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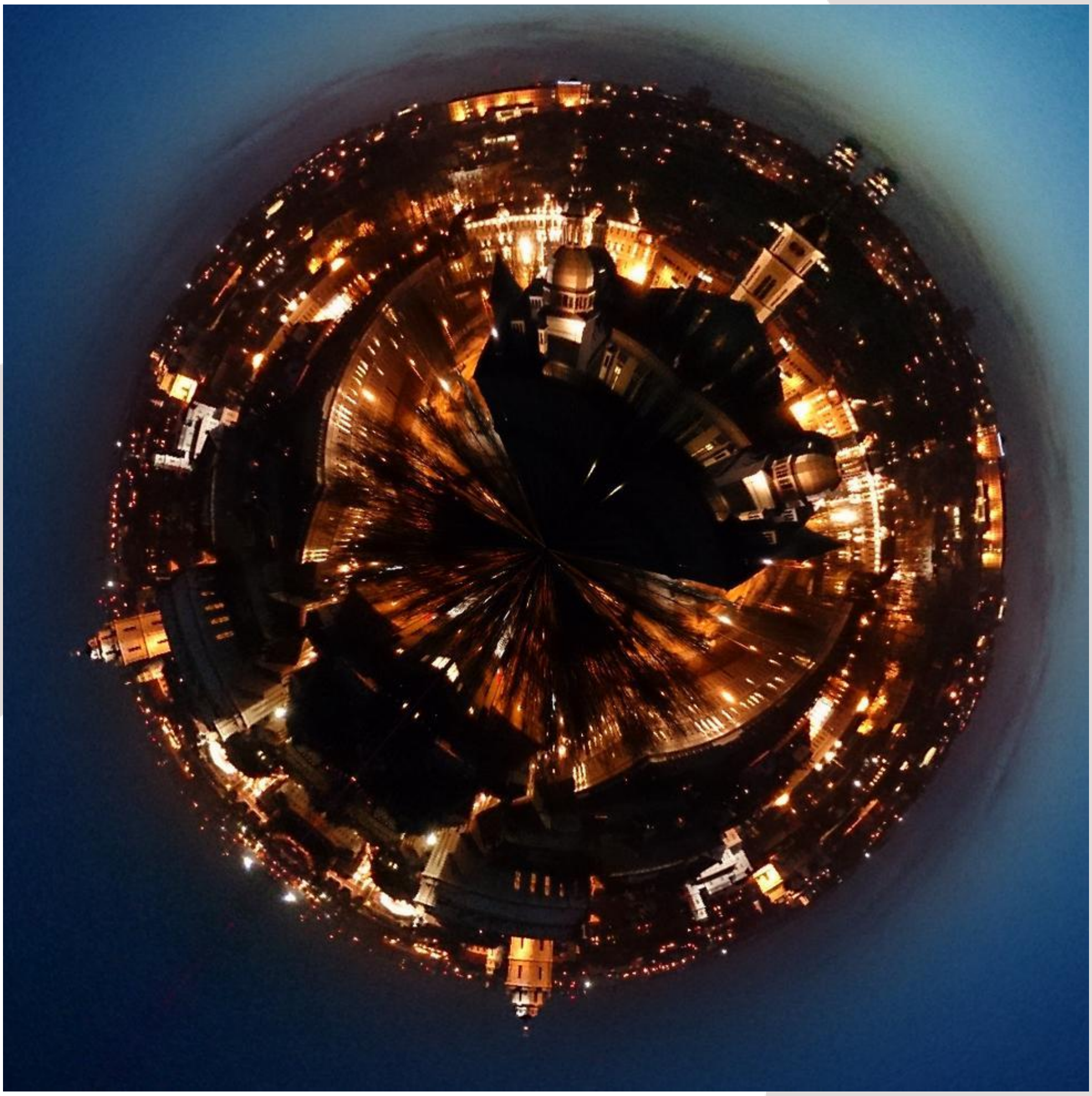

Demand response:
Potential DR services and technical requirements

WP1 report

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Contents

Foreword

This report summaries the findings from work package 1 in a demand response services feasibility study undertaken in Lithuania.

The project was undertaken on behalf of the Lithuanian TSO, LitGrid AB and the DSO, Energijos Skirstymo Operatorius AB, ESO. The project period is from June 2017 to April 2018.

The project consists of 8 work packages:

- **WP1 – Potential DR services and technical requirements for DR**
- WP2 – Evaluating of potential DR services providers engagement
- WP3 – DR illustrative cases
- WP4 – Potential capacities of DR services and it's providers
- WP5 – Technical requirements for DR services
- WP6 – Identification and assessment of DR implementation obstacles, and proposed prevention strategy.
- WP7 – Cost-benefit analysis of DR implementation
- WP8 – Recommendations on future DR potential development

Sub reports have been produced for each WP, and each of these 8 sub reports are also included as appendices in a main summary report.

1 Demand response tendencies, service providers and products

The following chapter provides an overview of the primary EU legislation related to demand response (DR), as well as the DR tendencies, service providers and type of products in Europe today.

1.1 Directives and regulatory framework

DR tendencies and products are often driven by EU policy. Four directives from the European Parliament are related to, or directly include, demand response as an instrument to reduce energy consumption or improve market integration in Europe:

- Energy Efficiency Directive (EED), 2012
- Renewable Energy Source (RES), 2009
- Energy Performance of Buildings Directive (EPBD), 2010
- Internal Market of Electricity Directive (IMD), 2009

Proposals for updates of all directives were undertaken by the commission on November 30th, 2016, as part of the Commission's broader package of initiatives ("Clean Energy for All Europeans").

The Building Directive & Renewable Energy Source Directive

Neither the 2010 EPDB nor 2009 RES use the term 'demand response'. However, other related terms or conditions for the functioning of demand response, such as smart grid and intelligent devices are used. The updates of the two directives do however mention demand response in the legal framework. (RES, 2009) (EPBD, 2010)

The updated EPDB includes a proposal for at 'smartness indicator', which should be provided as additional information to prospective new tenants or buyers (EPBD-update, 2016).

Art. 8.6 in the updated EPDB:
(..) The smartness indicator shall cover flexibility features, enhanced functionalities and capabilities resulting from more interconnected and built-in intelligent devices being integrated into the conventional technical building systems. The features shall enhance the ability of occupants and the building itself to react to comfort or operational requirements, take part in demand response and contribute to the optimum, smooth and safe operation of the various energy systems and district infrastructures to which the building is connected.

The updated RES includes demand response in regard to flexibility in district heating and cooling: (RES-update, 2016).

Art. 24.8 in the updated RES:
Member States shall require electricity distribution system operators to assess at least biannually, in cooperation with the operators of district heating or cooling systems in their respective area, the potential of district heating or cooling systems to provide balancing and other system services, including demand response and storing of excess electricity produced from renewable sources and if the use of the identified potential would be more resource- and cost-efficient than alternative solutions.

The Energy Efficiency Directive

In order to decrease dependency on energy imports, prevent further climate changes and to overcome the economic crisis, the EED of 2012 is aimed at achieving the European energy efficiency target of 20% by 2020.

Demand response is included as an important instrument in the 2012 EED. The Directive states that demand response increases the opportunities for consumers or third parties to reduce or shift consumption, resulting in energy savings. Demand response is anticipated to be based on final customers' responses to price signals, or on building automation. (EED, 2012).

Art. 15.4 in the 2012 EED:
Member States shall ensure the removal of those incentives in transmission and distribution tariffs that are detrimental to the overall efficiency (including energy efficiency) of the generation, transmission, distribution and supply of electricity or those that might hamper participation of demand response, in balancing markets and ancillary services procurement. Member States shall ensure that network operators are incentivised to improve efficiency in infrastructure design and operation, and, within the framework of Directive 2009/72/EC, that tariffs allow suppliers to improve consumer participation in system efficiency, including demand response, depending on national circumstances.

The directive is meant to improve conditions for, and access to, demand response, including for small final consumers. Taking into account the continuing deployment of smart grids, member states are required to ensure that national energy regulatory authorities are able to ensure that network tariffs and regulations incentivise improvements in energy efficiency and support dynamic pricing for demand response measures by final customers. Market integration and equal market entry opportunities for demand-side resources (supply and consumer loads) alongside generation should be pursued. (EED, 2012).

Art. 15.8 in the 2012 EED:
Member States shall ensure that national energy regulatory authorities encourage demand side resources, such as demand response, to participate alongside supply in wholesale and retail markets. Subject to technical constraints inherent in managing networks, Member States shall ensure that transmission system operators and distribution system operators, in meeting requirements for balancing and ancillary services, treat demand response providers, including aggregators, in a non-discriminatory manner, on the basis of their technical capabilities. Subject to technical constraints inherent in managing networks, Member States shall promote access to and participation of demand response in balancing, reserve and other system services markets, inter alia by requiring national energy regulatory authorities or, where their national regulatory systems so require, transmission system operators and distribution system operators in close cooperation with demand service providers and consumers, to define technical modalities for participation in these markets on the basis of the technical requirements of these markets and the capabilities of demand response. Such specifications shall include the participation of aggregators.

The update of the EED includes no further legislation directly including demand response. (EED P. , 2016)

The Directive for the Internal Market of electricity

The directive for the internal market in electricity (sometimes referred to as the electricity directive), includes demand response as an important instrument of energy security. The directive prefers the term 'demand-side management' (of electricity consumption) instead of demand response, though, in the proposed update for the IMD this is changed to 'demand response'. The 2009 IMD dictates that at least 80% of consumers shall be equipped with intelligent metering systems by 2020, which is a very relevant part of the demand response framework. (IMD, 2009).

Art. 3.10 in the 2009 IMD:
Member States shall implement measures to achieve the objectives of social and economic cohesion and environmental protection, which shall include energy efficiency/demand-side management measures and means to combat climate change, and security of supply, where appropriate. Such measures may include, in particular, the provision of adequate economic incentives, using, where appropriate, all existing national and Community tools, for the maintenance and construction of the necessary network infrastructure, including interconnection capacity.

Art. 8 in the 2009 IMD:
1. Member States shall ensure the possibility, in the interests of security of supply, of providing for new capacity or energy efficiency/demand-side management measures through a tendering procedure or any procedure equivalent in terms of transparency and non-discrimination, on the basis of published criteria. Those procedures may, however, be launched only where, on the basis of the authorisation procedure, the generating capacity to be built or the energy efficiency/demand-side management measures to be taken are insufficient to ensure security of supply.
2. Member States may ensure the possibility, in the interests of environmental protection and the promotion of infant new technologies, of tendering for new capacity on the basis of published criteria. Such tendering may relate to new capacity or to energy efficiency/demand-side management measures. A tendering procedure may, however, be launched only where, on the basis of the authorisation procedure the generating capacity to be built or the measures to be taken, are insufficient to achieve those objectives.
3. Details of the tendering procedure for means of generating capacity and energy efficiency/demand-side management measures shall be published in the Official Journal of the European Union at least six months prior to the closing date for tenders.
Art. 12 in the 2009 IMD:
Each transmission system operator shall be responsible for:
(…)
(d) managing electricity flows on the system, taking into account exchanges with other interconnected systems. To that end, the transmission system operator shall be responsible for ensuring a secure, reliable and efficient electricity system and, in that context, for ensuring the availability of all necessary ancillary services, including those provided by demand response, insofar as such availability is independent from any other transmission system with which its system is interconnected;
Art. 25.7 in the 2009 IMD:
When planning the development of the distribution network, energy efficiency/demand-side management measures or distributed generation that might supplant the need to upgrade or replace electricity capacity shall be considered by the distribution system operator.

The proposed update on the IMD is an entirely revised version and has great focus on demand response. It ensures that consumers are entitled to dynamic price contracts and able to engage in demand response. Also, it requires member states to define frameworks for independent aggregators demand response according to principles that enable their full participation in the market. The update clarifies the principle of balancing responsibility, and provides for a framework for more market compatible rules for the dispatch and curtailment of generation and demand response. In the proposed updated directive, nearly all the referred articles from the above 2009 IMD have been erased, while several new articles addressing demand response have been added including one titled ‘demand response’ (article 17). Article 3.10, article 8, and article 25.7 are completely removed. Article 12 (d) exists as before. (IMD-update, 2016).

Art. 13.4 in the updated IMD:
Member States shall ensure that final customers are entitled to receive all relevant demand response data or data on supplied and sold electricity at least once per yea
Art. 17 in the updated IMD:
Demand response

1. Member States shall ensure that national regulatory authorities encourage final customers, including those offering demand response through aggregators, to participate alongside generators in a non-discriminatory manner in all organised markets.

2. Member States shall ensure that transmission system operators and distribution system operators when procuring ancillary services, treat demand response providers, including independent aggregators, in a non-discriminatory manner, on the basis of their technical capabilities.

3. Member States shall ensure that their regulatory framework encourages the participation of aggregators in the retail market and that it contains at least the following elements:

(a) the right for each aggregator to enter the market without consent from other market participants;

(b) transparent rules clearly assigning roles and responsibilities to all market participants;

(c) transparent rules and procedures for data exchange between market participants that ensure easy access to data on equal and non-discriminatory terms while fully protecting commercial data;

(d) aggregators shall not be required to pay compensation to suppliers or generators;

(e) a conflict resolution mechanism between market participants.

4. In order to ensure that balancing costs and benefits induced by aggregators are fairly assigned to market participants, Member States may exceptionally allow compensation payments between aggregators and balancing responsible parties. Such compensation payments must be limited to situations where one market participant induces imbalances to another market participant resulting in a financial cost. Such exceptional compensation payments shall be subject to approval by the national regulatory authorities and monitored by the Agency.

5. Member States shall ensure access to and foster participation of demand response, including through independent aggregators in all organised markets. Member States shall ensure that national regulatory authorities or, where their national legal system so requires, transmission system operators and distribution system operators in close cooperation with demand service providers and final customers define technical modalities for participation of demand response in these markets on the basis of the technical requirements of these markets and the capabilities of demand response. Such specifications shall include the participation of aggregators.

Art. 20 in the updated IMD:
Smart metering functionalities
(…) (a) the metering systems accurately measure actual electricity consumption and provide to final customers information on actual time of use. That information shall be made easily available and visualised to final customers at no additional cost and at near-real time in order to support automated energy efficiency programmes, demand response and other services;

Art. 31.5 in the updated IMD:
Each distribution system operator shall procure the energy it uses to cover energy losses and the non-frequency ancillary services in its system according to transparent, non-discriminatory and market based procedures, whenever it has such a function. Unless justified by a cost-benefit analysis, the procurement of non-frequency ancillary services by a distribution system operator shall be transparent, non-discriminatory and marketbased ensuring effective participation of all market participants including renewable energy sources, demand response, energy storage facilities and aggregators, in particular by requiring regulatory authorities or distribution system operators in close cooperation with all market participants, to define technical modalities for participation in these markets on the basis of the technical requirements of these markets and the capabilities of all market participants .

Art. 32 in the updated IMD:
Tasks of distribution system operators in the use of flexibility
1. Member States shall provide the necessary regulatory framework to allow and incentivise distribution system operators to procure services in order to improve efficiencies in the operation and development of the distribution system, including local congestion management. In particular, regulatory frameworks shall enable distribution system operators to procure services from resources such as distributed generation, demand response or storage and consider energy efficiency measures, which may supplant the need to upgrade or replace electricity capacity and which support the efficient and secure operation of the distribution system. Distribution system operators shall procure these services according to transparent, non-discriminatory and market based procedures. Distribution system operators shall define standardised market products for the services procured ensuring effective participation of all market participants including renewable energy sources, demand response, and aggregators. Distribution system operators shall exchange all necessary information and coordinate with transmission system operators in order to ensure the optimal utilisation of resources, ensure the secure and efficient operation of the system and facilitate market development. (…)
2. The development of a distribution system shall be based on a transparent network development plan that distribution system operators shall submit every two years to the regulatory authority. The network development plan shall contain the planned investments for the next five to ten years, with particular emphasis on the

main distribution infrastructure which is required in order to connect new generation capacity and new loads including re-charging points for electric vehicles. The network development plan shall also demonstrate the use of demand response, energy efficiency, energy storage facilities or other resources that distribution system operator is using as an alternative to system expansion.

Art. 40 in the updated IMD:
Tasks of transmission system operators
1. Each transmission system operator shall be responsible for:
(…) **(d)** managing electricity flows on the system, taking into account exchanges with other interconnected systems. To that end, the transmission system operator shall be responsible for ensuring a secure, reliable and efficient electricity system and, in that context, for ensuring the availability of all necessary ancillary services, including those provided by demand response and energy storage, insofar as such availability is independent from any other transmission system with which its system is interconnected; (…)
4. In performing the task described in paragraph 1(i), the transmission system operator shall ensure that the procurement of balancing services and, unless justified by a cost-benefit analysis, non-frequency ancillary services, is: (…)
(b) ensures effective participation of all market participants including renewable energy sources, demand response, energy storage facilities and aggregators, in particular by requiring regulatory authorities or transmission system operators in close cooperation with all market participants, to define technical modalities for participation in these markets on the basis of the technical requirements of these markets and the capabilities of all market participants.

Updates to be adopted in 2017

All proposals for updating the four directives have been treated in the European Council several times during the first half of 2017, and few things remain unresolved. The Economic and Social Committee, and the European Committee of Regions have approved all. When approved by the European Council, the updated directives will then have to be treated in the European parliament to be enforced.

Network Codes

In addition to the above-described legislation, various Network Codes are also relevant in facilitating growth in demand response. These codes will be discussed in greater detail in WP5, but a brief description of the most pertinent is presented below:

- Guideline on electricity transmission system operation (draft) (European Commission, 2016, a)
- Network Code on Demand Connection (NC DC) (European Commission, 2016, b)

- Guideline on Electricity Balancing (NC EB) (European Commission, 2017)

In the Network Code on Demand Connection (NC DCC) (European Commission, 2016, b) demand response services can be provided to system operation. In this context, demand response services are services that maintain power system stability and resilience, and include: active power control, low frequency demand disconnection, reactive power control, transmission constraint management and system frequency control. The service must be available across a defined range of frequency and voltage (see article 27 to 30).

The Network Code on Electricity Balancing (NC EB) "requires that standard products are defined for the European balancing market (energy and reserves markets) to move towards a single European market with a cross-border regional approach". Meanwhile, the processes for defining these standard products (for example frequency restoration reserves and replacement reserves) are laid out in the Network Code on Load Frequency Control and Reserves (NC LFC & R). (ENTSO-E, 2015).

1.2 Role of markets and service providers

Demand response is increasingly seen as an instrument that can help to achieve energy efficiency, an efficient electricity system, to integrate renewable resources, and increase security of supply. This is also very clear from the proposed updates of the directives. Not least of which the Internal Market Directive, which includes a large number of new regulations with the objective to secure ideal conditions for demand response to the benefit of the electricity market.

The most important electricity market in the Baltic and Nordic countries is the day-ahead spot market. Its central function is to find the hourly price, which is done by comparing and clearing bids for demand and generation. For the demand side, aggregators (in the form of retailers/balance responsible) are used. The expected hourly demand for end-users is estimated by retailers/balance responsible.

The demand bids can be price independent or price dependent. For price independent demand, the retailer attempts to predict the hourly demand for the next day. This is relatively easy for a large number of consumers, as historical demand can be utilised and adjustments to this data can be made for temperature, holidays and other special occasions or circumstances.

Incentive based vs. price based
Demand response instruments are often segregated into 'incentive-based' and 'price-based' demand response. In incentive-based demand response consumers receive direct payments to change their consumption or generation upon request. They earn from their flexibility individually or by contracting with an aggregator (third-party aggregator or the costumer's retailor). In price-based demand response, the consumer adjust the consumption according to dynamic price signals (not on request). **(Smart Energy Demand Coalition, SEDC, 2017)**

If the demand is price dependent, the typical procedure is similar. The expected demand is now a function of price – in addition to the other parameters mentioned above. For the few largest end-users, the demand for the following day may be planned by the end-users and communicated to the retailer.

All demand is covered by these procedures – also if the electricity is purchased bilaterally. The TSO will thus receive a plan during the afternoon before the operating day that is in balance (i.e. for the following day anticipated supply is equal to anticipated demand).

Demand response can therefore be arranged in the following way for the day-head market:

- The end-user enters a spot contract (with free volume) with the retailer
- For each day:
    - The retailer (or balance responsible) predicts the (price dependent) demand for all its consumers
    - A bid is sent to Nord Pool spot by the retailer
    - Prices are found for the next day
    - The end-user receives the next day's prices from the retailer
    - End-user changes demand according to prices and preferences
    - Imbalance costs will occur if the predicted demand turns out to vary from the actual demand.

It is therefore a learning process where the retailer can continue to improve its predicted demand. It is worth noting that it is easier to predict demand from many consumers as random variations in demand tend to even out.

Independent aggregators

In the above description, the retailer is the aggregator and the retailer delivers electricity and the framework for flexibility *in one package.*

In some situations, it can be relevant to use an independent aggregator. An independent aggregator can activate flexibility in demand without having entered into the contract for delivering electricity to the end-user (ENTSO-E, 2015). E.g. SEDC has been a strong advocate for the use of independent aggregators (Smart Energy Demand Coalition, SEDC, 2017). SEDC has focus on incentive-based demand response (where end-users receive a payment for being active, in contrast to price-based demand response, where end-users react to a price signal – as with a spot price. Incentive-based demand response is likely more relevant in relation to demand response as a provision of some forms of ancillary services (where price based demand response can also play a role).

A 2016 report authored by the Nordic Energy Regulators concluded that for the Nordic electricity retail market, there is no need for independent aggregators (NordReg, 2016). The retail market in this respect is understood as the day-head and the intra-day markets. Since the Baltic countries are part of Nord Pool, the same can be assumed here.

Note, that third parties can have a supporting role, without being an aggregator. E.g. a company specialised in controlling heat pumps, can deliver this service to owners of heat pumps. The heat pump owner can for example enter a contract with a variable price with a retailer, and allow for the third-party company to take technical control of the heat pump (for example ensuring that the heat pump avoids using electricity during the most expensive hours each day.) In this setup, the retailer will still be the aggregator.

In markets other than the day-ahead and intra-day markets, an independent aggregator may play a stronger role. E.g. if demand should deliver frequency controlled reserve (primary or secondary reserve) it could be relevant for a TSO to enter a contract with an independent aggregator. If it is symmetric frequency reserve (both up and down), the net volume of the regulation is so small that there is no need for paying (or controlling) for the regulated volume. Imbalances forced on the balance responsible party (BRP) can be ignored and no special contracts or arrangement are needed between BRP and the independent aggregator.

In market areas that are less developed than the Nordic markets, an independent aggregator may also be relevant for day-head and intra-day markets.

1.3 Demand response in Europe today

Working group & studies

EU joint working group to boost information exchange

A joint working group (JWG) was established in September 2014 to boost the exchange of information and to facilitate discussions on a wide variety of demand side flexibility (DSF) related developments and topics within three Concerted Action (CA) programs. The JWG, in which the CA EED (Energy Efficiency Directive), the CA RES (Renewable Energy Directive) and the CA EPDB (Energy Performance of Buildings Directive) cooperate, has compiled in a 2015 report (Edelenbos, Togeby, & Wittchen, 2015).

DSF is defined in the above report as "the capacity to change electricity usage by end-users from their normal or current consumption patterns in response to changes in the price of electricity over time, or incentive payments." These price changes or incentives can be grid related and market related. Price signals from the market can come from the wholesale market, e.g. day-ahead or intra-day markets.

The report highlights that the increase of intermittent (renewable) generation will result in a greater need for flexibility and that DSF has the potential to contribute to an affordable, reliable and sustainable electricity system, as it increases the flexibility of the system. The key objective for the JWG on DSF was: "to define key success factors and potential threats for implementing EU Directives and regulation; to facilitate or stimulate effective DSF-solutions in the EU and its Member States taking into account the need for energy efficiency, the evolving share of renewable electricity generation and the key role that buildings, including nearly-zero energy, will have in the future." The report highlights actions to be taken by member states, the EU or other institutions to promote an efficient implementation of DSF.

Nordic Electricity Market Group seeks cost-effective consumer flexibility

The Nordic Electricity Market Group released a report commissioned by the Nordic Council of Ministers, which provides input to a Nordic strategy on how to address the potential need for consumer flexibility in a cost-efficient manner. The motivation for the report, is that the Council recognises that intermittent renewable electricity generation, such as small-scale hydropower, wind, and solar PV, has limited capacity to deliver flexibility to the power system. Hence, it is relevant to consider to what extent the provision of flexibility from the consumer-side could, and should, be facilitated. The report is part of the

Nordic Prime Ministers' green growth initiative: The Nordic Region – leading in green growth (THEMA, 2014).

In the report, it is stated that the long-term value of flexibility and the competitiveness of demand as a provider of flexibility is not clearly understood, both due to uncertainty in the development of power consumption and the impact of new market solutions and new technology. It is recommended for all Nordic countries that this uncertainty should be addressed by pursuing three overall strategic objectives (elaborated in the report):

- Promote efficient market solutions,
- Increase the knowledge and understanding on the factors affecting the value of (demand) flexibility, and
- Reduce the cost of demand response from small consumers by making relevant data easily available for consumers and third parties as a low cost, low risk measure.

Fingrid – Electricity market needs fixing

The Finish TSO recognises that maintaining power system security has become increasingly challenging as large amounts of weather-dependent renewable electricity have been added to the power system. In a 2016 paper, Fingrid argues that subsidies to promote renewable electricity have undermined the role of market-based investments, i.e., in today's electricity markets, subsidies have largely crowded out market-based investments. It is further argued that in healthy markets, price signals would give incentives for economic behaviour and for balancing supply and demand both in the short-term and long-term. The authors conclude that a political decision is needed urgently to put an end to the current vicious circle that risks derailing the goals of secure, sustainable and affordable electricity. The authors state that in a healthy market, the price of a product should reflect its value, for example, it is important that prices signal whenever there is scarcity in the markets.

The report identifies a number of development needs of the current Nordic electricity market design. It introduces two alternative development paths for the Nordic electricity markets. The essential question is: *"Will the price mechanism continue to be the primary means to incentivize economic behaviour in electricity markets? And if not, what would be the alternative in organizing power system operation and development?"*

The first development path, the "Markets", is characterised as an evolutionary development of the Nordic market design. It consists of development steps that can help restore the role of market-based incentives. However, the paper also introduces an alternative path for electricity sector development that builds on a stronger central control. In this case, distortive subsidies prevail and a more fundamental change is needed in how we think about the electricity sector development. (Fingrid, 2016).

Status of Incentive-based demand response

A status of the regulatory framework for incentive-based demand response in the European countries is performed regularly by the Smart Energy Demand Coalition (SEDC), a coalition for companies operating within demand-centred programs. The latest status report concludes that:

- The regulatory framework in Europe for Demand Response is progressing, but further regulatory improvements are needed
- Restricted consumer access to Demand Response service providers remains a barrier to the effective functioning of the market
- Significant progress has been made in opening balancing markets to demand-side resources
- The wholesale market must be further opened to demand-side resources
- Local System Services are not yet commercially tradeable in European countries

The SEDC lists Switzerland, France, Belgium, Finland, Great Britain, and Ireland as the countries that currently provide the most conducive framework for the development of incentive based demand response.

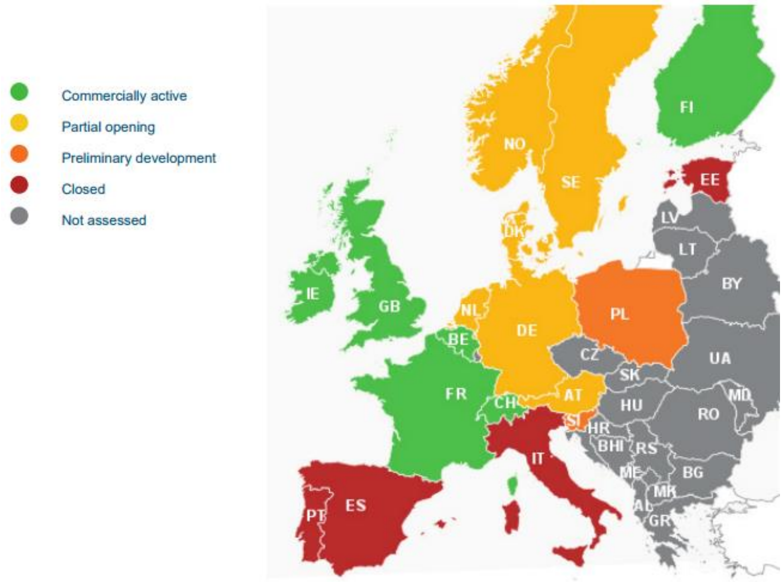

Figure 1: Map depicting the state of incentive based demand response in Europe (referred to as explicit demand response by the SEDC). Price-based demand response is not considered. (Smart Energy Demand Coalition, SEDC, 2017)

Great Britain has been one of the front runners according to the SEDC, with a range of markets open to demand-side participation. Independent aggregators can directly access consumers for ancillary services and capacity products, and the country recently has started considering a framework for independent aggregator access to the Balancing Mechanism.

According to the SEDC, with the exception of Finland, countries acting in the Nordic spot market do not offer as good frameworks for incentive based demand response. Estonia has been included for the first time in the latest mapping of demand response framework as a country that engages in regulation allowing good conditions for demand response. Latvia and Lithuania are not included in the status report, as they are not considered countries where 'progress in demand response development has been identified'. Regulatory barriers remain in Denmark, Norway, and Sweden although several markets in these countries are open to demand response in principle. (Smart Energy Demand Coalition, SEDC, 2017).

Status of meters

In price-based demand response consumers are exposed to time-varying prices, meaning that smart meters must be installed and the retailer must be allowed to offer the consumers the possibility of time-varying prices. By 2020, European member states are required to ensure implementation of smart metering for at least 80% of all consumers (IMD, 2009). The implementation might be dependent on a positive cost-benefit analysis.

To date, Member States have committed to rolling out close to 200 million smart meters for electricity. By 2020, it is expected that almost 72% of European consumers will have a smart meter for electricity. (Joint Research Centre, 2017).

In Lithuania mass roll-out of smart meters are expected to start in 2019 and to be completed in 2022.

European examples of demand response

Despite a growing focus on the required legislative frameworks, the use of demand response and demand response service providers are still not widespread, and DR is still largely an unknown concept for many consumers. However, some concrete examples of European consumers delivering demand response are to be found, a few of which are listed below.

Demand response in Norway & Finland dates back many years

Utilisation of demand response in the Nordic countries actually dates back many years.

In late 2002, Nord Pool experienced record high spot prices, a development that was driven by an extreme dry year. For example, in week 50 of 2002, the average price in the entire Nordic area (except Western Denmark) was 85 €/MWh, and the monthly average for December of that year was 70 €/MWh. A detailed statistical model was developed to analyse the hourly electricity demand in the four countries, with Data regarding electricity demand and temperature from 2000 to 2002 being utilised (Nordel, 2003). The results showed that in Norway there was a clear response to the high prices. For December of 2002, the actual demand was on average 800 MW lower than expected from the model (the model did not include the impact of prices). The response was increasing throughout the month. The result was less clear in the other Nordic countries. The reduced demand helped the entire system to come through the dry period without forced curtailment of demand.

The impact of time-of-Use tariffs (TOU) was also analysed in 2005. Here the profile of electric heating in households were compared between Denmark and Finland. In Finland (with TOU tariffs) a significant part of the demand is located in the night. It was estimated that the peak demand in Finland would be 1,000 MW higher if there was no TOU tariffs. (Elkraft System, 2005).

The same analysis also estimated that in 2005, 2,075 MW of demand response was contracted by the Nordic TSOs, and that an additional 1,660 MW is active in other markets, e.g. the day-ahead market. At this time, a conservative estimate of the total potential for demand response in the Nordic countries was 12,000 MW.

Electric boilers: DK

In Denmark, 600 MW electric boilers placed in relation to small district heating systems are active when prices are low. The boilers are active in several markets: Day-ahead, intra-day, regulating power and primary reserve. The largest market for the boilers is the regulating power market. When the electric boilers are active, natural gas consumption by small combined heat and power (CHP) units is reduced. The investment in electric boilers are motivated by the occurrence of low and negative prices in Denmark. Typically, there are 40-60 hours per year with negative prices. This number has been stable since 2009 – despite increase in the amount of wind power. The electric boilers (along with improved flexibility of traditional plants and more transmission capacity to e.g. Norway) have helped reduce the number of hours with negative prices.

KiWi Power, a demand response aggregator: UK

Kiwi Power is a demand response aggregator located in the United Kingdom. They offer larger consumers a system set-up where select loads are reduced when demanded by the National Grid. Consumption from different units are metered and reported via KiWi's control center to the National Grid. Examples of technologies that participate include air handling and cooling systems in buildings, pumping units in water supply systems. In addition, back-up generators are included in KiWi's demand response portfolio. (KiWi Power, 2017)

Reduced tariffs: NO

The Norwegian TSO, Stattnet, and several DSOs in Norway offer reduced tariffs to consumers who are willing to be disconnected in hours when production does not meet demand, or the distribution network is lacking capacity. Large consumers can offer their flexibility to the TSO with two different notifications periods, and two different limitations on duration (Statnett, 2017):

- 15 minutes notification, without limitation on duration of disconnection
- 2 hours notification, without limitation on duration of disconnection
- 12 hours notification, without limitation on duration of disconnection
- 15 minutes notification, with maximum 2 hours limitation on duration of disconnection.

The DSOs have different set-ups and tariff-structures for the flexibility, but are generally aimed at larger consumers and based on individual contracts. (Lysenett, 2017) (Glitre Energi -nettleiepriser-2017, 2017)

Demand response is active in various Finnish markets

Demand response is active in various Finnish markets, with the current volume of demand response in Finland is estimated to between 410 & 1,100 MW across several markets (see Table 1).

	Volume
Day-ahead	200-600 MW
Intra-day	0-200 MW
Regulating power	100-300 MW
Strategic reserves	10 MW
Frequency reserve for disturbance (FCR-D)	100 MW
Total	410 – 1,100 MW

Table 1: Demand response in Finland. (Fingrid, 2016)

1.4 Summary

The volume of realised demand response is growing in all markets. Market rules, new metering systems and procedures are being developed to allow demand to play a role in all markets. Demand response has a clear role in the current EU directives (for electricity market, energy efficiency, renewable energy, buildings), and an even more prominent role in the proposed directives.

Examples for existing demand response activities are presented from UK, Norway, Finland and Denmark. This include Time-of-Use tariffs and reduced tariffs for load that can be disconnected, day-ahead market, regulating power and ancillary services. In chapter 5 more details are presented about these products.

In many countries, there are still two areas that lack development:

- Small end-users both need smart meters and market procedures that in practise allow demand response.
- Demand can be used as reserves and regulating power, however procedures (including monitoring) are still to a large extent mostly adapted to generators.

Demand response exists in the Nordic market, e.g. with 600 MW electric boilers in Denmark and 410 – 1,100 MW across various markets in Finland.

2 Demand response pilot projects

Throughout Europe there are numerous demand response projects researching a broad range of relevant issues including:

- Communication to, and control of, electricity consumption.
- Potential value generation for end-users, grid companies and utilities.
- Technical capabilities
- End-user engagement and experiences

The following state of the art provides an overview of European demand response projects undertaken or currently underway. However, given the numerous DR projects in Europe, it should by no means be seen as an exhaustive list.

Project	Market	Sector
Linear: Belgium	ID	HH
PowerMatching City: Holland	DA & ID	HH
Customer-Led Network Revolution: UK	ID & reserves	HH & Ind. & SS
Smart Electric Lyon: France	ID & reserves	Ind. & HH
Consumer communication in Smart Grid: DK	ID	HH
DR-BOB project - DR in blocks of buildings: UK	ID	HH & SS
EirGrid – Demand Side Management: Ireland	ID	Ind. & HH
READY: Heat pumps	DA & reserves	HH
Demand as frequency controlled reserve	Reserves	HH & SS
FlexPower (Market design)	Reg. power	All
Demand response for direct electric heating	DA	HH
NOBEL GRID Project: EU	ID	HH & SS
GRID4EU: EU	ID & storage	SS
DRIP – DR in Industrial Production: EU	ID	Ind.
CASSANDRA	ID	HH & SS

Table 2: Selection of completed or ongoing DR projects. (ID: intra-day, DA: day-ahead, IND: Industry, HH: Household, SS: Service sector)

LINEAR: Belgium

Increased growth in electricity production from intermittent renewables, accompanied with falling traditional generation capacity in Belgium, led to the establishment of LINEAR (Local Intelligent Networks and Energy Active Regions). LINEAR was tasked with looking at the potential for demand side management in households, particularly their ability to adapt electricity consumption to solar and wind production.

Some of the key questions LINEAR sought to address included (Linear, 2014):

- How do households and industry stand to benefit from a change in behaviour?

- How will the costs and benefits be divided among parties involved?
- Which solutions will provide enough motivation and convenience to prompt a change in behaviour?
- To what extent will households be able and willing to change their behaviour?

The project involved 250 households with various controllable loads, including electric water heaters, heat pumps, smart appliances (i.e. washing machines, dishwashers, dryers, etc.), and electric vehicles (EVs). The field test involves automated demand-side management and smart devices to control electric devices in 75% of the households. These devices were controlled according to four different business cases:

- Rate control – variations in electricity prices
- According to wind production
- Minimisation of peak loads on transformers
- According to the voltage level

In one part of the project, 55 families were asked to alter their energy consumption based on different energy tariffs during the day (these prices were communicated the day before). These families were provided with support in the form of a Home Energy Monitoring System, which gave sight into their consumption, and provided a display showing the market-priced tariffs scaled-up to the targeted wind and solar predictions in 2020. (Cardinaels & Borremans, 2014).

In another portion of the project, 185 families were equipped with a Home Energy Management System and smart appliances (washing machine, dishwasher, tumble dryer, electric heating and electrical vehicle), and the appliances were turned on when more energy consumption was required, or turned off when less energy had to be used. Though, all systems were equipped with features to manage the comfort of the users (i.e. ensure that hot showers were always available, dishes clean when needed, etc.). (Cardinaels & Borremans, 2014).

The report authors summarised their findings as follows: *"The response to the variable Time of Use tariff scheme was weak while the Linear tariff scheme turned out to be too complex. The acceptance of the smart-start functionality, however, was much better. After 18 months of testing there was still no indication of user fatigue, and the participants that stopped using the system did so because of technical issues.*

The Linear field test demonstrated that automated demand response with household appliances is technical feasible. For each of the business cases Linear could improve the parameters controlled by the different algorithms. At the same time, Linear showed that in-house communication should need further development and standardization in order to keep the operational cost affordable."

PowerMatching City: Holland

The PowerMatching City project (phases 1 & 2) ran from 2007 to 2014. The stated goal of the project was to "demonstrate the energy system of the future with smart energy services, as well as the validation of costs and benefits of this system in order to enable the energy transition" (PowerMatching City, 2014).

This overall project goal was to be reached by investigating:

- The potential for demand side resources to assist in system balancing and grid congestion management
- Customer behaviour, including the identification and design of the most effective pricing/market mechanisms for encouraging customer participation

The project involved over 40 households in Hoogkerk, Holland and included hybrid heat pump systems (a heat pump accompanied with a natural gas boiler), micro CHP systems, EVs, PVs and battery storage.

The initial phase of the PowerMatching project found that demand side resources can be utilised to address grid congestion. With respect to hybrid heat pumps, the initial phase found that they are a "cost-efficient cornerstone in balancing networks when intermittent renewable energy sources are deployed on a large-scale." While the first phase found very little economic incentive for end-users to adjust their electricity consumption according to the day-a-head prices, the second phase of the project involved market prices varying each 5-minutes (PowerMatching City, 2014).

According to the project website, some of the project results from phase 2 of the project included:

> *"PowerMatching City demonstrated that smart energy systems are technically feasible and that energy flexibility makes economic sense. In fact, the net gains from the consumer market could well reach 3.5 billion euros. These benefits are based in part on money saved by the grid operators by avoiding costs for investments and maintenance of grids.*

A striking result of the pilot was that the system was much more flexible than anticipated on the basis of previous studies and that the demand and supply were easier to balance than expected.

If this smart and flexible energy system is to be implemented in the consumer market on a large scale then it will need to be standardised, both in order to reduce the costs of connecting the households in the smart grid and to lower the price of the smart energy services.

The partners in PowerMatching City recommend the development of a new market model for the optimal distribution of flexibility, whereby the value of flexibility is put to the best possible use. Fair distribution of the benefits among all the stakeholders (end users - consumers, energy providers and network operators) is essential for a successful business case." (PowerMatching City, 2015)

Customer-Led Network Revolution: UK

The driving force for the Customer-Led Network Revolution (CLNR) project was to prepare UK electricity networks for a future dominated by a larger proportion of distributed and renewable electricity generation. In order to plan for this future, the project aimed to better understand the impact (on both load and generation) of large-scale adoption of low carbon solutions such as heat pumps, EVs and PVs. In addition, the project was interested in determining the extent of end-user flexibility, and the cost associated with this flexibility. (Thompson, Foster, Lodge, & Miller, 2014).

According to the completion report, the (CLNR) was a "major smart grid demonstration project which brought together the key stakeholders in the electricity system (customers, energy suppliers and distributors) developing innovative technologies and commercial arrangements. The CLNR customer trials involved ca. 11,000 domestic, 2,000 SME (Small and medium-sized enterprises), industrial & commercial (I&C) and distributed generation customers.

- Domestic participants included ca. 650 on time of use (ToU) tariffs, 380 with heat pumps, 470 with solar photovoltaic (PV) panels and 160 electric vehicle (EV) users.
- 16 I&C customers provided a total of 17MW of demand side response (DSR) in trials for large scale fast reserve.

- A wealth of customer insight and analysis undertaken by Durham University from ca. 1,250 surveys and ca. 250 face-to-face interviews completed with more than 130 customers." (Sidebotham, 2015)

In order to establish a baseline, around 400 of the heat pumps do not face any special tariffs. Meanwhile, in order to investigate the impact of variable prices on consumption, roughly 20 heat pumps encounter a three-rate tariff designed to avoid the 16:00-20:00 peak. Lastly, roughly another 20 heat pumps were controlled remotely in order to monitor their ability to peak shave. (Delta Energy & Environment, 2014).

According to the project website, the main project headlines included:

- *"The project delivered important new learning from trials with real customers on real networks.*
- *Low carbon technologies are less disruptive and customers are more flexible than was previously assumed*
- *Time of use tariffs could deliver value in the next 10 years when delivered in conjunction with energy suppliers, but;*
- *Industrial & Commercial (I&C) Demand Side Response is fit for business as usual today*
- *Solutions to address the network impact of low carbon technologies can start relatively simply and evolve over time as the complexity of the constraint increases.* (Customer-Led Network Revolution, 2017)

Smart Electric Lyon: France

Coordinated by EDF, the Smart Electric Lyon project was launched in 2012. It was designed to last 4 years (but is still underway) and was divided into three phases (Smart Grids - CRE, 2013):

- Design and development of equipment
- The integration of equipment and small-scale field tests
- Deployment of tenders and large-scale services

The project includes 400 heat pumps, as well as hybrids, electric heating, hot water and air conditioning. The project aims to investigate consumer behaviour, i.e. how and why consumers react to different offers, investigate and develop new business models, and work with standardisation for communication between heat pumps and smart meters. (Delta Energy & Environment, 2014).

The project intends to bring together 19 industrial partners from various branches (including energy production, home automation equipment, telecommunications, etc.,) French academia, as well as 25,000 households. 90% of these households will receive detailed electricity consumption data along with benchmarking of their data and personalised recommendations on how to save energy. The remaining 10% of houses, as well as 100 tertiary sector buildings, will participate in field tests involving technical solutions (energy management systems, displays, controllable electric heating etc.) coupled with varying tariffs. (Smart Grids - CRE, 2013).

Consumer communication in Smart Grid: Denmark

EcoGrid EU is one of the largest EU-financed large-scale demonstration projects within Smart Grid. EcoGrid is investigating how to involve private customers – on a voluntary basis – in balancing an energy system with a large proportion of fluctuating energy sources by using market mechanisms and smart control of the power consumption (Trong, Salamon, & Dogru, 2016).

A major project objective is to analyse and communicate experiences with customer communication and user involvement in Smart Grid projects based on the EcoGrid project on Bornholm. Project findings regarding this objective were published in the final report in WP4: Preparation of communication measures and instruments. This work is part of the project: "Information to and education of the future electricity consumers".

The report aims to answer how it was possible to recruit and involve a tenth of all household customers (approx. 2.000) in the EcoGrid project on Bornholm and to what extent the experiences from the project can be applied outside Bornholm. In the report, a selection is undertaken of experiences most suitable to be applied in other demonstration projects and/or in the context of a broader and nation-wide roll-out of Smart Grid. Actions that are not recommendable have also been identified.

The project group has arrived at the following main recommendations:

- Preparation of communication strategy and contingency plan
  Closed online user platforms can engage the customer and contribute to problem solving. A contingency plan should be established with communication routines and platforms that can help avert negative consequences of unplanned outcomes, e.g. server crash etc.
- Implementation of pre-test
  A pre-test involving the entire value chain and a limited number of users should be conducted.

- Definition of requirements for technological solutions and ease of use
  Remote update of equipment should be a possibility so that the electrician/installer doesn't need to travel to the customer every time a need to update/change software occurs and so that errors can be solved centrally.
- Integration of flexible electricity consumption and energy savings
  It should be possible for consumers to choose the most competitive alternative, which could e.g. be a combination of instruments to promote respectively energy efficiency and flexible electricity consumption.

DR-BOB project – Demand response in blocks of buildings: UK

DR-BOB is a project focused on blocks of buildings in the UK, and aims to demonstrate the economic and environmental benefits of demand response in these buildings (DR-BOB, 2017).

The project looks to address the problem related to utilities being required to have enough energy to meet large peaks in demand caused by large numbers of people using energy simultaneously. Energy distribution networks must also have the capacity to meet this demand, but this is rather inefficient, as most of the time, demand runs far below capacity.

Blocks of buildings offer more flexibility in the timing of energy use, local energy generation, and energy storage compared to that of single buildings, but a lack of suitable products and technologies make it difficult to harness this potential.

The DR-BOB project suggests that peak electricity demand can be reduced by:
- shifting when some electrical equipment is used;
- using electrical equipment more efficiently;
- using other types of energy;
- storing locally generated renewable electricity and using it during times of peak demand.

DR-BOB further argues that if peak electricity demand is reduced, this will reduce the investments required in electricity production and electricity networks. These savings can then be passed onto consumers in the form of lower energy bills.

The DR-BOB project will pilot the tools and techniques required for demand response in blocks of buildings with differing patterns of ownership, use and occupation at;

- Teesside University campus in Middlesbrough in the UK,
- A business and technology park in Anglet in France,
- A hospital complex in Brescia in Italy,
- The campus of the Technical University of Cluj Napoca in Romania.

EirGrid – Demand Side Management: Ireland	EirGrid engages in Demand Side Management (DSM), which involves users of electricity having the capability to change their usage from their normal or current consumption patterns. Electricity consumers can currently participate in DSM through tariff-based schemes where they are encouraged to move their usage to cheaper off-peak times. Examples include Economy 7 (Northern Ireland) and NightSaver (Ireland) (EirGrid, 2017). EirGrid also engages in Demand Side Unit (DSU) or Aggregated Generating Unit (AGU), which is intended for medium to large electricity users. A Demand Side Unit consists of one or more demand sites that can reduce their demand when instructed by EirGrid. The Demand Side Unit has one hour to reduce its demand and must be capable of maintaining the demand reduction for at least two hours.
READY – Heat pumps	The point of departure for the READY project was that the energy system is changing and will be increasingly complex in the future. The share of wind power in Danish electricity consumption is expected to increase to 50% by 2020. This will give rise to a range of challenges related to electrical system balance, communication, data handling, as well as electricity markets. As such there exists a need to develop advanced solutions for using electricity more intelligently, and in the Danish context heat pumps provide an opportunity for integrating more wind power and other fluctuating electricity production into the energy system. The main purpose of the READY project was the development of a Smart Grid ready Virtual Power Plant (VPP) server that can control a large number of heat pumps. In this context, a VPP server is a unit that can control thousands of consumption appliances, but seen from the operator they act as one control-lable unit. The main aspects of the project were: • Large scale aggregation of heat pumps • Management of grid constraints

- Recommendation for future installations of heat pumps and controllers
- User involvement and business cases

Grid constraints in the distribution grids, delivery of system services, communication scenarios, grid and electricity metering measurements, various types of electricity users and their fluctuating loads, and the development of markets for congestion management was analysed in the READY project. A number of local grid companies were interviewed to provide input regarding constraints in their respective grids as well as potential communication scenarios and technologies that can be utilised to manage these congestions. (Ea Energy Analyses, 2014).

Demand as frequency controlled reserve: DK

A Danish research project was undertaken to address the realisation that as the amounts of electricity production from renewable energies increase in the electricity system, ancillary system services will receive greater attention. These services ensure the energy balance in the power system and have traditionally been delivered by central power stations. However, restructuring the power system requires new solutions and activation of alternative resources.

One of the important ancillary services is frequency control, which reacts fast to frequency deviations, which are a sign of imbalance between consumption and production in the power system. In 2006, Ea Energy Analyses participated in a theoretical project on "electricity demand as frequency controlled reserve" in cooperation with the Centre for Electric Technology (CET) at the Technical University of Denmark (Rasmussen, 2013). The project found good possibilities of incorporating the demand side as frequency controlled reserve. This can be achieved by disconnecting or connecting electricity consumption for a short period of time.

Together with the Centre for Electric Technology (CET) at the Technical University of Denmark, Østkraft, Danfoss and Vestfrost, Ea Energy Analyses later participated in the demonstration project “Electricity demand as frequency controlled reserve – Implementation and practical demonstration”. The aim was to demonstrate the practical implementation of demand as frequency controlled reserve, were 200 units for demand as frequency controlled reserve were installed on the island of Bornholm, both at private households and larger electricity consumers. The practical implementation was monitored closely, both with respect to the technical aspects and user experience.

The analysis in the project concluded that “DFCR loads can be dispatched with high reliability without endangering the system’s ability to remain within the range of acceptable frequencies” (Rasmussen, 2013).

FlexPower – Demand as regulating power: DK

With increasing share of renewable energy, and the closing of traditional power plants, new sources for ancillary services must be found. The FlexPower project successfully designed and tested a market for electricity demand as regulating power (Ea Energy Analyses, 2013). Focus was on how market design can hinder or promote the participation of electricity demand in the delivery of ancillary services. The demand side of the electricity system is generally an untapped source of dynamics. In this project, it was argued that for the end-user (industry or household) it must be simple and easy to understand. However, responsibilities such as e.g. predicting the amount of regulating power that the end-users can deliver at a certain point in time, may be placed on the party responsible for the system balance. The practical test included houses with electric heating, bottle coolers in shops, and a waste water treatment plant.

In Denmark (as in many other countries), central power plants have traditionally been the primary providers of regulating power, i.e. increases or decreases in electricity production with short notice. Expanding the share of electricity generation from intermittent sources (i.e. wind power), is anticipated to result in an increased demand for regulating power. In addition, as a greater portion of electricity production comes from intermittent sources, less production will come from central plants, thus further increasing the need for regulating power from new sources.

The FlexPower project has shown that regulating power consumption via a price signal can meet a portion of this growing demand for regulating power. The central idea behind FlexPower is to use 5-minute electricity prices to shift electricity usage from times with high prices, to times with lower prices, and thereby provide regulating power via an aggregated response from numerous units on a volunteer basis.

The project objective was to develop and test a real-time market for regulating power that will attract a large number of small-scale resources (demand and distributed energy resources) to the regulating power market. It is fundamental that the market should co-exist with the current market structure, be technologically neutral, and be simple and straightforward for the end-user.

A field-test with electric heating and bottle coolers demonstrated that a price signal based communication system can produce a predictable and reliable demand response. In the test, price signals were sent to SmartBoxes coupled to electricity-consuming devices, such as a refrigerators or heating units, and the boxes adjusted the temperature in accordance with pre-established consumer comfort settings and whether the electricity price was high or low. Via the implementation of improvements related to control strategies, and the inclusion of various price, heat demand, and weather forecasts, it is concluded that a price signal based demand response system could provide a new source of reliable regulating power.

Electric heating: DK

The project "Demand response in households" demonstrated how electrically heated households can respond to fluctuations in electricity prices (Togeby & Hay, 2009). More than 500 households participated in the demonstration project.

The experiment showed that informing the participants about the fluctuation of the electricity prices and pointing out the most expensive hours did not itself lead to any significant effect. Only participants with installed automatic devices to control the consumption had a significantly lower total consumption. The participants in the demonstration project saved 15-30 €/year by adjusting their consumption according to the electricity prices.

An interesting side effect of the demonstration project was that the households saved between 200-400 €/year just by participating in the project. However, they did not obtain these savings by adjusting their electricity consumption, but simply by buying their electricity at spot prices during the experiment instead of the fixed price they normally pay through their default supply company.

The evaluation report contains quantitative analyses of the data collected from the households, the development in the electricity price, temperature variations etc. It also presents qualitative telephone interviews with all participants and more thorough interviews carried out in smaller groups with a selected number of participants.

NOBEL GRID Project: EU

The project NOBEL GRID, funded by the European Union’s Horizon 2020 research and innovation programme, will provide advanced tools and ICT (Information and communications technology) services to all actors in the Smart Grid and retail electricity market in order to ensure benefits from cheaper prices, more secure and stable grids, and clean electricity. These tools and services will enable active consumers' involvement, new business models for new actors and the integration of distributed renewable energy production (GridInnovation-on-line, 2017).

The goal of NOBEL GRID is to develop and demonstrate, under real world conditions, innovative technologies and business models in order to improve EU citizens' quality of life, allowing all the actors of the distribution energy grid to participate actively at the energy market in a big share of distributed renewable resources (GridInnovation-on-line, 2017).

NOBEL GRID results will be based on three different actions (GridInnovation-on-line, 2017):

- Enabling Distribution System Operators (DSOs) to have secure, stable and robust smart grid by mitigating management, replacement and maintenance costs.
- Providing new services to all the actors of the distribution grid (e.g., prosumers, aggregators and Energy Services Companies (ESCOs)), such as active demand response and next generation distributed renewable energy integration.
- Developing innovative and affordable solutions for deployment of smart metering systems such as Smart Low-Cost Advanced Meter (SLAM) and Smart Home Environment solution.

NOBEL GRID Project: EU

Designed in response to a call for projects from the European Commission, GRID4EU is a Large-Scale Demonstration of Advanced Smart Grid Solutions with wide Replication and Scalability Potential for EUROPE. The project was led by six electricity Distribution System Operators (DSOs) from Germany, Sweden, Spain, Italy, Czech Republic and France, in close partnership with a set of major electricity retailers, manufacturers and research organizations. As a whole, the consortium gathers 27 partners. The six DSOs are RWE, Vattenfall, Iberdrola Distribucion, Enel Distribuzione, CEZ Distribuce and ERDF (GRID4EU, 2016).

Six Demonstrators, i.e. the six DSOs mentioned above, were tested over a period of 51 months in the six different European countries. The project strived at fostering complementarities between these Demonstrators, promoting transversal research and sharing results between the different partners, as well as with the wider Smart Grids community (GRID4EU, 2016).

The project aimed at testing innovative concepts and technologies in real-size environments, in order to highlight and help remove barriers to the deployment of Smart Grids in Europe. It focused on how DSOs can dynamically manage electricity supply and demand. The main topics addressed by the project are (GRID4EU, 2016):

- The improvement of MV and LV network automation technologies to face the constraints introduced by the increased amount of Distributed Energy Resources (DER) and new usages (e.g. electric vehicles, heat pumps), to reduce energy losses and maintain or increase quality of supply;
- The optimized and smooth integration of an increased number of small and medium-sized DER (photovoltaic, wind, combined heat and power, heat pump and direct or indirect storage);
- The balancing of intermittent energy sources (including better prediction) with demand response, and different storage technologies and services;
- The assessment of islanding as a solution to increase the grid reliability;
- The increasing use of active demand including the potential future developments of new usages and evolving customers' behaviours.

DRIP – Demand Response in Industrial Production: EU

Demand response (DR) is an important pillar in the context of Smart Grid concepts and can contribute significantly to achieving the 20/20/20 goals. DR aims at adjusting the electricity demand to the grid requirements at a given point of time and thereby facilitates the further integration of renewable energy sources (RES), the improvement of efficiency of electricity grids and – consequently – the reduction of CO_2 emissions (DRIP, 2017).

The main objective of this project is to facilitate the integration of RES in the electricity grid due to the usage of the flexibility potential in the energy consuming process of industrial customers (DRIP, 2017).

As a result, the benefits of active involvement of industrial customers in the electricity markets will be demonstrated. Based on the obtained results, a business model will be developed and a roadmap for the implementation of DR for the market side and policy makers will be presented (DRIP, 2017).

The specific objectives addressed are (DRIP, 2017):

- Technical, ecological and economic evaluation for the industrial customer of the flexibility potential that is available in its energy consuming processes.
- Demonstration of the potential benefits for the customer due to the flexibility in energy consumption that will reduce CO_2 emissions while maximizing benefits according to external conditions and inputs (external weather conditions, market prices, balancing prices, etc.).
- Demonstration of the potential benefits that the customer's flexibility entails for energy retailers as well as electric network operators (transmission and distribution), e.g. network stability at peak feed-in of renewable energy sources.
- Definition of the certification prerequisites of the proposed processes, and development of a business model in order to facilitate market acceptance of DR services and products.
- Informing different target audiences on project advantages and risk, increasing the involvement of other industries, and spreading the concept at the national and international level.

Cassandra: EU

Cassandra is a software platform for assessing strategic decisions in electrical power systems by modelling several aspects of the demand side. More specifically, the Cassandra platform is a simulation-based, decision-support tool for energy market stakeholders, helping in the provision of insights in the development of their programmes and strategies.

The software platform has been tested in two separate pilot cases: a large commercial centre near Milan, Italy, and a multi-residential building at Luleå, Sweden.

The findings from both pilot cases indicated that CASSANDRA had a substantial impact on participants given that they increased their awareness of their electricity consumption, which lead to a more energy efficient behaviour.
In particular, both pilot cases showed that participants managed to decrease their electricity consumption during peak times, and thus reducing their overall electricity bills. The pilot interventions also showed that people who were less committed to energy efficiency in the beginning, later managed to increase their interest and engagement, thus confirming the general hypothesis that receiving information on actual energy consumption and related costs can increase interest in energy saving practices. (CASSANDRA, 2017).

2.1 Summary

Numerous pilot projects involving demand response have been undertaken in Europe, a sample of which have been highlighted above. The general conclusions appear to be:

- Potential for demand response exists in all sectors
- Technology to activate this potential exists, or can be developed.
- The demand response impact is typically predictable, and realised as expected.
- End-users are willing to participate in pilot projects, and few negative side-effects are reported, e.g. concerning comfort or production.
- For small end-users, automation is necessary.
- A positive side-effect has been that some end-users, enabled by the new monitoring equipment they were provided with, reduced their electricity demand due to a greater awareness of their electricity usage.
- The overwhelming barrier appears to be that the economic benefits associated with participating in demand response are too small. This highlights the fact that:
    - a) transaction costs need to be very small if demand response shall grow in volume
    - b) the full system value of flexibility must be unlocked and distributed to all parties in order to provide the proper incentive to participate.

3 Methodology for DR potential assessment

For electricity demand to be active as demand response, it must be technically possible. As illustrated below, the technical potential is large. However, in many cases the regulation is not in place, e.g. interval meters must be in place for end-users to be active in the spot market, and retailers must have relevant contracts available. This is typically not the case for small consumers (below 30 kW).

3.1 Methodology utilised for estimating technical potential

The technical potential simply describes if a certain type of electricity demand can be used as demand response, e.g. moved in time or shifted to/from another fuel. Consideration to regulation, economy or willingness of the end-user are not included here, but is part of the following potentials.

Classic demand response

Certain types of electricity demand, such as heating, cooling and pumping, are the most relevant candidates for demand response, while other end-uses, such as computers, lighting, and compressed air have a more restricted potential.

Into hours with low prices

When electricity prices are low (or negative) costs can be reduced by increasing the demand in these hours, and decreasing the demand in other hours. It may be easier to increase demand (e.g. change set-points) than the opposite. This is the case if the utilisation factor is low, e.g.10%. In heating or ventilation are increase for one hour, then demand will (automatically) be reduced in the following hour.

Away from hour with high prices

When price spike (high prices) occur, a response is to reduce demand. The benefit (€/MWh) can be higher in this situation, but only actual demand can be reduced.

Examples

It is estimated that 5-10% of the electricity for lighting can be controlled during high prices. This may be reducing light in marginal rooms, reduced street lighting or lighting for advertising in less important hours.

It is estimated that 20-25% of pumping can be controlled. This can be pumping in relation to heating systems, special production prosseses or pumping of fresh water into water towers. Pumps with variable speed drives can be controlled so they temporarily run at lower speed.

50-70% of commercial cooling and freezing can be controlled. This is normal practise in e.g. industrial cold storage.

15-30% of ventilators and blowers can be controlled. For variable speed drives of ventilators, the electricity demand is reduced more than linearly with the flow. Therefore, controlling the flow up and down may result extra electricity demand. With large price variation, it may still be attractive.

Fuel shift

In addition to traditional demand response, fuel shift can also take place. Fuel shift involves changing from one fuel to another fuel, e.g. from natural gas to electricity. Direct electric heating (including electric boilers for steam generation), heat pumps, infra-red panels, induction heating or mechanical vapour recompression (MVR) are examples of ways to deliver heat from electricity. Fuel shift can take place with large capacities.

It is estimated that 95% of the current heat demand in industry can be changed to electricity at low prices. This will require a dual supply system.

Fuel shift – examples

In Denmark, 600 MW of electric boilers in small district heating systems utilise electricity when the price is low. The boilers are active in the day-ahead market, regulating power markets and utilised as frequency controlled reserve. Typically, the boilers replace natural gas based CHP.

In Germany, the car maker Opel has begun operating a 40 MW electric boiler. The boiler operates in the balancing market. **(Platts, 2017)**

3.2 Moving from technical potential to realised - methodology

The next question is whether the economic incentive is considered to be attractive, e.g. current price variation in the spot market may be considered to be too small. Finally, it is up to the end-user to decide whether they are interested in demand response. This may include an evaluation of potential side effects of demand response (that may be positive or negative), as well as the willingness to invest time and money in demand response.

Regulation

Most large end-users (above 30 kW) in Lithuania can enter a spot price in the spot market or in the intraday market (Elbas). Other markets, like regulating power and reserves, are not yet developed.

Many households and small commercial end-users in Lithuania have a meter with two to four time periods. This allows for adjustment of the demand in relation to the grid tariff. The roll-out of smart meters are underway in Lithuania. In 2020, 40% of end-users are expected to have a smart meter – increasing to 100% in 2022.

It is recommended to periodically update what share of the total electricity demand that have the relevant meter infrastructure, and have the full access to relevant markets.

Economic potential

Today, the price variation in the Lithuanian electricity market (day-ahead) is modest. The relatively large pumped hydro unit helps reduce the price variation. More wind and solar power (in Lithuania and in neighbouring countries), may increase price variation.

The economic potential can be described as the potential that can be realised – assuming minimum transaction costs and rational end-users. It is recommended to monitor and periodically review the economic incentives for demand response in all relevant markets.

Potential: Willingness

Today, the concept of demand response is to a large degree unknown to end-users, and the realised volume may be lower than the economic potential.

3.3 Methodology summary

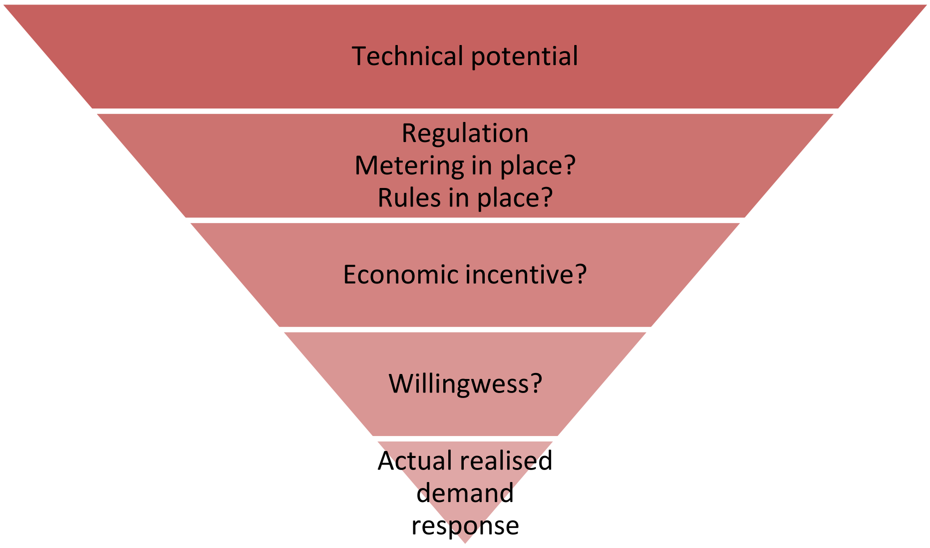

Figure 2: From technical potential to actual realised demand response.

In reviewing Figure 2, it should be noted that:

- The technical potential is related to the nature of the demand (some end-uses are more relevant for controlling). The potential can be divided into traditional demand response (moving demand in time) and fuel shift. The potentials are expected to develop slowly. Changes will happen, e.g. if heat pumps or electric vehicles are introduced in large numbers.
- Regulation is in the hands of Government, regulator, TSO and DSO. Meters and procedures for markets and ancillary services are important. It can be mapped which share of demand (for each main sector) can be active in e.g. the day-ahead market and as regulating power.
- The electricity market, including prices for ancillary services, are the drivers for the size of the economic incentive. The price volatility can the measured by a number of indicators, e.g.:
    - Range (min-max): Will describe the extreme values
    - Average, absolute hourly difference
    - Average, daily max-min difference
    - Number of hours with negative prices. Number of hour with low prices (e.g. below 10 €/MWh)
- Willingness is in the hands of the end-user. In a liberalised market, end-users can give priority to demand response as much (or little) as they find relevant. Willingness is motivated by the economic benefit, but can also be influence by lack of time, prior experience, tradition or personal views, including interest in environment and social issues.

The main drivers for development in the volume of activated demand response is – in the short term – expected to be the regulation and the economic incentive.

3.4 Inspiration from the US

Demand Response and Advanced Metering: US

It can be relevant to study the annual Federal Energy Regulatory Commission staff (FERC) report on demand response in the United States. The eleventh annual report on demand response and advanced metering by the FERC is based on publicly-available information and discussions with market participants and industry experts. The report addresses the six requirements, which directs the Commission to identify and review (FERC, 2016):

- Saturation and penetration rate of advanced meters and communication technologies, devices and systems;
- Existing demand response programs and time-based rate programs;

- The annual resource contribution of demand resources;
- The potential for demand response as quantifiable, reliable resource for regional planning purposes;
- Steps taken to ensure that, in regional transmission planning and operations, demand resources are provided equitable treatment as a quantifiable, reliable resource relative to the resource obligations of any load-serving entity, transmission provider, or transmitting party, and;
- Regulatory barriers to improved customer participation in demand response, peak reduction and critical period pricing programs.

The report estimates the 40.6% of end-users have a smart meter, and that US demand response programs have a potential of reducing the peak demand by 6.6%.

4 Demand response potential

This chapter presents the initial demand response potential results. Other activities in the project (survey and illustrative cases) will cast additional light on these subjects, and the results will therefore be updated thereafter.

4.1 Technical potential

The technical potential for classical demand response (movement of demand in time) has earlier been estimated for Denmark, and in Table 3 these estimates have been transferred to the Lithuanian context by adjusting the distribution of the electricity demand, i.e. in Denmark the % of electricity demand that goes to heating is higher, and the share for cooling and freezing in the household sector is lower (2nd column). The technical potential for a specific end-use (3rd – 6th columns) is expected to be the same in Lithuania as in Denmark.

The electricity consumption in households is 2–3 times larger in Denmark than in Lithuania (kWh/capita). This may influence the distribution of the electricity demand (2nd column). At present only the correction mentioned above has been done (heating, cooling and freezing).

The technical potential for demand response is estimated to be 32%, 21% and 18% respectively in households, the service sector and industry. However, metering is not in place to activate this potential – particularly for households and other users with a limited demand (regulation). Many end-users will find the resulting savings from demand response to be too small, and may not utilise the potential (incentive).

	Demand	DR potential	Hours	Days	Perma-nent	Total
	% of sector	% of demand	------ % of total sector demand ------			
Households						
Lighting	18%	5%	-	-	1%	1%
Pumping	6%	50%	1%	1%	-	3%
Cooling and freezing	22%	70%	15%	-	-	15%
IT	3%	15%	0%	-	-	0%
Other end-uses	8%	0%	-	-	-	0%
Food preparation	7%	0%	-	-	-	0%
Washing	15%	25%	4%	-	-	4%
TV	10%	0%	-	-	-	0%
Heating	11%	80%	9%	-	-	9%
Total	**100%**		**29%**	**1%**	**1%**	**32%**
Service sector						
Lighting	45%	10%	-	-	4%	5%
Pumping	5%	25%	1%	1%	-	1%
Cooling and freezing	15%	70%	11%	-	-	11%
Ventilation and blowers	12%	15%	2%	-	-	2%
Pressurised air	2%	5%	0%	-	-	0%
Other motors	5%	0%	-	-	-	0%
IT	9%	30%	3%	-	-	3%
Other end-uses	6%	0%	-	-	-	0%
Total	**100%**		**16%**	**1%**	**4%**	**21%**
Industry						
Lighting	11%	5%	-	-	1%	1%
Pumping	13%	20%	1%	1%	-	3%
Cooling and freezing	9%	50%	4%	-	-	5%
Ventilation and blowers	23%	30%	7%	-	-	7%
Pressurised air	11%	20%	2%	-	-	2%
Other motors	31%	5%	2%	-	-	2%
IT	1%	5%	0%	-	-	0%
Other end-uses	1%	0%	-	-	-	0%
Total	**100%**		**16%**	**1%**	**1%**	**18%**

Table 3: Technical potential for demand response. [Share of sector demand on specific end-uses most be updated to reflect Lithuanian demand! For households, the share of heating and cooking has been corrected]. (Ea Energy Analyses, 2015).

It is clear from Table 3 that the large majority of traditional demand response (shift of demand in time) is available for the very short term (hours).

Fuel shift

Table 4 lists the technical potential for fuel shift. The 2nd column indicates the % of energy demand that can be shifted from fuel (i.e. natural gas), to electricity for the listed process, during periods with low or negative electricity prices.

The ability to switch to electricity will typical require investment in an electric steam boiler or other equipment.

Meanwhile, the 3rd column displays the opposite, i.e. the % of energy demand that can be shifted from electricity to another fuel during periods with high electricity prices. In cases where electricity is used in heating or drying for example, if is often possible to shift to another fuel. This will also require new investments.

	Fuel -> Electricity	Electricity -> Fuel
Households & service sector		
Space heating	100%	50%
Industry		
Heating, boiling	95%	50%
Drying	80%	50%
Evaporator	95%	-
Distillation	95%	-
Burning	25%	-
Melting	25%	-
Other heating	33-42%	50%

Table 4: Technical potential for fuel shift. (Ea Energy Analyses, 2015)

Back-up generation

Many large end-users, such as airports, hospitals, IT centres, and others with critical functions, have their own generators that can act as back-up if the grid fails. There is currently no overview of the installed capacity of back-up generators in Lithuania. However, as an indicator, it can be noted that in Denmark there is roughly 300 MW of back-up capacity (with 100 MW in public institutions). (Ea Energy Analyses, 2008). Taking the size of the electricity demand into consideration, there is likely in the order of 100 MW of back-up generation in Lithuania. The survey and the illustrative cases will give more information about the installed capacity of backup generation.

The most relevant market for backup generation is regulating power. In this market, there are more high prices than in the day-ahead market, and the duration on activation is often short.

4.2 From technical potential to activated demand response

The surveys (WP2) and illustrative cases (WP3) will provide additional insight into the current willingness of end-users to be active with demand response. When this is completed, it will be possible to use updated values from Table 3 and Table 4, combined with values from Table 5 and Table 6, to estimate demand response potentials.

	TOU	DA/ID	Reg. power	Ancillary service
Households	50%	-	-	-
Service sector	100%	33%	-	-
Industry	100%	80%	-	-

Table 5: Impact of regulation. Factor to be multiplied to the technical potential. Current values are illustrative. Values will be corrected during the project.

	Economic attractive (% of technical potential)	Willingness (% of economic potential)
Households	10%	33%
Service sector	10%	20%
Industry	10%	10%

Table 6: Impact of willingness. Factor to be multiplied to the technical potential, times impact of regulation (Table 5). Current values are illustrative. Values will be corrected during the project.

4.3 Demand response services identification and classification

DR services

If demand can be controlled (e.g. increased or decreased for one hour) it can in theory be activated in the electricity market (day-ahead or intra-day) or as regulating power (a TSO product) or used as voltage control in a distribution grid. The type of control mechanism and documentation may vary. And the type of contract will vary.

There exists a sort of hierarchy:

- Demand response can be active in the day-ahead and intra-day market as soon as the meters and standard market procedures are in place. The reaction can be voluntary and the retailer will act as an aggregator. For large users, this can take place today. In many countries, meters and procedures are still not in place for small users (households).
- Being active as regulating power are more complex, e.g. a plan before and after activation must exist. There are numerous examples of large demands used as regulating power, e.g. in the Nordic countries.
- Controlling demand for voltage control in distribution grids is realistic, but exist only in pilot projects, today.

Demand response can also deliver primary reserves (e.g. as autonomous frequency controlled reserves). This has been demonstrated in pilot projects.

Classification

In terms of allocating potential DR services according to load type, the vast majority of Lithuanian electricity demand comes from the Industry, Services, and Household sectors (see Figure 3).

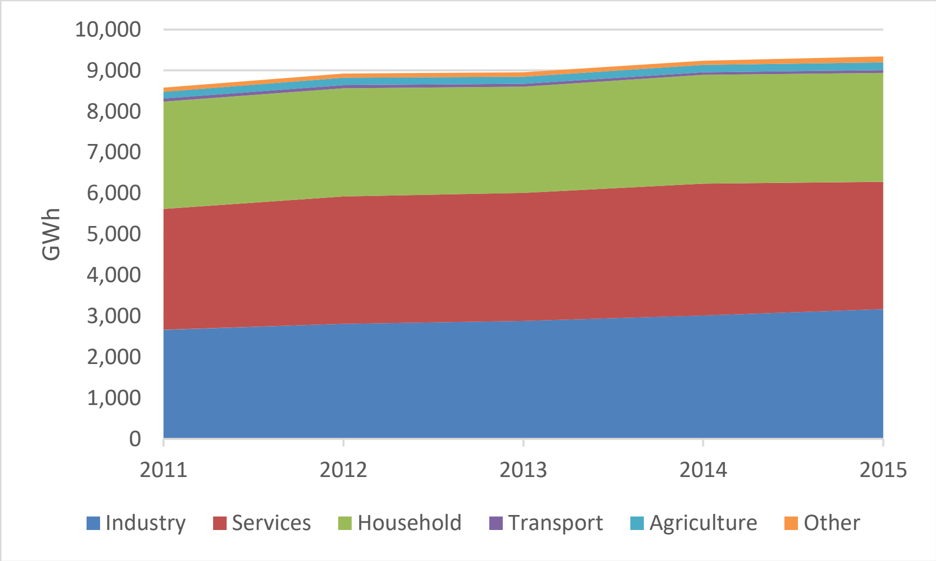

Figure 3: Overview of historic electricity demand in Lithuania according to sector

Returning to Table 3, indications of which DR services the individual loads may be capable of a delivering are now provided in Table 4. In addition, estimates of the % of load that are connected to a local grid, i.e. potentially available to a DSO, are also indicated. All loads are assumed to be available to the TSO. However, large demand is likely to be easier to activate (less need for aggregation).

	Demand	DR potential	DSO	Day ahead	Intra-day	Reg Power	Anc. services
	% of sector	% of demand					
Households							
Lighting	18%	5%	100%	x	-	-	-
Pumping	6%	50%	100%	X	X	X	X
Cooling and freezing	22%	70%	100%	X	X	X	X
IT	3%	15%	100%	-	-	-	-
Other end-uses	8%	0%	100%	-	-	-	-
Food preparation	7%	0%	100%	-	-	-	-
Washing	15%	25%	100%	X	X	X	X
TV	10%	0%	100%	-	-	-	-
Heating	11%	80%	100%	X	X	X	X
Service sector							
Lighting	45%	10%	75%*	x	x	x	x
Pumping	5%	25%	75%*	X	X	X	X
Cooling and freezing	15%	70%	75%*	X	X	X	X
Ventilation and blowers	12%	15%	75%*	X	X	X	X
Pressurised air	2%	5%	75%*	X	X	X	X
Other motors	5%	0%	75%*	-	-	-	-
IT	9%	30%	75%*	X	X	-	-
Other end-uses	6%	0%	75%*	-	-	-	-
Industry							
Lighting	11%	5%	15%*	x	x	x	x
Pumping	13%	20%	15%*	X	X	X	X
Cooling and freezing	9%	50%	15%*	X	X	X	X
Ventilation and blowers	23%	30%	15%*	X	X	X	X
Pressurised air	11%	20%	15%*	X	X	X	X
Other motors	31%	5%	15%*	X	X	X	X
IT	1%	5%	15%*	X	X	-	-
Other end-uses	1%	0%	15%*	-	-	-	-

*Table 7: Classification of loads according to potential DR services, and the estimated % of the load that is connected to a local grid. Small x's indicate limited potential. *Initial estimate, will be investigated further during the course of the project.*

5 Technical characteristics of DR services

The purpose of this section is to outline some of the required technical characteristics of demand response (DR) services (i.e. start time, duration, regularity etc.) that are connected to transmission and distribution grids, both from a short term, and a longer-term perspective. The chapter structure entails providing a brief overview of a potential DR market, then outlining the technical characteristics involved with participating in the respective market. In addition, while the issue of technical requirements for DR services will be the focus of WP5, the basic technical requirements for participation in each of the markets will also be touched upon.

5.1 Day-ahead market

Day-ahead market overview

The central Nordic energy market is the spot market (Nord Pool Spot) where a daily competitive auction establishes a price for each hour of the next day. The trading horizon is 12 - 36 hours ahead, and is done in the context of the next day's 24-hour period. The system price and area prices are calculated after all participants' bids have been received before gate closure at 13:00 EET.

Participants' bids consist of price and an hourly volume in a certain bidding area. Retailers bid in with expected consumption, while the generators bid in with their production capacity and their associated production costs. Different types of bids exist, e.g. bids for a specific hour or in block bids, which exist in several variations.

One type of bid is of special interest in relation to demand response: With the *Flexi order,* the bidder offers to reduce demand in a number of consecutive hours if the price is above a certain price. E.g. a bid can be *"I can reduce the demand with 10 MW in any hour, if the price is above 100 €/MWh."* The special feature with this bid it that the Nord Pool optimisation finds the relevant hours. If can also be used with generation.[1]

Determining the Spot Price

The hourly spot price is determined as the intersection between the aggregated curves for demand and supply for each hour – taking the restriction imposed by transmission lines into account. Figure 4 illustrates the formation of the system price on the spot market as a price intersection between the purchase and sale of electricity.

[1] See: www.nordpoolspot.com/TAS/Day-ahead-market-Elspot/Order-types/Flexi-order/

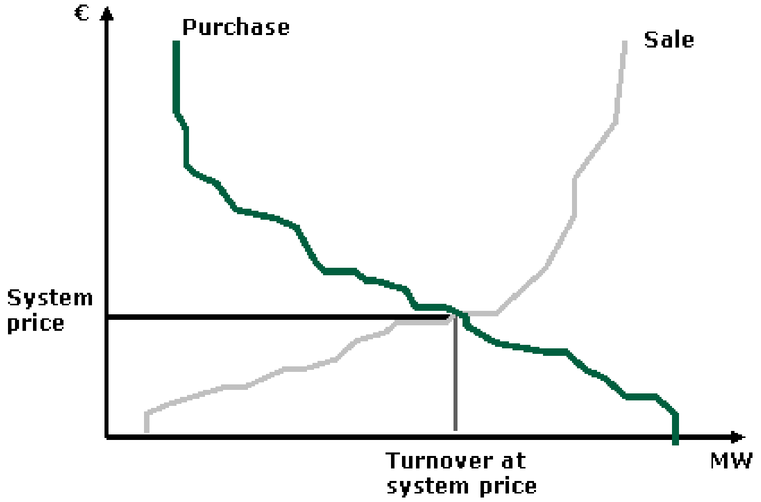

Figure 4: The formation of the system price for electricity on the Nord Pool Spot market (Nord Pool, 2014)

Bidding Areas

Countries are split into separate price areas

In order to manage grid congestions, the Nordic exchange area is divided into bidding areas. The bidding areas are consistent with the geographical area of each of the TSOs, with some countries divided into a number of areas to reflect regional market differences and/or constraints in the transmission system. For example, Norway is currently split into five price areas, Sweden into four, and Denmark into two.

Figure 5: Current bidding areas in the Nord Pool markets (Nord Pool, 2017a)

Price areas implicitly incorporate transmission capacity

Participants must make their bids according to where their production or consumption is physically located in the Nordic pricing areas. In this way, the transmission capacity between the different bidding areas is implicitly auctioned via the area spot price calculation. Thus, whenever there are grid congestions, different price areas are formed. The participants' bids in the bidding areas on each side of the congestion are aggregated into supply and demand curves in the same way that the System price is calculated.

The alternative to using the spot market is to trade bilaterally. However, bilateral trade can only take place within a price area. Nord Pool controls the use of the transmission capacity between price areas.

Nord Pool and several other markets are closely coordinated (see Figure 6), as a bid in Norway or Lithuania can influence the spot price all the way to Portugal – dependent on the direction of the flow and congestion in the transmission grid.

Figure 6: Coordination of day-ahead markets (2014). ENTSO-E[2].

Elspot trade in Lithuania

In 2016, Lithuania purchased nearly 12 TWh of electricity via the Nord Pool Elspot exchange, and while selling over 6 TWh (Nord Pool, 2017b). This corresponds to an average purchase of 1,365 MWh/h, and sales of 708 MWh/h. The development in Lithuanian Elspot traded volumes on a monthly basis from January of 2013 through to June of 2017 are displayed in Figure 7.

[2] See: www.entsoe.eu/about-entso-e/market/enhancing-regional-cooperation/Pages/Regional%20Cooperation.aspx

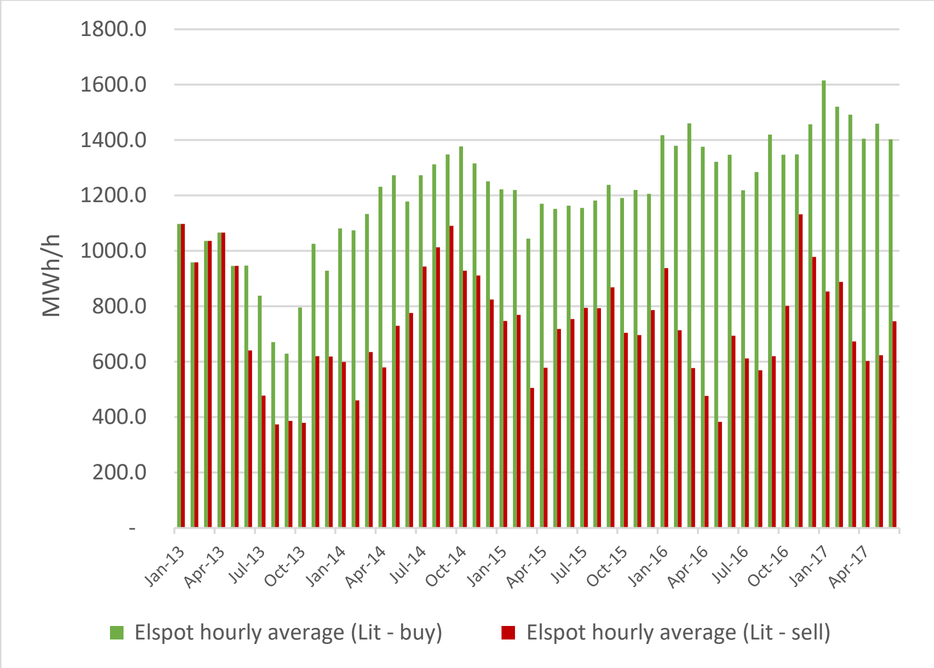

Figure 7: Traded electricity volumes on Nord Pool's Elspot for Lithuania, displayed as hourly averages on a monthly basis from January of 2013 through to June of 2017 (Nord Pool, 2017b).

Day-ahead technical characteristics

End-user electricity price is the hourly spot price + a small mark up

End-users with hourly settlement can enter a contract with the retailer where the hourly price is equal to the spot price, plus a small mark up. Typically, the contract can be with free volume, meaning that the end-user does not have to report the volume of demand beforehand. Such users can receive the spot price (typically before 14:00 the day before), and can adjust their demand accordingly in order to reduce their electricity bill. This will typically involve moving demand in time (to hours with low prices, and away from hours with high demand).

The technical characteristics of this DR service can thus be summarised as starting in reaction to the spot prices published the previous day, occurring daily, and a duration that is price dependent (though split into one-hour units).

Day-ahead technical requirements

The only technical requirement required to participate in the day-ahead market is an interval meter. Furthermore, the market system must allow hourly settlement for these users.

In order for the end-user to easily adjust their electricity demand according to the day-ahead published prices, it would also be necessary for the end-user to receive the prices, and/or have some electricity devices that can respond automatically. Examples in the commercial or industrial sectors include heating, cooling, or pumping, while a dishwasher or electric vehicle could be relevant examples for a residential user.

5.2 Intraday markets

Intraday market overview

Given that up to 36 hours can pass from the time the spot price is fixed, until the actual hour of operation, deviations in production and demand plans do occur. Deviations can arise due to e.g. unforeseen changes in demand, tripping of generation or transmission lines, and/or from updated prognoses for wind power generation.

Such deviations can be mitigated during the operational day via entering into hourly contracts in the Elbas market, where electricity can be traded from the time the spot market closes, up till 1 hour before the operating hour. Nord Pool facilitates Elbas trades by matching buyer and seller bids.[3] In this sense, the Elbas market differs from the Elspot market, as there is not one single clearing price, but instead the price of each trade is the result of matching a buyer and seller bid (like the stock market).

Market makers covering the Swedish and Finish price areas, ensures that there are always bids on these markets with a defined spread between buy and sell prices.[4]

Liquidity in the Elbas market is limited relative to the Elspot market. For example, the average traded volume for the entire Nordic area in 2016 was only 560 MWh/h (as compared to the more than 44,000 MWh/h on the Nord Pool Spot market). As such, for the entire market area, there is roughly 1.2% trade on the intraday market each time one unit is sold on the day-ahead market. This can be seen from Figure 8, which displays the average hourly traded volumes on the Elspot and Elbas markets for the entire Nord Pool market area per month from January of 2013 until June of 2017.

[3] The price is set in what Nord Pool describes as "a first-come, first-served principle, where best prices come first – highest buy price and lowest sell price" **Invalid source specified.**.
[4] See: www.nordpoolspot.com/globalassets/download-center/intraday/market-makers-elbas.pdf

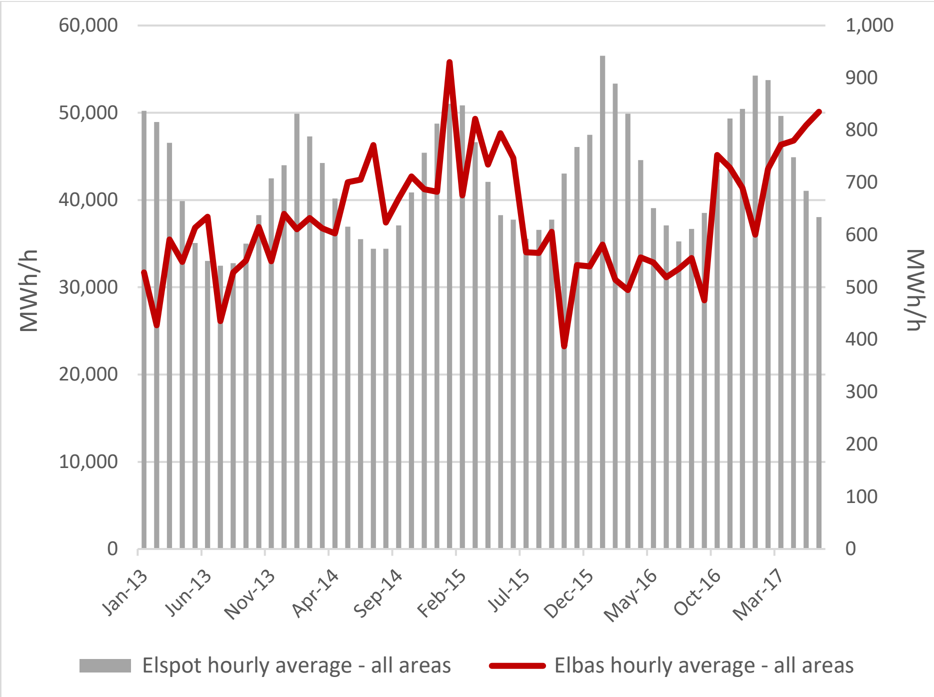

Figure 8: Average hourly traded volumes on the Elspot (grey bars and left axis) and Elbas (red line and right axis) markets for the entire market area per month from January of 2013 until June, of 2017. (Nord Pool, 2017b)

Lithuania started trading in the Elbas market in 2014, and as Figure 9 indicates, the volumes traded have increased steadily since this time, and Lithuania now has a ratio of Elspot vs Elbas trade similar to the area average indicated above.

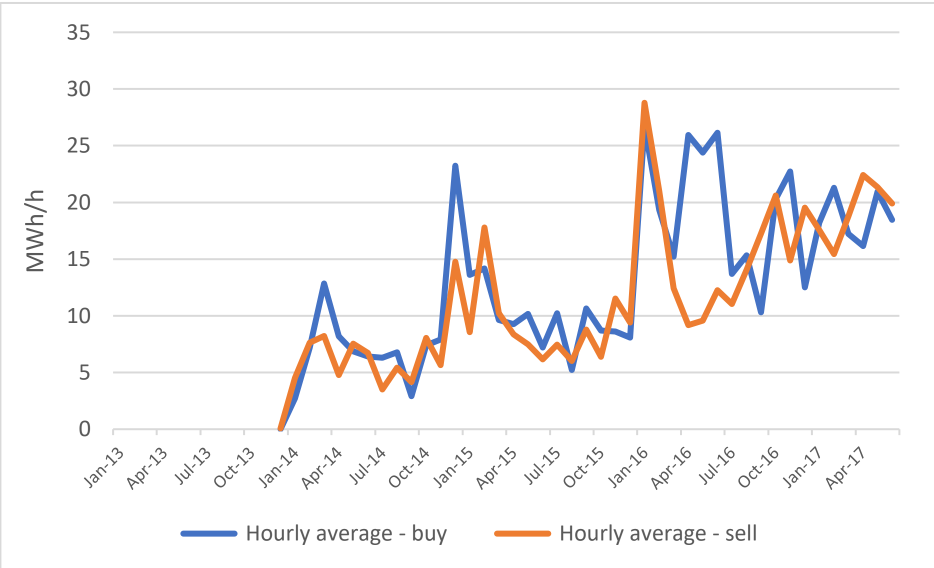

Figure 9: Average hourly traded buy and sell volumes on the Elbas market for Lithuania per month from January of 2014 until June of 2017 (Nord Pool, 2017b).

Intraday technical characteristics

Day-ahead trade involves prices that are known in advance, with the end-user simply having to adjust their electricity demand accordingly. Intraday trade is different, because the prices are not known beforehand, and the end-user must therefore be made aware that there is potentially an attractive offer to increase or reduce their electricity demand/supply.

The balance responsible party (or a retailer or an aggregator) can facilitate the activation of demand response. The balance responsible party (BR) could do so in a number of different ways, a few examples include:

- Having access to direct control of an electricity production or consumption device. In this case, the BRP could for example enter into an agreement that provides it with direct control over a device, and thus have the option to increase or decrease its electricity demand.
- Sending out a concrete offer to one more of its customers to increase or decrease its consumption/production. This option would require that the customer has previously quantified how much electricity it requires in the spot market, and can thereby deviate from this demand/supply in order for the BRP to buy/sell this quantity in the Elbas market. For example, if the customer had indicated that it would use 100 MWh during a given hour, it could later accept an offer to increase/decease this amount by 10 MWh/h, thereby allowing the BRP to buy/sell 10 MWh in the Elbas market.
- Sending out an updated electricity price. Based on historical data, the BRP would have a good sense of how much this updated price will affect the demand of its customers, and thereby the BRP can buy or sell this quantity of electricity in the Elbas market.

The technical characteristics of providing demand response via Elbas are thus similar to that in Elspot. The primary difference is that the request to activate will come with shorter notice. In addition, the number of activations are less frequent. Lastly, the duration of the activation will vary, but is currently made up of one-hour blocks.

Intraday technical requirements

As a minimum, end-users must have an interval meter and use hourly settlement, but there are also other required technical requirements, depending on the customer and market set up.

Direct control – required technology

The BR would need to have control over a specific device.

As an example, an industry may have a 10 MW electric boiler. It is attractive to use this boiler if the electricity price is below a certain price level, and relates to the efficiency of, and fuel price for, the alternative boiler. The BRP could remotely activate the boiler each time this price requirement was met. The reference situation (i.e. whether the electric boiler will be in use), will be determined by the spot price, if for example this is high, then the day-ahead plan will involve use of the alternative boiler, and if the day-ahead price is low, then the electric boiler would be used. If an Elbas price becomes available that is lower than the pre-determined price threshold, and the boiler was not in operation, then it could be activated. The reverse would also be true, i.e., if the electric boiler is in operation, and a high Elbas price is available, then the electric boiler could be shut off, thus allowing for the sale of some electricity. The end-user in such a setup be free to define the 'threshold' price and whether the service should be available at all times. The BR meanwhile, would just be informed regarding the current status.

For smaller users, this set up could also be established via a Virtual Power Plant (VPP) system covering many end-users, where the BR could for example control various heating/cooling units according to an agreement entered into with the owner of the unit.

Send out a concrete offer – required technology

This setup would require sending an offer, accept of the end-user, accept by the market and then activation. As such, the end-user would require technology that could both receive and send signals. Depending on the end-user, this could still be a semi-automated process.

Updated electricity prices – required technology

This option would simply require the BRP customers to be able to receive an updated price signal, and to adjust their electricity demand accordingly. These are relatively simple technical requirements, and the following examples for various segments have already been undertaken in commercial and/or demonstration projects.

Within industry, heating, cooling, and pumping are all examples that can be adjusted based on incorporating updated price signals into the plant's Supervisory Control and Data Acquisition (SCADA) system. Bornholms Forsyning's wastewater treatment plant in Denmark for example partook in a demonstration project where various pumps, circulation mechanisms, etc. were incorporated. These non-critical loads were in the form of induction motors that pumped water or moved cleaning brushes. A price signal was sent to the plant's SCADA system, and the SCADA used this signal to control selected processes, while giving first priority to ensuring that process constraints were not violated (Rasmussen, 2013).

For residential end-users, electric vehicle (EV) and heat pump owners are prime candidates for participating in the Elbas market, as they would simply have to install software that can receive updated price signals, and a simple algorithm and control system could then adjust the electricity demand accordingly. Both EV and heat pump owners could for example chose to shift their demand a few hours in time without altering the welfare of the end-user.

5.3 Balancing and ancillary services markets

Overview of balancing, reserves and ancillary services

Electricity production and consumption always have to be in balance, and after the close of the Elbas market an hour before the operating hour, the task of balancing the two is left to the TSO, which purchases a number of ancillary services, which can largely be grouped as follows:

- Primary reserves: Often known as frequency reserves, these supply an automatic adjustment of electricity production (or demand) based on the deviation in system frequency. Reactions here must be rather quick (within 5-30 seconds depending on the type).
- Secondary reserves: This is an automatic adjustment to secure planned power exchange with neighbouring areas and/or deal with large electricity balance disruptions. The purpose is to release and restore the primary reserves. Here the reaction must be within 30 seconds to several minutes.
- Tertiary reserves: Often referred to as regulating power, it is manual ordered reserves that can release and restore the secondary reserves. These must react fully within 15 minutes. Regulating power can receive payment for simply being available if necessary (a per MW payment), and/or payment for the amount of electricity supplied if activated (a MWh payment).
- Short-circuit power, reactive reserves and voltage control: these various services ensure a stable and safe power system operation. These system services will not be focused on in this report as they are likely less suited to demand response.

The ENTSO-E terminology for the various reserves are displayed in Table 8.

Function	ENTSO-E Terminology
Frequency stabilisation (Primary reserve)	Frequency Containment Reserves (FCR)
Frequency Recovery (Secondary reserve)	Frequency Restoration Reserves (FRR-A)
Balancing (Tertiary reserve)	Frequency Restoration Reserves (FRR-M) and Replacement Reserves (RR)

Table 8: Overview of the various system services

Additional descriptions of primary and secondary reserves, taken (and translated) from the Danish TSO's (Energinet.dk) website, are provided in the table below.

Primary reserves (Frequency Containment Reserves - FCR)	Primary reserve consists of production or consumption devices that automatically respond to frequency changes in the network using local frequency meters. Through the use of up or down regulation, the devices balance supply and demand in the network, so the frequency is stable around 50 Hz. In popular terms, the primary reserve "fine tunes" the frequency rate, and must therefore be able to be activated with few seconds' notice. The primary reserve should only be used to deliver effect until the secondary and manual reserves take over. The speed of delivery must be within 15 to 30 seconds, and the reserve can remain active for up to 15 minutes. Activation of the primary reserves take place automatically according to frequency deviations.
Secondary reserve (Load Frequency control - LFC)	Secondary reserve, in the European context called FRR-A, is an automatic 15-minute power control, also called Load Frequency Control (LFC). The reserve is essentially active during the entire day of operation and fulfils three functions. First, it frees up the primary reserve by bringing the frequency back to 50 Hz after the primary reserve initially stabilised it. Secondly, it equalises the imbalances that are too small for regulating power. Thirdly, it restores the agreed balance on the interconnector to Germany.

Table 9: More detailed descriptions of the automatic reserves purchased by Energinet.dk. (Energinet.dk, 2016)

In terms of the amounts of various reserves that will be required in Lithuania when it is no longer synchronised with Russia, it can be relevant to compare the amount of reserves that a well-connected country such as Denmark currently purchases. Denmark has an annual electricity demand of approximately 34 TWh, thus nearly 3.5 times that of Lithuania.

Denmark is actually split into two synchronous zones, with the Eastern portion (DK 2) being synchronised with the Nordic countries, and Western Denmark

(DK1), being synchronised with Germany in the large Regional Group Continental Europe. The table below displays the current ancillary services acquired in Denmark and Lithuania. From a Lithuanian perspective, the Western Denmark figure are likely more relevant, because it is most likely this system that Lithuania will be synchronised with.

Reserve type		Amount currently purchased (Amount purchased outside of Denmark)	Notes
West Denmark (DK1) – Synchronous with Germany and Continental Europe			
	Primary reserves (Frequency Containment Reserves - FCR)	+/- 23 MW* (10 MW via Skagerrak 4)	*Recalculated each year
	Secondary reserve (Load Frequency control - LFC)	+/- 100 MW (100 MW via Skagerrak 4)	
	Manual reserves	+ 268 MW	Daily auctions
East Denmark (DK2) – Synchronous with Sweden and the Nordic countries			
	Frequency-controlled normal operation reserve (FNR)	+/- 22 MW* (22 MW via SE/DKK market)	Recalculated each year
	Frequency-controlled disturbance reserve (FDR)	+ 180 MW (37 MW* via SE/DK market) (75 MW via Kontiskan: DK1-SE) (50 MW via Kontek: DK2-DE) (18 MW via Storebælt: DK1-DK2)	Recalculated on an ongoing basis
	Manual reserves	+ 630 MW	Energinet has entered into contracts with 5 suppliers for 2016-2020 for part of the required volume
Lithuania (LT) – Synchronous with Latvia, Belarus, Kaliningrad and IPS/UPS			
	Primary reserves (Frequency Containment Reserves - FCR)	0 MW	No requirements. The service is delivered by IPS/UPS
	Secondary reserve (Load Frequency control - LFC)	0 MW	
	Manual reserves	400 MW	Recalculated yearly
	Other reserve (12 hours notice)	484 MW	Recalculated yearly

Table 10: Current ancillary service requirements in Denmark and Lithuania. Figures in each cell indicate the value for up (+) and down (-) regulation (where applicable). The figures in brackets indicate the amounts that are purchased via transmission lines and/or a Danish/Swedish market. Please note that short-circuit power, reactive reserves, and voltage controls are not included. (Energinet.dk, 2016) and (Litgrid, 2017).

The required amounts listed in the table can vary from year to year, and many can also vary from hour to hour over the course of a year.

Balancing and ancillary services technical characteristics

Regulating power

Demand response as regulating power

Regulating power, also known as tertiary reserves, is an increase or decrease in demand (or generation) that can be activated within 15 minutes. Regulating power is activated manually by the local TSO. The typical procedure for regulating power is designed for generators, however, demand can also provide the same services in terms of improving the electricity balance in the system.

Currently, regulating power has a minimum bid size of 10 MW in the Nordic countries, must be able to maintain an activation for up to 45 minutes, and requires a plan for the controllable load and real-time metering. In addition, the bidding process in itself requires several active actions. First a bid must be made, then if chosen the supplier notified, and finally the actual regulation must occur. This is an undesirably heavy process for smaller resources, and for the small consumers, the 10 MW minimum requirement is impossible, and the cost of the other requirements is prohibitive.

The Nordic TSOs have indicated that in the future, many of these restrictions will be lifted, including the potential for:

- Allowing for ex-post verification instead of real-time measurement.
- A reduction in the minimum bid size
- Introduction of some relief from firmness (i.e. allowing for roughly the amount of energy asked for by the TSO)
- Implementation of automatic bids

In addition, a future with a greater variation of bids could benefit both TSOs and demand response providers. For example, with automation it would be possible for a large number of end-user units to respond almost immediately to a price signal or request. With a sufficient number of these units in its portfolio, an aggregator could deliver regulating power extremely quickly, and a shorter activation notice has greater value for a TSO than a longer activation notice. It can also be noted that some types of demand (e.g. heat pumps, direct electric heating) are very suitable for short regulations. While some generation would have difficulties with very short regulation – this is perfect for heat devices. These two aspects could lead to new categories of bids, i.e. with differentiated activation and duration times, thus providing TSOs with more balancing tools at their disposal.

Automatic reserves

Demand response as automatic reserves

Demand response can also act as automatic reserves, e.g. primary or secondary reserves. Primary reserves are directly controlled by the frequency. No communication is needed to activate this type of reserve. For example, an electric boiler or a steel plant can adjust their electricity demand according to the frequency variation in the grid.

Primary reserves must react in seconds, and this can easily be achieved by certain types of demand, e.g. thermal loads where there is no mechanical inertia. The demand can be active in the complete frequency range, or only at extreme frequencies (e.g. outside the normal frequency range: below 49.9 Hz and above 50.1 Hz).

The current technical requirements therefore include being able to react within seconds, maintaining the activation for up to 15 minutes, and being able to provide this service numerous times during a day if needed.

Balancing and ancillary services technical requirements

Regulating power

The required technology to provide regulating power would be very similar to that described in the previous section for the Elbas market, and would again depend on whether it was a direct control set up, or a system where the end-user received an updated electricity price, and then reacted to this price within a very short time frame.

An example of the latter was the Flexpower project that ran from 2010 to 2013, where a field-test with electric heating and bottle coolers demonstrated that a price signal based communication system can produce a predictable and reliable demand response (Ea Energy Analyses, 2013). [5] In this study, the only technology required was a communication system to send and receive the price signal, and a simple local controller that would then determine whether an end-user device should alter its current state of electricity usage. In addition, it is also necessary to measure the electricity usage on a 5-minute basis, though it is not necessary to relay this information in real time, as it can instead by done on for example a monthly basis for billing purposes. In order to improve the Balance Responsible's (BR) understanding of the response to the price signal, it could be cost-effective to also have online metering at a

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[5] For more on the Flexpower project, please see: http://ea-energianalyse.dk/projects-english/1027_flexpower_market_design.html

small % of the end users, thus providing the BR with updated estimates of their customers electricity demand.

Automatic reserves

In terms of the technical requirements, communication equipment is not required, only a simple device to measure the frequency is required. In addition, the end-user must have some form of automation in place that can quickly alter the consumption pattern of the electric devices in question. Industrial process could include pumping, commercial processes include heating and cooling, and residential examples include electric vehicles and heating and cooling.

Lastly, monitoring whether or not a unit has provided the agreed service can be done by random checks.

An example of a project that demonstrated the ability of using various electricity consuming appliances to supply frequency control was the research project entitled "Electricity demand as frequency controlled reserve" (Rasmussen, 2013).[6]

In Finland, the TSO Fingrid has acquired 456 megawatts of frequency controlled disturbance reserve for 2017, and about half of this comes from demand response (Fingrid, 2017).

5.4 DSO perspective on demand response

Demand response is relevant in relation to congestion in the transmission grid, e.g. demand can react when congestion leads to very high or low prices in a price area. This can take place in the day-ahead market, intra-day market or in relation to ancillary services. Demand response may also play a role in relation to capacity utilisation of distribution grids – however many conditions are specific for distribution grids.

Well-designed frameworks may delay the need for expansion of distribution grids.

Demand response may also – potentially – create challenges for distribution grids. For example, after a long period with high prices (e.g. in the day-ahead market), demand may be held back and released when normal prices occur. The same may occur with very low or negative prices. This may, in unfortu-

[6] For more on the Electricity demand as frequency controlled reserve project, please see: http://www.ea-energianalyse.dk/projects-english/927_electricity_demand_as_frequency_controlled_reserve.html

nate situations, lead to an extraordinarily high demand and overloading of distribution grids. Without demand response, e.g. charging of electric vehicles will vary a lot from house-to-house and the total load will be smoothed.

Time-of-use (TOU) tariffs are often used for distribution grids, and are a simple way to motivate demand to move away from peak periods. Very simple control systems (or none at all), are needed for end-users to adapt to a TOU tariff.

Distribution tariffs may (in the future) have *dispatchable* elements. Critical days can be announced, e.g. the day-ahead, and higher prices can be charged for using the distribution grid. The French Tempo tariff is an example of such a *Critical peak price.*

Note that distribution tariffs and electricity contracts must be added together, and in some occasions the distribution tariff may increase the motivation for demand response, while in other cases, the two may counter act each other.

The possibility to create a local market for demand response for controlling demand in distribution grids similar to the Nord pool day-ahead market does exist, but is not without its challenges (Ea Energy Analyses, 2014). The success of such a design will depend on the number of active participants. If a radial distribution line is in danger of being overloaded, a price signal could motivate users to reduce demand – and local generators to generate more (e.g. users with PV in combination with battery). However, often only a few participants may be located on a specific line. An alternative to a traditional market setup is for the grid company to enter bilateral contracts, where the end-user allows the grid company to disconnect (part of the demand) in critical situations.

Control of voltage to activate demand response

A 2013 report suggested a system to achieve demand response in a distribution grid (Bhattarai, Bak-Jensen, Mahat, & Pillai, 2013). The idea is to control the voltage (within the accepted limits, typically +/-10%) to increase or decrease the demand. Since different types of demand react differently to changes in voltage, the relationship between voltage and demand is estimated for the individual distribution grid. This information can then be used to manipulate the demand, e.g. during peak hours. Note that this will affect all customers connected to the grid, so it can be characterised as a non-market solution. However, since the contracted voltage levels are respected, it may be a relevant option in congested distribution grids.

Other grid needs

Distribution grids may have challenges in maintaining voltage. New demand, such as electric vehicles, or new generation, such as PV units, may mean that the grid will be operated differently in the future compared to what it was originally designed to.

Distribution grids may experience voltage problems, e.g. with a weak grid or in situation with a significant decentral capacity of PV capacity. With a weak grid, high demand may lead to situations with under-voltage. Here demand response can be used to maintain voltage be delaying demand. In a distribution grid with a large share of PV, over-voltage can occur when PV generation is high. Several options exist to avoid over-voltage (He & Petit, 2016):

- PV inverters can be controlled to adjust the reactive power
- PV's active power can be curtailed
- Demand can be increased (demand response)

In the LINEAR project, a simple control was tested: When voltage levels approached an upper limit, additional consumption was activated, and when voltage levels approached a lower limit, consumption was either switched off or delayed. Note that the control can be implemented autonomously, i.e. no communication is needed to active the control.[7] A maximum reduction of voltage problems in the field test compared to the reference case without voltage control was expected to be 30%. (Cardinaels & Borremans, 2014).

5.5 Summary

There are a number of different markets that demand response services can participate in, with varying technical requirements posed by each market. Two of the most important characteristics in this regard are the activation response time and activation duration. The figure below illustrates these two elements by displaying the ramp rates and timeframes for the various services and markets.

[7] This is similar to frequency controlled demand used as primary reserves (Rasmussen, 2013). In the LINEAR project only on/off control has been tested. Note that more demand can be included if change of set-point are also used. For a freezer or refrigerator changing the set-points are more "friendly". Only the units that are close to the set point will be affected. In this way comfort impact is minimised and the compressors are protected against short stot/start cycles, that may be harmful for the compressor.

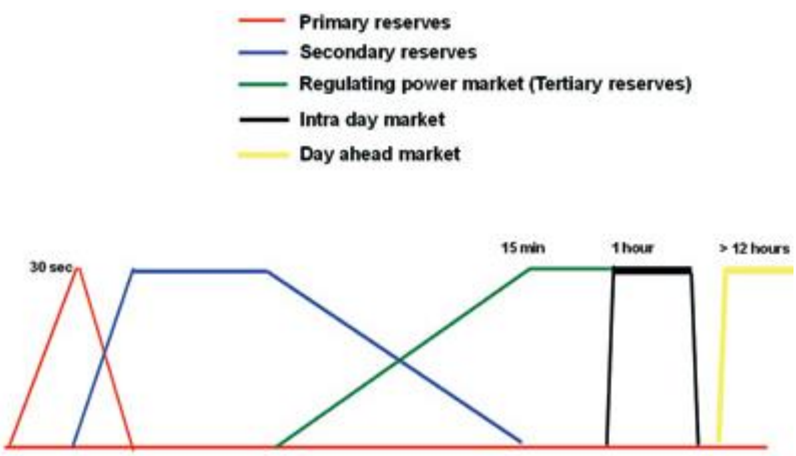

Figure 10: Timeframes and ramp rates for the various reserve types.

Table 11 below summarises the most relevant technical characteristics (start time, duration, regularity, etc.) for the various DR services described today, and estimates for the longer term.

DR Service	Activation time		Activation duration		Bid size / Trade lot		Activation regu-larity	
	2017	2025	2017	2025	2017	2025	2017	2025
Primary reserve (FCR)	30s	30s	15 min	5 min?	0.3 MW	0.1 MW?	Hourly+	Hourly+
Secondary re-serve (FRR-A)	15 min	5-15min?	contin-uously	60 min?			Hourly+	Hourly+
Tertiary reserve (FRR-M) & (BR)	15 min	5-15min?	60 min	15-60 min?	10 MW	1 MW	Daily+	Daily+
Intra-day	>1 hour	15 min?	15 min	15 min?	0.1 MW	0.1 MW	Daily	Daily
Day ahead	>12 hours	>6 hours?	60 min	30-60 min	0.1 MW	0.1 MW	Hourly	Hourly

Table 11: Overview of the various system services and their technical characteristics.

As can be seen from the table, it is assumed that the technical characteristic for the majority of the markets relevant for DR will be loosened going for-ward, thus becoming better suited for DR. This includes smaller bid sizes, shorter gate closer times, shorter activation durations, and a range of activa-tion notice times, all of which will allow for DR to play a more significant role going forward.

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