommendations to relax them. Although it is not a hard stopper, regulation should not be neglected as it can rapidly promote or discourage the deployment of smart grids.

5.1 Findings from demo

The EcoGrid EU demonstration is treated as an isolated entity in order not to interfere with current legislative frameworks. Therefore, no regulatory findings from this demonstration can be included in this study.

5.2 Replication study and recommendations

In this chapter, the replicability study and recommendations have been combined as the regulatory aspect has been investigated in a more general way without providing specific recommendations per regulatory regime in Europe. The whole problem is seen from a European perspective and the recommendations apply to all European countries. Of course, some member states are expected to have already overcome some of the barriers mentioned below and be one step closer to implementation of Demand Response.

Reach complete implementation of European directives

Full transposition of the Electricity Directive (2009/72/EC) and the Energy Efficiency Directive (2012/27/EU) is one of the prerequisites for a large scale integration of demand response programmes. These two directives open up market access and participation to demand response, placing it on an equal footing with generation and in a transparent and non-discriminatory manner. However, in some European countries, the Electricity Directive and Energy Efficiency Directive are not fully transposed. Although, the resulting regulatory barriers will not be observed as definite ‘showstoppers’, they do in general discourage an efficient and swift development and implementation. In addition, the lack of clear definition of responsibilities of new roles like aggregators leads to long discussions and does not help the fast deployment of demand response solutions.

This section will explain the most important, currently observed, regulatory barriers for further replication.

Full implementation of Network Code on Electricity Balancing to promote greater integration, coordination and harmonisation of electricity balancing rules

ENTSO-E is, with guidance from the Agency for the Cooperation of Energy Regulators (ACER), currently drafting a set of rules – translated in network codes – to facilitate the harmonisation, integration and efficiency of the European electricity markets. Those who are particularly related to demand response for balancing are the network codes on demand connection, system operation and balancing, as well as the related guidelines on tariffs.

In this matter, it is important that the stipulations in the NC on balancing will allow the EcoGrid EU concept. As at the moment of writing, the definitive version of the Network Code on Electricity Balancing is not yet available. However, in the current version of the NC on EB, there is a tendency to go to a reactive balancing market with single imbalance pricing settlement and short Imbalance Settlement Period.

Set up of a smart roll out plan taking into consideration the cost of Smart meters

One barrier for aggregation and demand-side management for the customer and aggregator is the needed investment in smart meters. Within the current liberalised energy market the question is which actor should take the initiative in this respect, as the cost and benefits of implementing smart meters accrue to multiple actors. Meter ownership is also an important factor to consider, since advanced meters can be strategic assets, providing significant value to suppliers and consumers [10].
Before the decision of a possible roll out, a regulatory framework around smart meters (with a clear assignment of roles and responsibilities), specific standards for interoperability and an extensive definition of roles and responsibilities related to ownership and handling of measuring equipment and data should be drawn.

**Set-up of regulation incentivizing more intelligent operation**

Increasing penetration of DER requires investments in capacity and in ‘smartening’ the network (i.e. ICT) in order to capture potential role of DER in markets. This requires adaptation of traditional network regulation in the following directions:

a. **Optimal decision-making regarding the choice between OPEX and CAPEX-based solutions within network management;**
   Traditionally, the system operators have been remunerated according to their CAPEX while the OPEX was a pass through cost. Although this logic has been ensuring high security of supply, has not been taking into account the challenges that fluctuating forms of energy could bring to the power systems. As a result, regulation should incentivise the system operators towards a more efficient operation by putting incentives on the OPEX as well.

b. **Incentives (including remuneration) for innovative approaches:**
   In order to stimulate a more efficient and sophisticated system operation, a strong push by innovation is required. Regulators should incentivise innovation to promote a more efficient system operation.

c. **Network tariff structures:**
   The network tariffs should incentivise demand response and energy-efficient behaviour while providing a stable framework for both customers’ bills and system operators’ revenues.

A nice example for advancements of smart meter roll out would be given by the Nordic countries where a roll out of Automatic Meter Reading and central data hubs is in process.

**Put in place a transparent legal framework on data security and protection, privacy and intrusion is key to use the full potential.**

Meters with frequently metered data (hourly, 15 min) can only be used to their full potential when there is sufficient consumer involvement and public support, which requires a transparent legal framework on privacy and data security. The processing of personal data and integration of ICT on a significant scale becomes a major concern as it is personal data. This legal foundation requires definition of roles and responsibilities regarding data management: Who owns data? What is the minimum amount of data that must be shared with other actors?. Furthermore, it has to provide the right protection measures and has to set boundaries which protect consumers from potential abuse. Detailed consumption data can be a valuable commercial asset, and a clear division of roles is important to avoid potential abuse.

For the successful integration of DER and the optimal use of the services it may provide, it is key that a sector-specific framework regarding privacy and data sharing issues is further developed. Absence of such a framework may hinder the deployment of smart grid solutions, including demand response options and the EcoGrid EU concept.

**Improve current institutional framework to provide consensus on roles and responsibilities**

The existing ambiguity leads to confusion regarding the particular roles of public and private actors in the smart grids context in general and in particular in the EcoGrid EU concept.

For all stakeholders relevant for the EcoGrid EU concept, it should be clear which roles, boundaries and responsibilities they have. Continuing uncertainty on the future roles and responsibilities of different market parties in the value chain does not benefit the emergence of smart grid solutions such as the implementation of demand response products.
Especially\(^6\), the role of DER versus DSO and TSO need to be addressed. However, as the market services that may be provided by DER may be relevant for both DSOs and TSOs, there is an increasing need for collaboration and coordination of responsibilities and tasks. For example, coordination between DSO and TSO concerns the hierarchy of decisions for system balancing (i.e. balancing market procedures) or the commitment of DER to perform particular (technical) operations.

### Provision of aggregation services to any consumer

In accordance to the Energy Efficiency Directive 15.8, the first priority to fulfil these requirements must be to ensure third party service providers and incumbent players can provide aggregation services to any consumer, within any electricity market where generation participates.

### Reach market transparency for reflecting true real-time market conditions

Market transparency is a prerequisite for reflecting the true conditions in the market real-time, but also day-ahead and intraday. Ensuring market transparency will tackle the current lack of information in some Member States preventing aggregators and consumers from calculating the value of demand response bids, notably in markets controlled by DSOs and TSOs.

### Accept locational pricing for congestion management

Another use of EcoGrid EU could be for congestion management. However, apart from the technical feasibility of the solution, there is a big debate on whether a differentiation of consumer prices per location would be acceptable:

- Regulators could be reluctant to a variation in prices across producers and consumers dependent on location as it could raise the issue of discrimination. Will it be socially acceptable to differentiate prices in the case where the choice of location for either producers or consumers is very limited or de facto non-existent due to for example spatial planning policies?
- However, the regulation in some member states allows to some extent already a differentiation based on location. In some German smart grid projects, local congestion issues are taken into account via a so-called traffic light system.\(^7\) This could be considered as a first, positive step in adapting the regulatory framework into a direction that allows for specific targeted (additional) benefits for smart grid concepts like EcoGrid EU.

In the EcoGrid EU project, the prices of the TSO can be adapted according to local congestions to avoid negative impacts of an EcoGrid EU price signal on the distribution grid. Current regulatory proposals include the increased variability of network tariffs (i.e. dynamic tariffs). It is likely that the dynamics of these tariffs will gradually increase within the regulatory framework in a stepwise manner.

### Revision of electricity tariff structure to reflect better the benefits/costs of production/consumption

For the implementation of smart grids – and the EcoGrid EU concept in particular – differentiation in tariffs and prices is key in triggering demand response potential. These prices refer to network costs, taxes and levies and energy and supply. These signals ideally should contain the true costs or benefits of energy produced/consumed, location of production and consumption, and (type and amount of) flexibility delivered.

In most European countries, the share of energy and supply to the overall electricity price is increasing and on average equal to 43% [11]. This means that the financial compensation for participant; will be perceived smaller.

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\(^6\) \[^2\] report also addresses the role for DSOs and private parties in the case of flexibility services provision, electric vehicle charging points and energy efficiency services.

\(^7\) However, such systems may have significant disadvantages that need to be considered before implementation. The system could for example be subject to strategic behaviour (i.e. gaming) in the case of sequentially operating markets.
Incentivisation via both retail and network tariffs should be further investigated (e.g. alternative pricing options that allocate the additional costs of network reinforcement and grid losses to the network customers responsible for creating those costs). Further research is needed before practical implementation of these concepts. Results of on-going studies and smart grid projects will contribute to this.
6 Recommendations to policy makers

The EcoGrid EU project was a very interesting exercise that not only produced valuable lessons from the demo, but also triggered important reflections regarding the future of Demand Response and the path towards its integration in the current power system. In order to help the reader understand better the outcomes of the replication study, a description of the necessary steps that need to be taken for a deployment of the concept is given below. A graphical representation of these steps can be found in Figure 3 (page 14). After this, the main outcomes and messages from the EcoGrid EU project are presented as a final conclusion.

6.1 Replication Roadmap

The replication of a smart grid project like EcoGrid EU, would require several changes in different aspects in order to achieve a robust and long lasting solution. To do this, it is very important to identify first the point at which the power system of today is currently standing. This chapter intends to define this point and explain the necessary steps to be taken (shown in Figure 3) in order to arrive to a fully integrated response in different markets and voltage levels. It is important to keep in mind, that demand response should not be viewed independently to the general structure of the power system. As a result, it should not be limited to the real time operation but follow the logic of the existing electricity markets that are trying to balance production and consumption well in advance (i.e. day ahead and even before).

6.1.1 Customers

Starting point:

Electricity is regarded as a given
Currently, residential customers take electricity supply for granted by disregarding the time dependent nature of electricity production

Steps to be taken:

- **Sufficient information on system needs and prices**
  Customers need to become aware that the price of energy is not constant and that they could contribute to the needs of the system

- **Proper incentives and motivation**
  Innovative ways of motivating people should be explored like environmental awareness, social consciousness etc.

- **Information on profit opportunities**
  Efficient communication of market actors towards customers that they can profit by helping the system

- **Clear communication of the expected use of customer data**
  Customers should be aware of what their personal data is going to be used for.

- **Possibility to communicate their flexibility**
  System operators and market actors should be able to receive information (direct via meters or indirect via effects on balancing) regarding the flexibility of consumers

- **Maintain a local/community character**
  The demonstration on Bornholm showed that in a small community, people influence each other in favor of smart grids. As a result, it would be desirable to maintain a community/municipality character of interaction between customers and service providers.
• **Try to increase comfort via automation while also doing Demand Response**
  Customer comfort could be the “Trojan horse” for DR. By providing automation services that may increase the comfort of customers (like smart operation of heating etc.) could enhance the acceptance of DR.

• **Target automatic response**
  Automatic response should be targeted first for system balancing according to the findings of EcoGrid EU project.

• **Robust after sale service**
  End users should feel confident when participating in DR. A trustworthy and reliable actor should serve as single point of contact towards end customers.

6.1.2  **Technology**

Starting point:

**Existing ad hoc solutions**
Currently, DR is implemented in the industrial sector with tailor made technological solutions for each case.

Steps to be taken:

• **Identification of minimum functionalities of smart meters**
  Before rolling out smart meters, the minimum functionalities and capabilities should be identified in order to make the investment future proof.

• **Technology standardization**
  Standardized interfaces should be developed in order to allow for different types of information exchange in data collection and interaction between home devices and the mechanism providing the flexibility request signal.

• **Rollout smart meters**
  This would be the next step after the identification of the minimum functionalities.

• **Ensure customer data security and privacy**
  The technology should make sure that the customer’s data is secured and given only to the identified parties.

• **Develop necessary data handling capabilities**
  The ICT technology should be able to efficiently receive process and store data from a large number of end users.

• **Design communication and control equipment suitable for the targeted application**
  In order to harvest the maximum flexibility from residential sector, appropriate equipment should be used that is primarily designed for this reason.
• Off the shelf, plug and play automation and monitoring equipment
  When going to a rollout of DR to residential consumers, the equipment that will be used should be designed and tested for this specific purpose. Modifying existing equipment that has not been built for this purpose is not advised in this case. In addition, the automatic equipment should require minimum effort from the end users and maintain the plug and play capabilities even when changing energy providers.

• Ensure long distance control for maintenance of equipment
  Getting flexibility from residential sector implies a very large number of customers that have limited technical capabilities. For this reason, the maintenance of the equipment should be done remotely in order reduce the required man force.

• Move towards “DR friendly” home appliances
  No matter how sophisticated the DR solution may be, if the appliances to be controlled do not accept this functionality, the flexibility potential will not be maximum.

6.1.3 Market

Starting point:

Demand Response participation mainly from large industries
Currently, mainly the large industry is participating in DR in Europe.

Steps to be taken:

• Identification of the sector with the highest potential at lower cost
  It is advice, that before going towards a roll out of DR, the sector with the higher potential at lower cost should be identified. Taking as a given the current participation of large industry, possible candidates for next step could be the tertiary sector, commercial buildings, SMEs situated in distribution grid, residential houses etc.

• Perform a cost benefit analysis to prove the business case
  A proper cost benefit analysis should be perform to analyse all the effects that DR will have across the value chain of the power system before moving to an implementation of a solution.

• Remove liabilities from BRPs to be balanced in real time
  In addition to the balancing price incentives for load, the responsible BRPs should be able to react according to the financial incentives and not being banded by any contractual obligations to maintain their initial position (unless requested by the TSO).

• Implement single balancing pricing for load
  Load should be remunerated when helping the system in both up and down-regulation cases. This implies the adoption of single balancing pricing for load.

• Develop robust forecasting tools for load and imbalance
  Although according to EcoGrid EU concept, the response of the load is on a voluntary basis, it should still be forecasted. One of the advantages of an appropriate forecasting for DR is the better anticipation of system imbalances.
• Develop possibilities for DR to participate in cross boarder balancing
  In order to be future proof, DR should be looking towards the evolutions in power balancing in Europe. Cross boarder balancing is a trajectory that has already been adopted by different TSOs and regulator in Europe and DR should be a part of it.

6.1.4 Regulation

Starting point:

Partial implementation of electricity directive 2009/72/EC and energy efficiency directive 2012/27/EU
The implementation of the two directives is ongoing and it is advised to follow these recommendations. In order to assist smart grid deployment, full implementation of the two directives should be targeted and the following points should be taken into account.

Attention points:

• Define regulation related to data handling roles, tasks and responsibilities
  Data handling regulation is one of the barriers that could delay the uptake of DR. It is important to define the roles of different actors regarding this aspect in order to appoint responsibilities, tasks and ambitions.

• Adapt the regulation framework to allow 15 minute settlement for residential customers
  In some countries, the current regulation does not allow residential customers to be settled by 15 minute intervals due to increased risk for the customers. This barrier should be overcome to promote DR.

• Clear definition of roles and responsibilities of market actors
  DR has led to the emergence of new actors in the electricity system and in the change of the roles and responsibilities of the existing ones. Regulation should clarify these roles and responsibilities in order to remove barriers hindering DR.

• Technology standardization
  As aforementioned, the standardization of technical solutions is key for the future of DR. Regulation has an important role to play in commanding standardization and implementing it into regulation.

• Move towards shorter imbalance periods to match EcoGrid EU
  The imbalance period is the time interval in which the imbalances are netted and an imbalance price is calculated. In order for EcoGrid EU to coexist with the current markets, this period should be harmonised with the EcoGrid EU price. A good compromise would be the 15 min.

• Proper and clear implementation of Network Codes
  The Network Codes that are currently being drafted take into account DR and should be implemented after they are finalized.

6.2 Final recommendations

This project has received funding from the European Union’s Seventh Framework Programme for research, technological development and demonstration under grant agreement No 268199. The European Commission is not responsible for information presented in this report, nor does it represent the official EC policy and viewpoints.
6.2.1 Customers

**EcoGrid should serve as best practice approach for recruitment and customer involvement**

The project was very successful in involving their customers in the project. It became clear that for both the recruitment and training the social skills of the installers were next to their technical skills very important. This led to the customers declaring that they were very satisfied with the communication and the amount of information about EcoGrid EU.

The required effort for a well-functioning customer support should not be underestimated and in a future roll-out/demo project the project should be planned to keep home visits on a minimum level. Customers are important assets of smart grids and should be valued by user-friendly designs and support. Also the automation hardware should be appealing to the customers and by this the drop-out rate can be reduced. As customers are impatient, they should only be engaged in case the hard- and software is tested and well-functioning.

**Demand response solutions should move forward as customers are willing to be part of smart systems**

It has been found out from the project that the residential customers are eager to participate in a smart grid project. Without being the major one, one of the factors that still motivated the EcoGrid EU participants was the prospect to save electricity costs. But also environmental issues and interest in innovation are motivating factors for the costumers. In EcoGrid one of the important reasons for a lot of the participants was to be part of an exciting new project.

In a future roll-out a diverse mix of participants should be targeted and also customers with less energy-efficient buildings and heating devices.

**Automation is promising and should increase the comfort of the customers**

The automatic response was found to be very promising compared to the manual one. Respondents, who were aware of their automatic control of heating, indicated that the automation system was convenient, not very noticeable, and there was a slight increase in comfort as compared to no automatic control of heating. The automation system could even increase the comfort of some of the customers and one of the future motivating factors for customers could be higher comfort levels. As a result, it is advised to focus a possible roll out of demand response on automatic response in order to have more promising results.

**Automatic control and suitable algorithms should be implemented to capture short term flexibility**

The short-term flexibility depends on the automation, the optimization algorithm of the automation and on the characteristics of the house as for example the type of the heating device. Short-term flexibility could be enabled. Especially the best case load shifting with full automation that focuses on load shifting is very promising. On average a demand response potential of 0.0147KW/house was found as a response to real time prices and 0.012kW as a response to Day Ahead prices accordingly. This could give a balancing potential of approximately 50MW for 3 million houses.

6.2.2 Technology

**Technology standardization and plug and play functionalities should be a prerequisite**

As mentioned before one of the findings of EcoGrid EU is that the technological aspect is very important for the success of a Demand Response project. Regulators should develop communication standards and technology suppliers should respect them in order to avoid interoperability problems that lead to incompatible technologies and finally lead to dissatisfaction of the end users.

Having as guideline the fact that the end users are not technology experts, manufacturers should make sure that the equipment targeting the residential sector requires the least possible capabilities from end consumers regarding installation, operation and maintenance. Solutions close to
“plug and play” should be developed that maintain this functionality even if the customers decide to change energy or flexibility service providers.

Finally, through EcoGrid EU but also other smart grid projects, it has been shown that the financial profit for the end consumers is not so big. As a result, the cost of the equipment used by the end consumers to offer their flexibility should be as low as possible in order to be attractive for them to participate in such a project. However, no compromise should be done on the robustness of the technology as it has a direct impact on the life and comfort of people.

6.2.3 Market

The development of the market design per country should follow an evolutionary, customized approach

With the current results, DR can complement the conventional generators for balancing when it runs on a voluntary basis. EcoGrid EU can attract additional flexibility for balancing and increase the efficiency of the market. However, with the current set up, it cannot replace the conventional balancing units due to the fact that the service is voluntary and the system operator cannot fully rely on this.

The further integration of demand flexibility in the day-ahead and intraday markets is a first step in the direction of enabling the flexibility from final customers. Furthermore, industries have more and more the possibility to participate in the balancing markets also with smaller units.

In a second step new real-time approaches like EcoGrid concept should be implemented.

The existing market designs in Europe differ and they have to be taken into account for the implementation of EcoGrid concept. A harmonisation of the balancing rules should be driven by the Network Code on Electricity Balancing which it is currently ongoing. In this Network Code also the participation of customers and renewable energies is encouraged.

Before the replication an economic analysis should be performed including aspects like the investigation of the balancing market design, the flexibility potential, the current costs for ancillary services, the possible profitability from price differences and so on. Hence, a further evaluation will help to better enable the participation of demand flexibility.

Identification of proper ways to define a consumption baseline and data quality should be investigated to measure flexibility potential and actual delivery

EcoGrid has the advantage that no baseline is needed for billing purposes. When participating on the balancing markets the final customers are billed according to their total consumption and the corresponding real time prices. However, smart metering and a robust baseline methodology are required in order to evaluate the flexibility potential of a country through pilot projects and also attribute the provided service to the corresponding BRP.

In addition, proper information regarding the activation of flexibility should be provided to the affected BRP in order to avoid counter activation of flexibility that would even out the desired effect.

To be in line with the Transparency Directive, a clear and transparent publication of balancing information close to real time is required.

Develop trustworthy forecast algorithms of demand flexibility

8 For example, some European TSOs allow in their prequalification criteria the pooling of smaller units (like for example the German and the Austrian TSO).
Although no baseline is needed for each single participating unit in EcoGrid EU, a forecast of demand flexibility will be important. The TSO and probably the BRPs will need the possibility to forecast the response on a price signal and the available demand flexibility.

The developed forecast models for demand flexibility can also help to integrate demand response in the day-ahead markets as BRPs can use these methods for incorporating the demand flexibility in their procurement strategy. An additional demonstration project focusing on this specific points would be desirable in order to bring demand response one step closer to realization.

**Put in place flexible billing and reward of flexibility**

Innovative products from suppliers/aggregators/BRPs should be developed and flexible billing should be allowed to provide an incentive to the end users help the system. The market actors’ attitude towards the end consumers should move from “energy supplying” towards “service supplying”.

6.2.4 Regulation

**Regulation should play a critical role in accelerating the evolution of smart grids**

Although regulation is most of the times general enough in order not to prevent the evolution of innovative solutions, it could even act as an important catalyst in promoting promising advancements that would have been delayed otherwise. **Policy makers are already taking steps** towards the integration of DR in the power system via different European Directives. These documents state clearly that access of demand to the power system should be given on an equal basis as production. In addition to this, European Commission has mandate the TSOs via ENTSOE to develop clear rules (Network Codes) for system operation and market facilitation that foster the participation of DR in energy and ancillary services markets.

However, the increasing need of ancillary services to the power system makes the intervention of regulation more important and should act as a neutral actor assisting market actors overcome problems that hinder demand response. An indicative example where regulation could play a significant role is the introduction of new actors in the value chain like aggregators of Flexibility Service Providers. **Regulation could have a major contribution in defining the roles and responsibilities** among them and help energy stakeholders assess better their business models and move faster.

Another aspect of equal importance is the need of standardization and interoperability on the technological side. Numerous technological solutions are currently being developed without necessary following standardization rules. In order to ensure competition in the market, it is important that consumers can switch energy suppliers without having to change their equipment. For this reason, regulators should make sure that well designed standards are developed that facilitate interoperability. Minimum functionalities should be identified regarding the smart meters and a potential roll out should not be delayed in case of a positive cost benefit analysis.

To sum up, it is important to note that regulation should not stay only in the formalization of existing practices, but define rules that will help identified innovative solutions to move forward. In this effort, special attention should be paid in not designing too specific rules that could impose restrictions on specific cases.
7 Bibliography

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[7] "EcoGrid EU: Deliverable 7.3 "Exploitation Plan"."
[9] "Southern Californià Edison Smart Grid Strategy and Roadmap”.
[15] "PROYECTO SECH-SPAHOUSEC "Anàlisis del consumo energético del sector residencial en España" INFORME FINAL”.
Appendix A  EcoGrid EU customer groups

Six different groups were part of the EcoGrid project as can be seen in . The groups had different characteristics that have an impact on the available load shifting potential and are therefore necessary to comprehend the different price reactions of these groups.

<table>
<thead>
<tr>
<th>Reference group</th>
<th>Manual group</th>
<th>Group 1A</th>
<th>Group 1B</th>
<th>Group 1C</th>
<th>Group 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>350 households</td>
<td>480 households</td>
<td>190 households</td>
<td>346 households</td>
<td>70 households</td>
<td>413 households</td>
</tr>
<tr>
<td>with smart meters</td>
<td>with smart meters</td>
<td>with smart meters and automation equipment</td>
<td>with smart meters and automation equipment</td>
<td>with smart meters and automation equipment</td>
<td>with smart meters and automation equipment</td>
</tr>
<tr>
<td>No pricing information</td>
<td>Receive real-time pricing, but must alter consumption manually</td>
<td>Heat pumps react autonomously to prices</td>
<td>Resistive electric heating react autonomously to prices</td>
<td>Heat pumps react autonomously to prices</td>
<td>Resistive electric heating, water boilers and controllable PV react to aggregator control</td>
</tr>
</tbody>
</table>

Figure 13 Customer groups

The composition of heating devices varied between the groups as can be seen in . The annual peak and average consumption varied between the groups; amongst others this depended on type of the heating devices, but also on the usage of the house as holiday house or all-year residence (house type). Normal houses (77%) and holiday houses (18%) accounted for the highest share of the actively involved participants. In comparison group 2 had a high share of holiday houses (58%) and of apartments (9%). The other groups had a share of 89-97% of all-year residence houses, except for the reference group. The reference group had a share of 82% houses and 10% holiday houses with a smaller heated area an average. This also has an impact on the average heating area per group and on the average energy consumption per group. The average energy consumption from the heating systems was very low for group 1C (3200 kWh/a; 40 kWh/m²a) and group2 (3400 kWh/a; 43 kWh/m²a). In comparison group 1A and 1B had reported higher average energy consumption with 4300 and 6000 kWh/a respectively 31 and 52 kWh/m²a.

Figure 14 Allocation of heating devices of the EcoGrid groups (Some participants have more than one heating device)

Some groups also included prosumers - with photovoltaics (13% group 1A and manual group, 9% 1C and the rest 4-5%) and wind turbines (group 1A and 1C 2%).

Moreover, the price reaction was different: the manual group could react only manually and in the other groups the heating devices could automatically react to the real-time prices. The automated groups got additionally also price information via the feedback-system to react manually on the real-time prices. In general two different optimization algorithms were implemented to allow the heating systems to optimally react to the prices. The optimization algorithm of the groups 1A-1C focused on limiting the consumption during the highest prices of the day taking into account indoor/ outdoor temperature and price forecasts. The algorithm of group 1C was further integrated in an aggregator. Group 2 optimized the energy consumption of the electric heating for the whole day, based on the forecasts of the real-time prices.
Appendix B  **Real time market price calculation**

Figure 15 gives a complete description of the real-time market. The main objective of the EcoGrid EU market, labelled step 2 in Figure 15, is to maximise social welfare with respect to the day-ahead market.

That is, a series of decisions were taken in the day-ahead market and now the EcoGrid EU market must provide balancing power, considering the starting points that the day-ahead market dictates.

These starting points are the day-ahead load and wind power forecast, which will be different in real-time, giving rise to an imbalance. The starting points also include conventional generator set-points and prices (i.e. up and down-regulating prices are spread around the day-ahead price). In this way, the EcoGrid EU demonstration setup tries to emulate the existing market setups in Scandinavia today as much as possible.

The original EcoGrid EU concept intended to clear the market every five minutes. However, this was deemed impractical by the implementation teams. As a result, the market is only cleared once per hour. Subsequently, every five minutes, a five minute imbalance optimization is carried out (see step 3 in Figure 15), which adjusts the price for demand to try and remedy any new imbalance that has occurred since the market last cleared.

The core of the EcoGrid market is in the Step 2 which combines all the data available (estimates of model parameters for the load forecasting, load forecasting, day-ahead unit commitment, day-ahead wind power forecast, spot price and balance signal) to generate real time prices (12 prices) for the next hour. The last step consists in balancing this price every 5 minutes using the balance signal and the spot price for the next 5 minutes.

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**Figure 15 Representation of the real time market implementation**
Appendix C  Qualitative financial consideration of EcoGrid EU

The JRC approach proposes the following workflow to carry out a cost-benefit analysis of a smart grid project.

Figure 16: Work flow proposed by EC JRC for a CBA of a smart grid project

On the basis shown in Figure 16, EC JRC proposes a definite path summarized in the following steps or actions:

Figure 17: Definite path to perform a CBA for a smart grid project (proposed by EC JRC)

In EcoGrid a slightly different approach is taken, although it is based on EC JRC’s CBA. The main differences between the JRC’s CBA and this study are:
- Only those functionalities and services related to the overall solution are considered, instead of taking into account the whole set of functionalities/services associated to each asset.
- Only the expected benefits resulting directly from the solution are identified and not all the benefits that would have come from the use of each individual asset.

The aim of putting in practice these adaptations is to simplify the procedure and the final results and to better connect to partners and stakeholders interests, needs and information availability. The quantification of benefits and costs is not performed, neither the comparison and sensitivity analysis focusing more on the qualitative aspects of the solution.

Taking all these issues into consideration, the following figure shows the steps of the CBA methodology that is followed in this study:

![Figure 18: Simplified path to perform a CBA for a smart grid project](image)

### Boundary conditions

The objective of the EcoGrid EU project is to demonstrate a real-time market concept in a large-scale field test by exploiting flexibility in electricity consumption. A detailed explanation of this concept is described in subsection 1.2.

The specific test field is Bornholm, a Danish island of 588 km², which make the density to 71.9 inhabitants per km². The main industries on the island include fishing, dairy farming, arts and crafts like glass making and pottery using locally worked clay. Tourism is important during the summer.

The boundary conditions of the specific test field are the following:

- The Bornholm power system is connected through a long submarine cable to the Swedish power system. The power system contains 3 voltage levels, 60kV, 10kV, and 0.4kV. At 60kV level, the distribution network has 18 nodes, 23 60/10kV transformers with on load tap changer, 22 cables and 26 overhead lines.
- Bornholm has a peak demand for electricity of approximately 55 MW and a base load of 25MW. The generators include 14 diesel (oil) units with a total capacity of 35MW, 1 steam power plant with 25MW capacity, 1 combined heat and power plant with 37MW capacity, 35 wind turbines with a total capacity of 30MW, and one 2MW biogas plant.
- Activation resources are provided by household, industrial and commercial customers. The participants in the EcoGrid EU project can be divided in 6 equipment groups, namely [12]:
  - 354 participants with electric heating, in which the participants get a smart meter as well as a HEMS (Home Energy Management System) from GWR (Green Wave Reality), provided by IBM.
  - 261 participants with heat pump based heating, in which the participants get a smart meter as well as a HEMS from GWR, provided by IBM.
  - 486 participants with a manual control of their flexibility, in which the participants get a smart meter. The participants have to manually respond to the varying prices.
  - 430 participants with electric heating, in which the participants get a smart meter and a Siemens HEMS installed.
Smart businesses, which get a smart meter and an EMS from Siemens installed. The EMS can control either a manure mixer or an electric forklift charger depending on what is available at the respective participants. A battery pack from a tele site, a manure mixe and a few fork lift chargers will also be controlled.

Statistical reference group, which get a smart meter installed. The group functions as a reference group for the consumption patterns and is used to verify DR for the other participant groups. The group uses technology from a distribution of households with equipment from IBM for electric heating and heat pump and Siemens for electric heating. 320 participants belong to this group.

The boundary conditions should, also, include a list of aspects that have to be taken into account to perform a CBA, such as: the discount rate, time horizon of the calculations, schedule of the implementation, inflation rate, installed flexibility, flexibility used for up-regulation, flexibility used for down-regulation, total activated power for up-regulation, total activated power for down regulation, load growth factor, ...

Identification of assets

The main assets that form part of the Solution have been structured in Table 7 according to their location (consumer facility, TSO ...), the type of asset and a description of the component.

Table 7 Assets for real time pricing

<table>
<thead>
<tr>
<th>Location</th>
<th>Asset</th>
<th>Comments</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumer</td>
<td>Smart meter</td>
<td>It has a 5 minutes resolution</td>
<td>The extra cost of increased resolution</td>
</tr>
<tr>
<td>Consumer</td>
<td>Electric heater</td>
<td>Flexible load</td>
<td>Appliance – No cost</td>
</tr>
<tr>
<td>Consumer</td>
<td>Heat pump</td>
<td>Flexible load</td>
<td>Appliance – No cost</td>
</tr>
<tr>
<td>Consumer</td>
<td>Other equipment</td>
<td>The Consumers with manual control can use any device they have</td>
<td>Any appliance the user wants – No cost</td>
</tr>
<tr>
<td>Consumer</td>
<td>HEMS</td>
<td>They control the reaction to price signals</td>
<td>Automation equipment and electricity consumption cost of automation</td>
</tr>
<tr>
<td>Consumer</td>
<td>Feedback system</td>
<td>Display operations to the user</td>
<td>Development and maintenance of GUI</td>
</tr>
<tr>
<td>Consumer</td>
<td>Communication</td>
<td>GPRS, ADSL, ...</td>
<td>Communication mechanism with a shared cost</td>
</tr>
<tr>
<td>TSO</td>
<td>Price response forecast</td>
<td>Software to forecast the sensitivity of users to prices</td>
<td>Development and maintenance cost</td>
</tr>
<tr>
<td>TSO</td>
<td>Real Time Market price calculation</td>
<td>Software to calculate the real time price signal</td>
<td>Development and maintenance cost</td>
</tr>
<tr>
<td>Two-way Communications (high bandwidth)</td>
<td></td>
<td>The real time market price broadcast mechanism, the access to the customer portal, etc. depend on the communication infrastructure</td>
<td>Communications cost sharing</td>
</tr>
<tr>
<td>DSO</td>
<td>Congestions identification</td>
<td>Load flow based software to identify congestions</td>
<td>Already available – No cost</td>
</tr>
<tr>
<td>DSO</td>
<td>Price response forecast</td>
<td>Software to forecast the sensitivity of users to prices</td>
<td>Development and maintenance cost</td>
</tr>
<tr>
<td>DSO</td>
<td>Real Time price calculation</td>
<td>Software to calculate the real time price signal, additional to the one sent by the TSO</td>
<td>Development and maintenance cost</td>
</tr>
<tr>
<td>Two-way Communications (high bandwidth)</td>
<td></td>
<td>The real time market price broadcast mechanism, the access to the customer portal, etc. depend on the communication infrastructure</td>
<td>Communications cost sharing</td>
</tr>
</tbody>
</table>
Identification of functionalities

The next step determines the functions that are expected to be implemented through the assets deployed in the project. It is important to note that the type of assets involved, individually can provide functionalities that are not related with the objectives of the project but, within this analysis we have only considered the functionalities related with the objectives of EcoGrid. This means that we have not tried to do a direct mapping between asset and function, but instead have listed the functions related with the project that need the contribution of the assets identified.

The main functionalities have been selected from the list of 33 functionalities grouped in 6 services proposed by the Annex III Smart grid services and functionalities IEC task force for Smart grids 2010A (Annex III) [13] and are listed in Table 8.

Table 8: Functionalities of EcoGrid

<table>
<thead>
<tr>
<th>No.</th>
<th>Functionality / Service</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.</td>
<td>Use of network control systems for network purposes</td>
<td>Side effect of the solution: Nodal/localized real time price signals will be able to be used by the DSO to avoid congestions in the distribution network using the flexibility of the consumers.</td>
</tr>
<tr>
<td>11.</td>
<td>Allow grid users and aggregators to participate in ancillary services market</td>
<td>Direct effect of the solution: Real time pricing will allow consumers to directly participate in the provision of regulating power to the TSO by making use of their flexibility. Mainly loads with inertia like, heaters or air conditioning, although other kind of equipment can be used, too and it will depend on the decisions taken by the consumer.</td>
</tr>
<tr>
<td>16.</td>
<td>Solutions for demand response for system security in the required time</td>
<td>Side effect of the solution: Demand response, activated by real time pricing, will be able to be used for the avoidance of localized contingencies.</td>
</tr>
<tr>
<td>22.</td>
<td>Facilitate consumer participation in the electricity market</td>
<td>Direct effect of the solution: Real time price signals directly sent by the TSO to the consumers will allow their participation in the regulating power market. This participation will provide flexible resources in real time and the reduction of the electricity price by reducing the use of fast acting conventional power plants.</td>
</tr>
<tr>
<td>24.</td>
<td>Improvement to industry systems (for settlement, system balancing, scheduling)</td>
<td>Direct effect of the solution: The main objective of the solution is to provide, to the TSO, system balancing resources by any kind of grid users connected to it and in particular small consumers.</td>
</tr>
<tr>
<td>28.</td>
<td>Sufficient frequency of meter readings</td>
<td>Side effect of the solution: Real time prices to activate regulating power are issued every 5 minutes and the meters are required to store the electricity consumption during those periods to make the settlement afterwards.</td>
</tr>
<tr>
<td>30.</td>
<td>Consumption/injection data and price signals by different means</td>
<td>Side effect of the solution: Different types of customers exist for demand response, some have automation to drive their loads but some others have to operate their equipment manually. The same way the real time price can be sent directly to the system controlling the loads or made accessible through the feedback system to those without automation. Other solutions like e-mail, SMS... could exist in the future.</td>
</tr>
<tr>
<td>31.</td>
<td>Improve energy usage information</td>
<td>Side effect of the solution: The real time price gives valuable information to the consumers to manage their electricity consumption and the feedback system provides information about electricity real time prices, current consumption and consumption pattern. All this information is a valuable input to achieve an efficient use of electricity.</td>
</tr>
</tbody>
</table>
Identification of benefits

This section describes the benefits of EcoGrid EU, some of the benefits are directly focused by the project and other ones can be considered as side effects of implementing the proposed solution. The selected benefits are related to the whole solution and not to each particular function. This is a deviation from the methodology but we consider that in this way it is conceptually easier to understand the benefits of the whole solution. In addition, it avoids the computation complexity of functions providing the same benefit but in opposite directions. The benefits have been selected from the list provided by the JRC methodology [14], in which this analysis is based.

Table 9: Benefits of EcoGrid

<table>
<thead>
<tr>
<th>No.</th>
<th>Benefit</th>
<th>Direct or side effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.</td>
<td>Deferred generation capacity investments</td>
<td>Side benefit</td>
</tr>
<tr>
<td>3.</td>
<td>Reduce ancillary service cost</td>
<td>Direct benefit</td>
</tr>
<tr>
<td>6.</td>
<td>Deferred distribution capacity investment</td>
<td>Direct benefit</td>
</tr>
<tr>
<td>14.</td>
<td>Reduce electricity costs</td>
<td>Side benefit</td>
</tr>
<tr>
<td>20.</td>
<td>Reduce CO2 emissions</td>
<td>Side benefit</td>
</tr>
<tr>
<td>21.</td>
<td>Reduced SOx, NOx, and PM-2.5 Emissions</td>
<td>Side benefit</td>
</tr>
</tbody>
</table>

The benefits identified have been classified either as a direct benefit of the solution proposed or as a side benefit of it. From the description of the EcoGrid concept it appears that the main objective of the project is to facilitate the participation of any customer, mainly small customers, in the regulating power market, as a way to reduce its cost by displacing expensive generation that is used for those purposes.

Reduction of ancillary services cost

We have highlighted the reduction of ancillary service cost as the only direct benefit of the project and the rest of them have been considered side effects of the project.

Defer generation investments

The EcoGrid solution may defer generation capacity investments by being a direct competitor in the provision of regulating power that in the future could reduce the use of expensive conventional generation for that purpose.

Defer distribution capacity investments

Real time pricing allows the activation of flexibility that can be used during operation for congestion management, contributing in this way to the deferral distribution capacity investments. The use of localized real-time pricing for transmission congestion has been included as an added benefit. Nevertheless, it has not been thoroughly elaborated as it was not the primary project objective and because its utilization would require the implementation of additional components together with the integration and coordination of other stakeholders.

Reduction of electricity costs for LV and MV customers

The reduction of the electricity costs for MV and LV consumers comes from the participation of EcoGrid customers in the Real-time market for power regulation.

Reduction of emissions

The substitution of conventional generation by customer resources leads to the reduction of CO2 and other emissions.

Quantification of costs

The main costs identified within EcoGrid are the investments and maintenance required by the assets listed in the table called "Assets for real time pricing". An approximate cost could have been calculated from the costs incurred during the deployment of the pilots in Bornholm, but taking into account that the purpose of the project has been to prove the real-time price concept and not to...
achieve a competitive cost oriented solution, the quantification of the cost would not had been realistic and it has not been performed.

Baseline establishment

The baseline describes the traditional solution that would be carried out if the EcoGrid solution were not implemented. This baseline or control-state represents the business as usual approach and consists in the installation of additional conventional power plants to provide capacity for the regulation market. Considering that in Denmark wind generation is a real alternative for electricity generation, the main challenge of integrating DER is to have additional fast acting power to mitigate the fluctuations that renewable sources of energy experience and which affect to the price in the regulation or balancing market.

The baseline conditions corresponding to this traditional solution should be quantified in the following way, calculating the expected yearly increase of:

- Generation mix and expected new capacity installed.
- The total cost of regulating power.
- The annual investment in distribution facilities.
- The total cost of electricity per type of customer (LV and MV connected customer) enrolled into the real time pricing program.
- The increase in CO₂, NOx, SOx and PM emission tons and their cost.

Comparison of Costs and Benefits

An important and final task during a cost/benefit analysis is the comparison of the costs and benefits and the rate of return of the investments. Therefore, the quantification of benefits has to be done by calculating the percentage reduction of costs in the system produced by the use of the EcoGrid approach, respect to the investments that would have been necessary to do with a Business as Usual approach. In this project the comparison has not been done due to the lack of reliable data for costs and benefits, as it has been explained in the corresponding sessions.

Qualitative impact analysis

There are certain benefits, like consumer participation or awareness about energy efficiency, which are difficult to monetize and include in a CBA, as well as, other aspects of social impact, e.g. job creation, strengthening of know-how and competitive positions, improvement of safety conditions and social acceptance.

New indirect benefits can result from setting up a service platform on top of the infrastructure laid out in the EcoGrid EU project. New services and products enabled by the EcoGrid EU infrastructure may include energy efficiency applications, aggregation of services (e.g. demand response, vehicle2grid services), smart appliances, Renewable generation increase, etc. In turn, the set-up of these services and products fosters innovation and leverages new business ecosystems that may have a positive impact on the society at large but is difficult to quantify.

To conduct a qualitative assessment of the Ecogrid project, other non-monetized benefits have to be taken into consideration and are presented in the next sub-sections:

- Contribution to the policy objectives, which is described by the contribution to KPIs presented in the next section.
- Contribution to other non-monetary impacts on society, such as, environmental impact, social impact, job creation, ...

Identification of KPIs/Benefits

The main KPIs/Benefits provided by the EcoGrid solution are selected from the list provided by the JRC methodology (annex IV, Key performance indicators and benefits – IEC task force for smart grids 2010C) and are presented in Table 10.

<table>
<thead>
<tr>
<th>No.</th>
<th>KPI/Benefit</th>
<th>Direct or side</th>
</tr>
</thead>
</table>

This project has received funding from the European Union’s Seventh Framework Programme for research, technological development and demonstration under grant agreement No 268199. The European Commission is not responsible for information presented in this report, nor does it represent the official EC policy and viewpoints.
The main benefits of EcoGrid are those related with the participation of customers in demand response events to provide regulating power to the TSO. These direct benefits are listed with numbers 34, 35, 39, 41, 46 and 65 in Table 10. These benefits correspond with the main objective of the project.

Other benefits are called side effect benefits because they are provided by the results of EcoGrid although have not been the main objective of it. Within this side effect we can mention number 4 that is linked with the hosting capacity of renewables, because EcoGrid contributes to it by providing a mechanism that is able to avoid contingencies through the activation of nodal real-time pricing.

We mentioned the reduction of CO₂, SOₓ, NOₓ, and PM-2.5 emissions as a side benefit of balancing the variability of energy generation of renewables and the reduction of the emissions poured by the fossil fuel generation that would need to be used for these purposes, instead.

Externalities and social impact

Apart from this, EcoGrid will produce social impacts linked to a general mass roll out of real-time pricing and a high penetration of renewable resources, which will make worth considering the following impacts: jobs: not only jobs created by the installation of new renewable resources, but also other categories that may be impacted by new kind of services provided by suppliers, aggregators, BRPs and industry equipment providers.

Social acceptance: The acceptance of real-time pricing will be dependent on the validation of the economic benefits to the customers and minimum change in their habits, together with the sustainability of increasing the penetration of renewables. The educational process will be essential to improve the lack of awareness.

Environmental impact

This impact is mainly motivated by the reduction of CO₂ emissions and in turn, this reduction is mainly caused by the lower carbon intensity of the electricity generation than that of fuel based plants and the avoidance of switching off renewables generation due to congestions or security risks.
Appendix D  Balancing design characteristics

i.  Imbalance Settlement Period (ISP)

The imbalance settlement period is the time unit for which Balance Responsible Parties’ (BRP) imbalances are calculated.

The Network Code (NC) on Electricity Balancing (EB) envisions the harmonization of the imbalance settlement period within and between Synchronous Areas. In the latest version of the NC on EB, there is a clear tendency to harmonize the ISP across Europe to 15 minutes unless you can prove the importance of another ISP with a CBA. A period of 15 minutes is currently used in Belgium, Netherlands, Germany and some other countries.

ii.  Imbalance pricing methodology

This is the way the different imbalances (positive, negative, favouring the system, deteriorating the system) are being priced. The Network Code on Electricity Balancing shall require the harmonization of the pricing method for balancing products. Currently, two different pricing models exist:

- Single price model where positive and negative imbalances are priced in the same way
- Dual price model where imbalances that help the system are not priced the same way as the ones deteriorating it. For example, for an existing state of the system, the BRP caused the imbalance needs to pay the imbalance price, while the one helped the system receives the DA price.

In the current version of the NC on EB, the harmonisation of the imbalance pricing settlement is envisioned and it is promoting a default single price mode.

iii.  Volume calculation

There are different ways that the position of the portfolio of a BRP is calculated.

**Single portfolio calculation (one imbalance volume per BRP)**

The production and consumption of a BRP are calculated in a single portfolio and imbalances are calculated according to the following formula:

\[ \text{Imbalance}_{BRP} = (\text{Injection} - \text{Offtake}) \]

The injection is equal to the sum of the volumes purchased, the import and the allocated (physically) injected volume. The offtake is equal to the sum of the volumes sold, the export and the allocated (physical) offtake volume. This difference is corrected with the imbalance adjustment.

BRPs will be settled according to their total position and they have the possibility to adjust production or demand to achieve the desired position. Consequently, they have more means to balance their portfolio or move to a position that could help the system. This is the most common way of how imbalance volumes are calculated in continental Europe.

**Double portfolio calculation (Two imbalance volume per BRP)**

In some countries the BRPs need to have separate portfolios for production and consumption. The imbalance settlement is done separately according to the following formulas:
A BRP with a double portfolio calculation cannot correct the real-time balancing of consumption by means of real-time generation units. On the other hand, separate portfolio calculations can apply different imbalance pricing schemes on production and consumption in order to trigger market reactions differently. Accordingly, this mechanism is mostly implemented with a different pricing mechanism for consumption and production.

iv. Reserve product prioritization

There are different kinds of reserves that the TSOs use depending on the overall design of the balancing system. According to the definitions of ENTSOE, regarding the Restoration Reserves, they are divided in two categories:

- Automatic Frequency Restoration Reserves (aFRR) that are controlled via a LFC Controller by the TSO via a continuous automatic signal that is sent to the units participating;
- Manual Frequency Restoration Reserves (mFRR) that are activated by a manual way via signals that the dispatchers send from the control room of the TSO to the participating units. These reserves have an activation time faster than 15 minutes;
- Replacement reserve (RR) means operating reserve used to restore the required level of operating reserves to be prepared for a further system imbalance. RR includes operating reserves with activation time from 15 minutes (in Continental Europe) up to hours.

It should be noted that the aforementioned categories can be either contracted or non-contracted reserves. The prioritization of the activation of reserves depends on the balancing design and it can be said that in the case of a pro-active design mFRR and RR are a large part of the activated balancing energy. This is in contrast with re-active designs where in general aFRR accounts for more than 90% of the activated balancing energy. Consequently, the market design determines which reserve products are required and at which volume. This will be further elaborated in the examples below.

v. Imbalance price and other imbalance information publication

Today, the publication time still varies depending on the design of the balancing market design:

- For re-active balancing markets, the information is published close after the operating time in order to give information to market actors enabling them to react on real time imbalances. Of course, the market actors bare some risk since the information they see concern the near past and are not guaranteed for the future.
- For pro-active balancing markets, market actors are not expected to react on the system’s needs without demand from the TSO, therefore a large part of the balancing information is published later.

Transparency Guidelines are promoting the publication of relevant balancing information close-to-real time. Therefore, TSOs will be obliged to publish close to real time the balancing information.
Appendix E  Flexibility potential of Spain and Belgium

In this section, an analysis of the flexibility potential for Spain and Belgium is performed in order to help with the overall assessment of the replication study from a market perspective.

Spain

Flexibility of customers suitable to be used in an EcoGrid type solution:
- As it has been mentioned before, the type of equipment usable for EcoGrid and belonging to small customers are: Air conditioning systems, electrical heating, electrical water boilers and electric vehicles. In Spain the spread of that type of equipment is as follows [15]:
  - **Air conditioning**: 7,889,160 houses are equipped with non-portable air conditioning systems, being 6,568,693 of them heat pumps based. Considering that the average nominal power of each air conditioning system is around 2,000 W, it makes a total installed demand power of approximately 16,000 MW. The total yearly consumption is equal to 1,400,000 MWh, which implies the use of this capacity during 90 hours per year (per household).
  - **Electric heating**: 6,811,053 houses are equipped with non-portable electric heating systems, being 3,297,169 of them based on heat pumps and the rest of a mixture of radiators, accumulators and so on. Considering that the average nominal power of heat pumps is around 3,000 W and the mixture of radiators is around 2,000 W, the total installed demand power is approximately 17,000 MW. The total yearly heating consumption is about 4,400,000 MWh, implying a use of this capacity during 260 hours per household.
  - **Electric boilers**: 4,919,094 houses are equipped with electric boilers and considering that the nominal power of each is around 2,000 W, the total installed demand is equal to 10,000 MW. In this case, a total energy consumption of 4,480,000 MWh implies 480 hours of use.

Electric heating and air conditioning are seasonal services. Therefore, their installed power cannot be added. On the other hand electric boilers are used all along the year and this total available installed demand can be added to the other types of equipment (air conditioning or electric heating), which amounts to a total installed capacity of approximately 26,000 MW. Since the use of electric heating and air conditioning are supplementary and do not consume at the same season of the year, taking the installed capacity of one of them (they are almost the same) and adding the one of the electric boilers, could be considered as a valid assumption.

The yearly peak power in Spain can be as high as about 44,000 MW, depending on the weather conditions, and the normal daily one is about 36,000 MW. Within this analysis, the flexibility of other type of customers is not considered (e.g. commercial buildings and small industries).

During the period of study considered in the report of deliverable D7.2 for the Spanish case study [2] the maximum down-regulating power contracted was about 6,000 MW and the maximum up-regulating 4,000 MW. Then it appears that the available flexibility could be enough to participate in a real-time pricing market, although we should take into account that the participation would be limited to a few hours a day and variable according to the season of the year.

Belgium

The estimated flexibility is an important factor for its replicability. In this paragraph, the maximum flexibility is estimated for different devices. The presented results are derived from the project Linear [16]. There are two important remarks on this total sum of load shifting potential. First, no estimation of heat pumps is done due to the limited market share today. Nevertheless, a fast growth in the use of heat pumps for heating domestic hot water and homes can be expected in the near future, gradually replacing today’s electric heaters and offering larger flexibility potential. Secondly, the current penetration of electric vehicles in Belgium is 0.2% of the total Belgian fleet which is expected to rise in the coming years. In addition, regarding the potential of white good appliances, it would be not realistic to consider the total installed capacity. As a result, aggregated results were used from the LINEAR project that are considered to be indicative.

Table 11: Maximum flexibility per device (15 minutes) for Belgium, divided for day and night

<table>
<thead>
<tr>
<th>Device</th>
<th>Maximum Flexibility (15 minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air conditioning</td>
<td>16,000 MW</td>
</tr>
<tr>
<td>Electric heating</td>
<td>17,000 MW</td>
</tr>
<tr>
<td>Electric boilers</td>
<td>10,000 MW</td>
</tr>
<tr>
<td>Total</td>
<td>43,000 MW</td>
</tr>
</tbody>
</table>
Influence on demand flexibility: Social aspects

To use the technical demand flexibility the end consumers have to be willing to participate in the load shifting and depending on the response type and on the design of the tariff the technical demand flexibility is influenced by the behavior of the end consumer:

- **Automatically controlled devices:** The energy management system has to be understood by the end consumers and the settings have to be changed by the end consumer. After the system is adjusted, the demand flexibility depends mainly on the energy management system.

- **Manual load shifting:** Especially for the manual response the ongoing active involvement is crucial. Moreover, the "demographic characteristics" and the mindset are relevant.
Appendix F  Market profitability study

After analysing the market design and the flexibility potential of Spain and Belgium, a study on the profitability of EcoGrid EU has been performed. For Spain, a high level assessment of the times where DR for balancing could be profitable has been done, while in Belgium some more concrete results are provided as the outcome of a balancing market integration analysis.

**Spain**

The available data has been used to identify time slots with relevant deviations in prices, respect to the day ahead prices, which could incentivize the participation of demand in real time pricing events. The following deviations in prices have been considered: 2.5%, 5.0% and 7.5%.

Approximately 20% to 25% of the hours have a daily market price bigger than a 2.5% of the initial price. If we consider the 5.0% deviation as a reasonable profitability limit, about 12% of the hours could be acceptable for EcoGrid EU real-time market.

The EcoGrid EU real time market is intended to cope with large imbalances between generation and demand (leading to important energy price variations) by involving customer flexibility in system operation.

The table above shows that the price stability found at the Spanish market leads to the conclusion that the opportunities for EcoGrid EU markets are limited at the moment (the data used for this calculation is the one obtained from OMEL for years 2012 and 2013, which has been used in deliverable D7.2). This is due to the big total installed capacity existing in Spain (102,000 MW), respect to the installed capacity of fluctuating renewables (29,000 MW), which currently exists, although it will change in the future when the relative participation of renewables increases and old conventional plants are decommissioned.

**Belgium**

A calculation of the maximum avoided balancing costs for the Belgian power system using DR has been performed, considering the required comfort characteristics imposed by the customer. The results are presented in Table 12.

It has to be noted that this profit comes from avoiding activating free bids both for up and down regulation and that different elasticity curves for the customers have been assumed.

<table>
<thead>
<tr>
<th>Elasticity (€/MW^2h)</th>
<th>Annual system profit up (m€)</th>
<th>Annual system profit down (m€)</th>
<th>Total annual profit (m€)</th>
<th>Avoided incremental bids (%)</th>
<th>Avoided decremental bids (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>2.69</td>
<td>2.30</td>
<td>4.99</td>
<td>30.04</td>
<td>20.47</td>
</tr>
<tr>
<td>0.3</td>
<td>0.55</td>
<td>0.42</td>
<td>0.97</td>
<td>11.43 (13.9GWh)</td>
<td>7.92 (15.5GWh)</td>
</tr>
<tr>
<td>0.4</td>
<td>0.43</td>
<td>0.25</td>
<td>0.68</td>
<td>8.75 (10,650MWh)</td>
<td>6.07 (11,910MWh)</td>
</tr>
<tr>
<td>0.5</td>
<td>0.36</td>
<td>0.16</td>
<td>0.52</td>
<td>7.09 (8.6GWh)</td>
<td>4.92 (9.7GWh)</td>
</tr>
<tr>
<td>1</td>
<td>0.14</td>
<td>0.03</td>
<td>0.17</td>
<td>3.68</td>
<td>2.55</td>
</tr>
</tbody>
</table>

Table 12 gives an indication on the amount of up and down regulating power that would be replaced by EcoGrid EU customers and the costs or benefits which result from that replacement. The analysis has been performed for different elasticity behaviours of the customers.
Figure 19 Price elasticity curve (\(\alpha = \frac{\Delta p}{\Delta Q}\)). This is one of the major parameters defining the DR potential of a system. The starting point of the curve is the DA price (in this example 30€/MWh) which is the price to be sent if the system is perfectly balanced. The more customers participate, the lower the “\(\alpha\)” factor is and the more flexibility is offered at lower cost.
Appendix G Alternative ways of stimulating demand response

Demand response is the reaction of the demand to a signal. This reaction can be on a voluntary basis or via a predefined obligation. Two different principles exist to motivate this behaviour change:

- **Price-based demand response** (e.g. real-time pricing, critical-peak pricing and time-of-use tariffs): Customers respond to the retail electricity price, reflecting the value and cost of electricity, using time-varying rates. Customers will base their behaviour on the published information of electricity prices. This information can be published by different actors across the value chain each one taking his own risk in case of adapting the price to his needs. It should be noted that this is a voluntary reaction of the customers to a price signal and there is no binding contract on flexibility volume offered.

- **Incentive-based demand response programmes**: These programmes pay participating customers to reduce their loads at times requested by the program sponsor. For these programmes, the different partners agree on volumes rather than on prices. Such incentive-based demand response programmes are usually implemented by large industrial and commercial customers. There is also a possibility to apply this kind of incentive to residential consumers but it always requires a communication of the available volume before the activation of DR. Since there is a flexibility volume communicated from load to the flexibility service provider, a contractual agreement is usually in place managing the provision of flexibility and penalizing the flexibility source in case it does not meet its promises.

Both mechanisms should be available to different types and sizes of consumer to ensure the full potential of demand response will be made available.

![Diagram of Alternative types of Demand Response](image)

**Figure 20 Alternative types of Demand Response for balancing**

It can be seen from Figure 20 different combinations are possible when the TSO would like to incentivize demand response for balancing. The EcoGrid EU concept is an additional and relatively simple way but the different alternatives should be also examined when trying to introduce residential DR in a country.