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Demand Side Management − Providing Flexibility to Europe’s Electricity Systems and Markets

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Glossary

ACER	Agency for the Cooperation of Energy Regulators
APG	Austrian Power Grid
BRP	Balance Responsible Party
BSP	Balance Service Provider
CCP	Combined-Cycle Power Plant
CEER	National Regulatory Authorities in the Council of the European Regulators
CHP	Combined Heat and Power
COP21	21st Conference of the Parties
CPP	Critical Peak Pricing
DA	Day-Ahead
DG	Distributed Generation
DR	Demand Response
DSM	Demand Side Management
DSO	Distribution System Operator
DSR	Demand Side Response
ED	Electricity Demand
EEG	Erneuerbare-Energien-Gesetz
ENTSO-E	European Network of Transmission System Operators for Electricity
EURELECTRIC	Union of the European Electricity Industry
ESS	Energy-Service Storage
GHG	Greenhouse Gas
GT	Gas Turbine Power Plant
GVA	Gross Value Added
ID	Intraday
PSC	Power Supply Company
PV	Production Value
RES	Renewable Energy Sources
RES-E	Renewable Energy Sources-Electricity
RTP	Real-Time Pricing
TOU	Time-of-Use Pricing
TSO	Transmission System Operator
UNFCCC	United Nations Framework Convention on Climate Change
VOLL	Value of Lost Load

Abstract

The increasing share of electricity generated from renewable energy sources and the implied unavoidable volatility of generation enforces adaptions of future electricity systems and markets.

In the first section of this Master's Thesis, the parallel development of renewable energy sources and demand side management in the European Union is outlined. Therefore, legal framework conditions in form of EU directives and regulations, starting in the late 1980s up to recently proposed regulations, are analyzed. These define the European Union's master plan towards an Energy Union until 2030.

In the second section of the Master's Thesis, demand response concepts of selected stakeholders are analyzed (ENTSO-E, EURELECTRIC and ACER/CEER). Analyzed stakeholder positions allow to draw conclusions on the organization of future electricity markets, considering impacts of aggregators and demand response.

The third section of this Master's Thesis emphasizes critical situations induced by the high share of volatile renewable energy sources, so called cold dark doldrums, which are already present today. During such critical situations, demand response could present itself as a valid alternative to fossil-fired generation capacity. To quantify the Austrian respectively European demand response potential, electrical appliances and applications in the residential, commercial and industrial sector are investigated. Industrial consumers, especially energy intensive industries, hold the biggest potential for demand response as installed power is high but the number of potential processes is low. To achieve the maximal load reduction effect of industrial demand response, it is assumed that qualified industrial processes are completely shut down for the duration of demand response activities, in order to utilize their full capacity. The total resulting potential amounts to 581 MW for Austria. This Master's Thesis not only determines the demand response potential of industrial processes, but also addresses financial aspects. This is done by comparing costs of demand response actions (losses in gross value added) to costs for existing gas-fired power plants, which become dispensable when realizing demand response. However, this should not only be done due to economic deliberations and for profit maximization, but especially due to environmental reasons.

Kurzfassung

Der steigende Anteil der Elektrizitätserzeugung aus erneuerbaren, volatilen Energieträgern erfordert Anpassungen der zukünftigen Elektrizitätssysteme und -märkte.

Im ersten Abschnitt dieser Masterarbeit erfolgt die Darstellung europäischer Rahmenbedingungen für die parallele Entwicklung erneuerbarer Energiequellen und von Demand Side Management. Dazu werden rechtliche Rahmenbedingungen, in Form von EU-Verordnungen und Richtlinien, beginnend in den späten 1980er Jahren bis hin zu erst kürzlich vorgeschlagenen neuen Regelungen, untersucht. Diese definieren den Masterplan der Europäischen Union für eine Energie Union bis zum Jahr 2030.

Im zweiten Abschnitt der Masterarbeit werden Demand Response Konzepte ausgewählter Stakeholder untersucht (ENTSO-E, EURELECRIC und ACER/CEER). Daraus abgeleitete Stakeholder-Positionen erlauben Rückschlüsse bezüglich der Ausgestaltung des zukünftigen Elektrizitätsmarkts unter Berücksichtigung der Einflüsse von Aggregatoren und Demand Response.

Im dritten Teil der Masterarbeit wird speziell auf kritische Situationen, sogenannte kalte Dunkelflauten, hervorgerufen durch den hohen Anteil erneuerbarer Energieträger, eingegangen. In solchen kritischen Situationen könnte sich Demand Response als geeignete Alternative zu fossilen Erzeugungskapazitäten herausstellen. Um das Demand Response Potential Europas bzw. Österreichs beziffern zu können, werden Anwendungen und Applikationen aus dem Haushalts-, Handels- und Industriesektor untersucht. Industrieprozesse, speziell in energieintensive Industrien, weisen dabei die größten Potentiale für Demand Response auf, da die installierte Leistung groß, die Anzahl an in Frage kommenden Prozessen jedoch gering ist. Damit sich durch industriellen Demand Responses auch der gesamte, potentiell mögliche Lasterreduktionseffekt ergibt, wird davon ausgegangen, dass betroffene Industrieprozesse für die Dauer von Demand Response Maßnahmen komplett abgeschaltet werden um deren volle Leistung nutzbar zu machen. Dadurch ergibt sich ein österreichisches Gesamtpotential von 581 MW. Diese Masterarbeit behandelt aber nicht nur Demand Response Potentiale von industriellen Prozessen, sondern auch finanzielle Aspekte. Dazu werden die durch Demand Response Aktivitäten entstehenden Kosten (Bruttowertschöpfungsverluste) den Kosten bestehender gasgefeuerter Kraftwerke, welche bei Umsetzung von Demand Response nicht mehr benötigt werden, gegenübergestellt. Dies sollte nicht nur aus betriebswirtschaftlichen Überlegungen und zur Gewinnmaximierung umgesetzt werden, sondern vor allem auch aus Umweltgründen.

1. Motivation, Research Questions and Approach

Climate change is one of the most challenging tasks of our time. Thus, in 1992 the United Nations Framework Convention on Climate Change (UNFCCC) has been adopted. This international environmental treaty has been ratified by 197 countries and targets to ensure stabilization of the atmospheric greenhouse gas (GHG) concentration to prevent dangerous anthropogenic effects on the climate system.[1] In 1997 the Kyoto Protocol, which commits its parties by setting internationally binding emission reduction targets, has been ratified. The protocol sets a higher burden on developed countries as their past and current industrial activities lead to high levels of GHG emissions.[2] As a follow-up for the Kyoto Protocol the UNFCCC's 21st Conference of the Parties (COP21), which took place in Paris in 2015, sets new and challenging climate targets. The agreement has been ratified by 168 of the 197 parties and aims to keep the global rise in temperature below 2°C with respect to pre-industrial levels, preferably even below 1,5°C.[3] However, political circumstances in the USA, whose current president decided to drop out of the Paris Agreement, do not lift our chances to reach the set target.[4]

In order to actually reach those ambitious targets fundamental changes regarding energy generation, transmission and consumption in all different energy sectors have to be accomplished.

In July 2015, the Commission of the European Union adopted a communication paper regarding the launch of the consultation process-phase on new energy market design. The paper defines the development of a resilient Energy Union, based on a forward-looking climate policy as a strategic objective. Focusing on making the European Union the world leader regarding renewable energy sources (RES), the efficiency first principle has been declared as basic guideline. With this principle set in place, the objectives of ensuring affordable energy prices and reliability of supply for anybody will be targeted. To reach all of those objectives, fundamental system changes of the European energy systems and the electricity market will be necessary.[5]

Today's electricity market system grasps consumers' energy demand as passive and predetermined. Therefore, the demanded energy has to be provided, which has been done on a large-scale level using centralized, conventional power plants. During the past few years, more

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1 (United Nations Framework Convention on Climate Change, 1992)
2 (United Nations Framework Convention on Climate Change - Kyoto Protocol, 1997)
3 (United Nations Framework Convention on Climate Change - Paris Agreement, 2015)
4 (USA steigen aus Pariser Klimaabkommen aus, 2017)
5 (Launching the public consultation process on a new energy market design, 2015, pp. 1, 3, 8)

and more decentralized electricity generation based on RES - especially wind and photovoltaic - entered into the market. This leads to a permanent change of roles for the market participants. Hence, measures like total integration of all market players, energy efficiency, demand flexibility and the role of energy service providers are key features highlighted in the EU communication paper. Especially the integration of cost-effective flexible demand has to be taken into account when reviewing the market system.[5]

Regarding the role of consumers, the paper states active and beneficial market participation as a fundamental target. To ensure efficient participation, transparent information on costs, consumption and offers is a necessity. Active market participation should not be a complicated or time-consuming task. Existing barriers like price caps, price regulations, taxes and other governmental regulations that do not promote consumers market participation, should be abolished. Therefore, the incorporation of demand response as an equal player besides generation might be a reasonable approach.[5]

As of recently, the European Commission adapted its framework conditions on the internal market in electricity (included in the “Winter Package”) featuring new regulations on the flexibilization of electricity demand. In the light of this event, the goal of this Master’s Thesis is to investigate the future role of the demand side and its impact on the overall electricity system.

This Master’s Thesis focuses in particular on the following research questions:

- What is the past, present and targeted state of framework conditions for the parallel development of renewable energy sources and implementation of demand side management on a European level?

- Which concepts and measures are proposed and pursued by relevant stakeholders in order to establish demand side management in the electricity market?

- Which sectors, processes and applications hold the most potential for demand response (residential, commercial and industrial sector)?

As an approach to answer the presented research questions, literature research has been conducted, considering scientific papers as well as legislative texts. Based on these literature sources, calculations were conducted and the attained results are presented in form of figures, diagrams and tables. From these results conclusions are drawn and explained.

2. Development of the Demand Side Management Idea

During the 1980's, the concept of demand side management has been established by Clark W. Gellings.[6] In his work Gellings pointed out that electricity demand has been looked at as a predetermined figure, where the utility's task is to estimate the required amount and plan necessary adoptions of the electricity system. Due to increasing difficulties regarding prediction and low-cost supply, the idea of extending utility activities to the customer side was established as a new concept. Customer behavior should be considered as a utility planning option, where the utility directly and indirectly controls the time and the amount of electricity used. This requires looking at those factors from an integrated demand and supply-side point of view.[7]

2.1. The Concept of Demand Side Management

Gellings defines the concept of actively affecting the electricity demand as "Demand Side Management" (DSM):

> *"DSM is the planning, implementation, and monitoring of those utility activities designed to influence customer use of electricity in ways that will produce desired changes in the utility's load shape, i.e., changes in the time pattern and magnitude of a utility's load".*[7]

Measures like load management, new uses, strategic conservation, electrification, customer generation and adjustments in market shares are included in the utility's program.[7]

Generally, the most basic and practical DSM concept for utilities is the concept of load shaping. The shape of the load varies due to time-of-day, day-of-week and seasonal characteristics. Load shaping includes six principles (Figure 1): *Peak Clipping, Valley Filling, Load Shifting, Strategic Conservation, Strategic Load Growth* and *Flexible Load Shape*.[7]

- *Peak Clipping* focuses on reducing the load during peak load times, i.e. by directly controlling the consumer's appliances. The load of industrial and commercial customers can be directly controlled and interrupted. As a result, operating costs and dependency on essential fuels can be reduced by economic dispatch.[7]

[6] (A review of demand-side management: Reconsidering theoretical framework, 2017, p. 1)
[7] (The Concept of Demand-Side Management for Electric Utilities, 1985, pp. 1-3)

- *Valley Filling* is another form of load management, which focuses on establishing off-peak load. For instance, this could be accomplished by measures like substitution of fossil fuel-powered space or water heating by electricity powered heating systems. During times when long-run incremental costs are lesser than average electricity costs, valley filling can help to decrease the average costs.[7]

- The third load management principle is *Load Shifting.* Load is shifted from peak to off-peak periods. This is mostly accomplished using storage technologies like storage space heating or coolness storage as well as customer load shifts.[7]

- *Strategic Conservation* describes changes of load shape due to utility programs targeting the consumption of end-users. This principle includes a reduction in sales and a change in pattern of use. Conservation effects, which occur naturally, have to be identified by the utility and eventual efficiency stimulating measures have to be analyzed regarding their cost effectiveness. Increasing efficiency and thermal rehabilitation of buildings are only two examples for Strategic Conservation.[7]

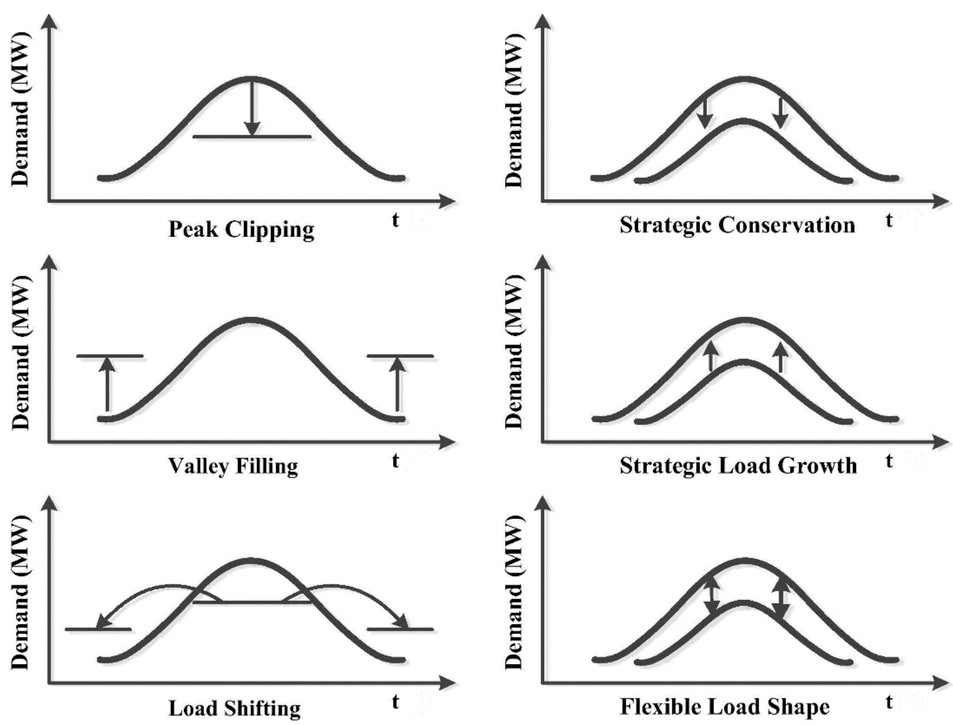

Figure 1: Load shaping principles
Source: ScienceDirect [8]

[8] (Optimal operation of power system incorporating wind energy with demand side management, 2015, p. 3)

- *Strategic Load Growth* also targets the end-user side. Its basic principle is an increasing number in sales, stimulated by the utility. Strategic Load Growth goes beyond the principle of Valley Filling. It includes progressing electrification i.e. for electrical vehicles, heat pumps and automation, the substitution of fossil-fueled applications and economic development in the service area.[7]

- Last but not least the *Flexible Load Shape*. This principle is based on reliability and the willingness of consumers to change their load shape if they are offered proper incentives. Flexible Load Shape includes i.e. interruptible loads, individual customer load control systems or pooled, integrated energy management systems.[7]

Gellings especially pointed out the importance of marketing for the electric utilities. He stated that marketing is the process of understanding the customer's wants and needs and includes satisfaction of those, by offering proper products and services. Thus, utilities require detailed information on customer preferences and corresponding financial effects for themselves for the future development of effective DSM concepts.[9]

In 1992 experiences with early DSM efforts in the USA and Canada have been analyzed. It has been found that DSM measures can be very cost effective, as the costs to save 1 kWh were less than the costs for generating 1 kWh with a new power plant. At times, costs for efficiency measures have been even less than the electricity costs of existing power plants. Furthermore, DSM provides the opportunity to increase customer satisfaction by reducing energy bills, to retain customers, preventing them from changing their supplier and promote the utilities environmental image. Higher environmental standards and restrictions for new power plants, regarding pollution and hazardous wastes, additionally force utilities to implement DSM programs. Finally, regulators use different incentives i.e. directions, financial penalties or least-cost planning requirements, to promote DSM.[10]

Different utility-initialized studies estimated a technical DSM potential of about 30-35%. However, those studies neglected the effects of existing barriers regarding acceptance of DSM on the end-user level and associated costs in order to overcome those barriers. Studies that incorporated those barriers and included not only DSM programs but also market forces, standards and codes,

[9] (The Concept of Demand-Side Management for Electric Utilities, 1985, p. 3)
[10] (Utility Demand-Side Management Experience and Potential - A Critical Review, 1992, pp. 3-7)

estimated savings up to 27% of the forecast electricity sales in 2008 for the three largest electricity utilities in New York State. This equals approximately 80% of the estimated technical potential.[10]

In 1989, the concept of demand response (DR) started to develop. This concept focuses on the response of electricity consumers to spot prices, which are based on marginal costs of supply. Three different response categories where defined:[11]

- *Curtailment* of service when an indicator exceeds a specific threshold (i.e. prices).
- *Substitution* of electricity by other fuels whenever this becomes economical
- *Storage* of storable electricity based end-products. Electricity intensive production steps are shifted to periods of lower electricity cost.

Adapting to varying spot prices by shifting production to periods of lower costs enables significant savings in electricity cost.[11]

Up to this point of time, DSM programs mainly focused on energy efficiency and conservation programs. When price peaks and power scarcity became a growing problem, the focus got shifted to dynamic pricing. Since the 2000s, more and more price responsive DSM programs have been emphasized. The digital revolution additionally boosted this shift, providing new communication technologies and opening the mass-market to price-responsive DSM programs.[12]

2.2. Parallel Development of RES and Demand Side Management − European Union

In the late 1980s, the European Union started to emphasis DSM programs focusing on rational use of energy to secure the energy supply and reduce energy imports. Therefore, the JOULE 1 program (1989-1992), a part of the Framework Program for Research and Technological Development (1987-1991), has been adopted. One of the programs tasks was to develop energy

[11] (Optimal Demand-Side Response to Electricity Spot Prices for Storage-Type Customers, 1989, pp. 1, 6)
[12] (Primer on Demand-Side Management - With an emphasis on price-responsive programs, 2005, pp. 4, 11, 15)

technologies leading to an increase in energy efficiency and a reduction of energy usage via end-use conservation, energy conversion and storage.[13]

Another European program on energy efficiency was the SAVE 1 program (1991-1995). Part of this program were pilot studies on DSM and least-cost planning next to sectoral targeting and monitoring of energy efficiency and other measures. Furthermore, measures to improve the efficiency of electricity (cf. 2.2.1) were implemented.[14]

2.2.1. Council Decision (89/364/EEC) − Action Program for improving the efficiency of electricity use

In 1989, first European action programs, specifically targeting the efficiency of electricity use, have been established. Concerning this matter the Council of the European Communities stated its visions in this Council Decision:[15]

- Increasing efficiency in electricity use would lower the amount of primary energy required, reduce the required amount of investments in production capacity, lead to a reduction of emissions and lower electricity cost.

- A reduction of electricity consumption would directly lead to lower consumption of non-renewable raw materials and pollution.

- Most efficient electrical appliances and processes should be promoted and efficiency of the appliances should be improved.

The Council suggested different actions which might be taken under the community action program, focusing on consumer information, technical advice for consumers, efficiency of electrical appliances and equipment, demonstration and studies and support activities.

[13] (JOULE 1 - Specific research and technological development programme (EEC) in the field of energy - non-nuclear energies and rational use of energy, 1989-1992)
[14] (SAVE 1 - Promotion of energy efficiency in the Community, 1991-1995)
[15] (Council Decision (89/364/EEC) - Community action programme for improving the efficiency of electricity use, 1989)

Those suggestions included first rudimentary concepts of DSM:[15]

- More detailed information on electricity tariffs, metering and accounts
- An improved labelling system for appliances and equipment
- Focusing on electronic control of domestic and industrial electricity consumption via remote reading and control microprocessors
- Offering advice on purchase, installation and use of most efficient appliances to consumers

2.2.2. European White Papers

As environmental concerns significantly increased, the White Paper on the energy policy of the European Union (1995) pointed out benefits of renewable energies and declared them as the main sustainable energy source of the future. To promote those renewable sources, supportive market regulations in form of fiscal regulations, expanding electricity capacities and access to networks are a requirement. Furthermore, the paper pointed out the necessity for new approaches like Integrated Resource Planning and DSM to increase energy efficiency. To reach full efficiency and conservation potential, existing barriers and opportunities had to be identified.[16]

The White Paper on renewable sources of energy (1997) presented more details on the topic. RES provided only 6% of the EU-15's gross energy consumption and those sources were exploited very unevenly. To live up to the targets stated in the Kyoto Protocol, a series of actions, especially the promotion of RES had to be tackled. The Union's minimum target was to achieve a share of 12% of RES by the year 2010. This target was based on the projected energy use before the Kyoto targets. On the one hand, efforts taken to ensure that the Kyoto targets were met, might have increased this share. On the other hand, new Member States to the EU could have made it harder to reach the target. The White Paper also pointed out the important role of electricity, which had a share of about 40% of the Union's total gross energy consumption. To

[16] (White Paper: An Energy Policy for the European Union., 1995, pp. 14, 34-36)

promote RES in this sector, market liberalization including adequate market-based instruments could function as a basis. Member States have been enabled to preference RES in dispatching.[17]

The paper also presented a projected scenario on the development of RES by 2010 (cf. Table 1). The historic, projected and actually achieved shares of RES are summarized in Table 1.

RES Capacity in the EU 1995-2010				
		historic	projected	achieved
		1995 [17]	2010 [17]	2010
Biomass	**[Mtoe]**	44,80	135	118,22 [18]
Wind	**[GW]**	2,50	40	84,28 [19]
Photovoltaic	**[GWp]**	0,03	3	29 [20]
Geothermal (heat)	**[GW_{th}]**	1,30	2,5	12,00 [21]
Geothermal (electricity)	**[GW]**	0,50	1	0,82 [22]
Hydro (LSH, SSH) [23]	**[GW]**	92,00	105	101 [22]
Other RES	**[GW]**	0,00	1	–
- Concentrated solar power	**[GW]**	–	–	0,50 [24]
- Wave power	**[GW]**	–	–	0,24 [22]
- Ocean thermal energy	**[GW]**	–	–	

Table 1: Historic, projected and achieved RES capacity in the EU, 1995-2010
Source: Own representation

Most of the EU's RES targets have been fulfilled to a high extend by 2010. Especially the installed power capacity of wind and photovoltaic power plants has reached unexpected high levels.

2.2.3. Directive (2001/77/EC) − Promotion of electricity produced from RES in the internal electricity market

In 2001, the EU Directive on the promotion of electricity produced from RES for the internal electricity market has been adopted. The directive points out the necessity for national indicative targets for RES electricity consumption and a guarantee of origin for such electricity. Furthermore,

[17] (Energy for the Future: Renewable Sources of Energy. White Paper for a Community Strategy and Action Plan., 1997, pp. 5, 11, 15, 28, 38-44)
[18] (Annual Statistical Report: 2012 European Bioenergy Outlook, 2013, p. 6)
[19] (Wind in power: 2010 European statistics, 2011, p. 3)
[20] (PV Status Report 2011, 2011, p. 17)
[21] (Renewable Energy in Europe - Markets, trends and technologies, 2010, p. 84)
[22] (Renewable Energy Progress in EU 27 2005-2020, 2013, pp. 8, 9)
[23] Large-scale hydro power (LSH); small-scale hydro power (SSH)
[24] (Solar Power from Europe's Sun Belt, 2009, p. 3)

an EU-wide framework for a support scheme should be developed but for now, as there is to less information regarding the impact of national schemes, the target is to ensure the functioning of those national schemes until a common framework is established. The framework should allow electricity generated from RES, to compete with electricity generated from non-renewable sources, limiting costs for consumers as well as reduce the necessity for a support scheme in the intermediate-term.[25]

The directive obligates Member States to present reports and adopt their targets on the percentage of electricity consumption from RES every five years for the next ten years. Furthermore, every two years, national reports on the success of meeting the national indicative targets are to be published. Based on these reports the Commission assesses the progress of the Member States on the national indicative targets and the consistency with the 12% gross energy consumption target and the 22,1% share of electricity from RES target by 2010.[25]

As for the guarantee of origin, Member States are obligate to install one or more bodies without generation or distribution functions to supervise those guarantees.[25]

The Member States have to ensure that transmission system operators (TSO's) and distribution system operators (DSO's) have to guarantee the transmission and distribution of electricity from RES, prioritize the access of RES to the grid and also prioritize the dispatch of RES capacity as far as these measures do not compromise the safety and reliability of the system. Therefore, a framework for required grid connections and grid reinforcements has to be established by the Member States, whereby Member States are allowed to impose TSO's and DSO's with the full or at least with parts of those costs if appropriate.[25]

As described above, the European Union's focus on RES and especially on electricity from RES leads to fundamental transformations of the energy system. To enable full integration of RES and to achieve environmental targets the participation of the demand side will be a necessity. Therefore, demand response programs are to be established and facilitated.[26]

[25] (Directive (2001/77/EC) - Promotion of electricity produced from renewable energy sources in the internal electricity market, 2001, pp. 1-5)
[26] (A Demand Response Action Plan for Europe - Regulatory requirements and market models, 2012, p. 3)

2.2.4. Directive (2012/27/EU) − Energy Efficiency

The Directive on energy efficiency (transposition by June 5, 2014) is based on a 20% primary energy saving objective compared to projected consumption in 2020. This target is not only associated with energy savings but is also set as one of the EU's headline targets for jobs and sustainable growth within the European 2020 Strategy. Previous EU Conclusions stated that the Union is not on track regarding the efficiency targets and that further actions are necessary especially in the sectors: buildings, transport/products and processes. The paper points out the important role of the public sector for energy efficiency, operating as a promoter for efficient products, buildings, services and behavior changes, as the spending of this sector represents 19% of the EUs' gross domestic product. As for the electricity grid, Member States shall assess its potential for efficiency improvements and ensure a timetable for the introduction of concrete measures.[27]

As a concrete measure, the directive sets a target for energy efficiency on final customer level. Energy distributors and/or retail energy sales companies shall be obligated to achieve an annual rate of 1,5% in energy savings on final customer level from January 1, 2014 to December 31, 2020. Therefore, a proper scheme has to be adopted by the Member States. As a calculation basis, the average energy sales over the most recent three-year period prior to January 1, 2013 are to be used. Once per year, achieved energy savings per obligated party or per obligated sub-category of parties are to be published by the Member States.[27]

It has been found out, that the potential for high-efficiency cogeneration, district heating and district cooling is significant and stated that the share of those technologies should be expended. To integrate those cogeneration plants, Member States should establish rules regarding the sharing of costs for the necessary grid infrastructure. Access to the electricity grid should be prioritized for high-efficiency cogeneration as well as the dispatch of such electricity taking into account the stability of the system. Rankings for the access and dispatch of RES and high efficient cogeneration should be established and published by the Member States prioritizing RES. High efficiency cogeneration plants should be deployed to provide balancing services to the transmission grid. Therefore, transparent, non-discriminatory bidding systems shall be ensured.[27]

As for the roll-out of smart meters, the directive refers to 2009s directive and the target of equipping at least 80% of the consumers with smart meters by 2020, frequently informing

[27] (Directive (2012/27/EU) - Energy efficiency, 2012, pp. 1-8, 15-23, 27, 46)

consumers about their consumption and time-of-use and enabling them to adapt their consumption. Smart meters' minimal functions at least must be designed in a way that full potential regarding efficiency targets is taken into account. The compliance with current data protection legislation i.e. data communication security and final consumer privacy has to be ensured and identification of customers' supply to the grid must be possible. Consumption data should be available for the three last years and time-of-use data (day, week, month, year) should be available for at least the last 24 months.[27]

The directive also points out the possibilities of DR regarding efficiency and energy savings. DR can utilize billing information and therefore lead to a shift in consumption enabling energy savings and cost saving due to a more efficient use of generation capacities and networks. Cost savings on grids, achieved by DSM, DR and distributed generation (DG) should be reflected by grid tariffs. Grid tariffs and regulations should be designed to establish system services for DSM, DR and DG in organized electricity markets (over-the-counter markets and forward, day-ahead and intra-day electricity exchanges for trading energy, capacity, balancing and ancillary services) and should not hamper:[27]

- Load shifting from peak to off-peak times considering availability of RES, cogeneration and DG
- Energy savings due to DR achieved via aggregation
- Reduction of energy demand achieved from consultation of energy service providers
- Connecting and dispatching generation on a low voltage level
- Connecting and dispatching generation near to consumers and
- Energy storage

Member States, especially in the field of system services i.e. balancing and reserve, should promote market participation of DR besides generation. Therefore, technical modalities are to be specified by regulatory authorities, TSOs, DSOs and aggregators. Regarding the financial promotion of DR price signals could be a possibility, i.e. time-of-use tariffs, critical peak pricing, real time pricing and peak time rebates.[27]

The directive also addresses schemes for certification and listing of providers of energy services i.e. energy performance contractors who carry out energy efficiency measures. Resulting financial savings can at least partially contribute to a reduction of investment costs for new infrastructure. Barriers that hinder the development of such energy performance contractors should be removed.[27]

2.2.5. Communication from the Commission (COM (2016) 860 final) − Clean Energy for all Europeans

In November 2016, the European Commission presented the so-called "Winter Package", taking another step towards the development of the Energy Union. The package focuses on the transition of the EU's economy to a clean energy economy. Due to the package, an increase in GDP of up to 1% and 900.000 new jobs could be generated within the next decade starting 2021. Therefore, additionally up to 177 billion Euro per year have to be invested by the public and private investors. These measures should lead to 43% lower carbon intensity in 2030 compared to nowadays levels and a share of 50% RES in the electricity sector. The three main goals of the package are: *Putting energy efficiency first*, *achieving global leadership in renewable energies* and *providing a fair deal for consumers.*[28]

Regarding *putting energy efficiency first*, the paper states:

> *Energy efficiency is the most universally available source of energy. Putting energy efficiency first reflects the fact that the cheapest and cleanest source of energy is the energy that does not need to be produced or used.*[28]

The active management of energy demand is especially pointed out in the paper. This requires optimized energy consumption and leads to cost reductions for consumers and reduces dependency on energy imports. Especially over-capacity of fossil-fired generation can be retired from the market by energy efficiency measures. Therefore, the Commission proposes to set a binding target at EU level to achieve 30% energy efficiency by 2030. The energy saving obligation, stated in Directive (2012/27/EU), of 1,5% annual energy saving by energy distributors and/or retail energy sales companies should be extended beyond 2020 as it has shown positive effects regarding private investments and energy service providers. As for the electricity market, demand side participation will be forced via a new electricity market design.[28]

[28] (Communication from the Commission (COM (2016) 860 final) - Clean Energy for all Europeans, 2016)

The package also targets the buildings sector, focusing on accelerated renovation rates and launches a “European Buildings Initiative” with a “smart financing for smart buildings” program and furthermore a program focusing on the installation of electric recharging points to increase the share of electricity in the transport sector.[28]

Finally, yet importantly, “Ecodesign and energy labelling” will be enforced within the “Ecodesign Working Plan” which should enable potential annual saving of about 600 TWh of primary energy by 2030.[28]

The second main goal of the “Winter Package” is to *achieve global leadership in renewable energies*. Although Europe has lost its leading role in the PV industry, it is the global leader in wind energy with 43% of all globally installed wind turbines being produced in the EU. To achieve global leadership, the Commission will engage in industry-led initiatives.[28]

The stated target of a 27% share of RES in the EU by 2030 stays in place and is binding on EU level. Member States will ensure their contribution to reach the target via the integrated national energy and climate plans, which will be addressed in the Regulation on the Governance of the Energy Union.[28]

Electricity generation from RES will reach a share of 50% by 2030. Therefore, the “Renewable Energy Directive” and the “proposals on a new electricity market design” will set a level-playing field for all technologies, considering variability of generation and decentralization of RES. For full integration of RES into the electricity market, rules for short-term trading close to the time of delivery and measures to reward flexibility of generation, demand and storage are necessary. For existing installations, small-scale RES and demonstration projects the priority dispatch system will be continued (generation from these sources will be dispatched prior to generation from other sources). For the time after 2020, policy predictability for investors will be provided via the “Renewable Energy Directive”. The interconnection of European energy networks will be enforced. Bioenergy will continue to represent a large share of Europe’s energy mix.[28]

Summed up under the third main goal *providing a fair deal for consumers*, the paper proposes to empower consumers. Providing clearer information would extend the possibilities to participate on the energy market and gain financial advantages for consumers. For businesses, competitiveness levels would rise. Providing latest information via smart meters, simplifying energy bills and removing contract termination fees alongside a certified comparison tool, will give consumers more information and control. Therefore, the Commission has presented the “second biennial report in energy costs and prices”.[28]

Generating, storing, consuming, sharing or selling back energy to the market by consumers will be eased by regulatory changes within this package. Removing wholesale and retail price caps and enabling consumers to offer DR directly or via aggregators will increase efficiency. Measures to counter energy poverty are facilitated by the commission.[28]

To reach the described targets and integrate specific needs of different territories, multi-stakeholder action is a necessity. The Commission will facilitate an “initiative on accelerating clean energy innovation” including a funding approach for “high risk - high impact clean energy innovations” as well as “industry-led initiatives”. Furthermore, “support measures for the transition in coal and carbon intensive regions” and “inefficient fossil fuel subsidies”, causing distortions in the energy market will be targeted. Finally yet importantly, Annex II “Boosting the clean energy transition” provides information on concrete short-term energy transition actions to encourage Member States when stating their 2030 targets and increase participation of all stakeholders.[28]

2.2.6. Proposal for a Directive (COM (2016) 761 final) − Energy Efficiency

To satisfy the *energy efficiency first* principle stated in the “Winter Package” the Commission proposed a new directive on energy efficiency amending 2012’s directive.

The binding energy efficiency target for 2030 suggested by the proposal is 30%. Furthermore, 2020’s energy consumption values have been updated and 2030’s values have been added. The primary energy consumption in 2020 shall not exceed 1.483 Mtoe compared to 1.474 Mtoe stated in the amended directive. The final energy consumption shall not exceed 1.086 Mtoe compared to 1.078 Mtoe. For 2030, energy consumption shall not exceed 1.321 Mtoe of primary energy and 987 Mtoe of final energy.[29]

For the period, starting with January 1, 2021 to December 31, 2030 a new energy savings target has been established. The obligation demands 1,5% in energy savings based on annual energy sales to final customers and the most recent three-year period prior to January 1, 2019. This annual savings rate shall continue after 2030 in periods of ten years to reach the EU’s 2050 climate targets unless Commission reviews starting 2027 and every following ten years identify it not to be necessary anymore. Energy generation for own use, either from generation units in or on buildings, can be recognized for achieving the set targets. It has to be noted, that this special regulation, among others, is limited to not more than 25% of total energy savings.[29]

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[29] (Proposal for a Directive (COM (2016) 761 final) - Energy Efficiency, 2016)

Some Articles have been reorganized in the new directive, i.e. Article 7a and 7b regarding “Energy efficiency obligation schemes” and “Alternative policy measures” were added. Most of the Articles and Paragraphs regarding electricity have been modified to only affect gas. Evaluation of the directive shall be done not later than February 28, 2024.[29]

2.2.7. Proposal for a Directive (COM (2016) 767 final) − Promotion of the use of energy from renewable sources

This proposal presents principles and measures to ensure that the EU can reach its target of a 27% share of RES by 2030. This proposal complements the proposals for a “Directive on common rules for the internal market in electricity” and a “Regulation on the internal market for electricity”. The following outtakes focus on electricity generated from RES (RES-E).[30]

The proposal evaluates non-distortive support schemes for RES-E to be an effective measure to increase the share of RES in the electricity sector by granting support besides the market revenues, considering the grid constraints as well as supply and demand. Those support schemes shall ensure that RES-E is competing on the market, responding to price signals and that producers of RES-E are trying to maximize their revenues. Furthermore, assessment of support schemes shall be done every four years, determining their necessity and cost-effectiveness. However, priority dispatch of RES-E and high-efficient cogeneration shall no longer be practicable for newly installed generating infrastructure nor for generating infrastructure undergoing a capacity increase or being subject to significant modifications requiring a new connection agreement.[30]

The paper also sets the framework conditions for the support of RES-E generators, which are located in other Member States. Utilizations of at least 10% (2021-2025) and 15% (2026-2030) of the annually newly supported generation capacity should be open to generators located in other Member States and the generated electricity should be counted towards the Member State financing its generation.[30]

Starting 2021, Member States shall install one or more single administrative contact points. The task of these contact points is to coordinate the permit granting process for building and operation of RES plants and corresponding distribution and transmission infrastructure. This process should

[30] (Proposal for a Directive (COM (2016) 767 final) - Promotion of the use of energy from renewable sources, 2016, pp. 59-90)

not exceed a period of three years. Furthermore, the single administrative contact points shall guide the applicants through the application process and provide a manual of procedures for small-scale projects and renewable self-consumers.[30]

The proposal targets the simplification of notification procedures for installations with an electric capacity of less than 50 kW and for repowering programs. The single administrative contact point reviews the notifications for such programs and decided within six months if the notification is sufficient. Sufficient notifications automatically lead to permits, whereas insufficient notifications will have to apply for a new permit with a reviewing period of one year.[30]

Within the proposal, the term *renewable self-consumer* is established. A *renewable self-consumer* is defined as:

> *An active customer who consumes and may store and sell renewable electricity which is generated within his or its premises, including a multi-apartment block, a commercial or shared services site or a closed distribution system, provided that, for non-household renewable self-consumers, those activities do not constitute their primary commercial or professional activity.*[30]

Renewable self-consumers are allowed to consume their generated renewable energy and sell the excess energy without being burdened with not cost-reflective charges or procedures. They retain their rights as consumers and are not considered suppliers up to a generation threshold of annually 10 MWh for households and 500 MWh for legal persons. For multi-apartment blocks, the threshold value applies to each renewable self-consumer. Compensations for fed in energy generated by RES should be reflective to market prices. Third party management of such installations is possible.[30]

Last but not least it should be assessed if it is possible for district heating and cooling systems to provide balancing services, demand response and storing of renewable excess electricity in a cost-effective way on a biannually basis.[30]

2.2.8. Proposal for a Directive (COM (2016) 864 final/2) − Common rules for the internal market in electricity

The proposal for a Directive on common rules for the internal market in electricity is an integral part of the EU's Winter Package. Electricity plays a key role for the Union's citizens and industry as well as for reaching climate targets established in the Paris Agreement. To achieve full integration of variable and decentralized electricity from renewable sources, establish cost-reflective prices and enable and encourage consumer market participation adaptations of the market rules are required.[31]

In general, the proposal adds storage of electricity to its common rules besides generation, transmission, distribution and supply.[31]

The paper defines demand response as:

> *The change of electricity load by final customers from their normal or current consumption patterns in response to market signals, including time-variable electricity prices or incentive payments, or in response to acceptance of the final customer's bid, alone or through aggregation, to sell demand reduction or increase at a price in organized markets as defined in Commission Implementing Regulation (EU) No 1348/2014.*[31]

To encourage DR the possibility of final customer participation in all organized markets alongside generation shall be facilitated by Member States. For this purpose, technical modalities have to be defined by national regulatory authorities, or where necessary by TSOs and DSOs in cooperation with final customers and DR providers. For ancillary services required by TSOs and DSOs (including balancing and non-frequency services but excluding congestion management) DR shall be assessed based on its technical capabilities. Furthermore, framework conditions regarding transparent roles, rules and responsibilities and encouragement of market participation of aggregators shall be established.

The paper defines the term aggregator:

> *An aggregator is a market participant that combines multiple customer loads or generated electricity for sale, for purchase or auction in any organized energy market. If an aggregator is not affiliated to any other supplier or market participant, it is called an independent aggregator.*[31]

[31] (Proposal for a Directive (COM (2016) 864/2) - Common rules for the internal market in electricity, 2017)

The regulatory framework of Member States shall at least include regulation elements such as aggregator's market participation not requiring the consent of other parties, clear rules regarding market roles for all participants, common rules on data exchange between market participants and a conflict resolution mechanism. However, direct compensations from aggregators to supplier/generators shall not be required. In exceptional situations Member States may allow compensation payments to fairly assign balancing costs and benefits between aggregators and balance responsible parties (BRPs) but only if actions of one market participant lead to imbalances for other market participants, resulting in a financial cost.[31]

To facilitate DR activities, final customers shall be able to conclude dynamic electricity price contracts with their suppliers if they request it. Final customers have to be fully informed of the risks and opportunities of such dynamic contracts. The main developments, market offers and impacts on customer bills shall be monitored and reported for at least ten years after such contracts become available by National Regulatory Authorities. Furthermore, there shall not be any switching-fees or customer fees for changing supplier. Changing supplier shall be possible within three weeks. Adequate fees for early contract termination shall be allowed if such contracts include demonstrable advantages for customers. The same regulations apply to aggregator contracts.[31]

Customers' access to at least one tool to compare supplier's offers shall be ensured by Member States. Customers shall be informed about the availability of such a tool, which can be operated, by public authorities or private companies. Comparison tools shall be certified and monitored by an independent competent authority.[31]

The proposal pursues the idea of "active customers" and "local energy communities". Active customers shall be allowed to generate, store, use and sell their self-generated electricity acting on their own or via aggregators to all organized markets. Therefore, active consumers shall not be burdened with any disproportional or not cost reflective charges. The network charges for fed in electricity and electricity consumed from the grid are to be accounted separately and necessary installations for self-generation may be managed by a third party. Local energy communities are characterized as associations of local shareholders or members who perform generation, distribution, supplier or aggregator activities at local level. Those communities shall be entitled to participate in all organized markets on their own or via an aggregator, install small decentralized or distributed generation capacity and be connected to the DSO's network if relevant.[31]

To encourage and enable additional market participation of DR the implementation of smart meters shall be forced by Member States. Final customers shall get free and easy access to near-real-time metered data on time of use and consumption. Smart Meters must be able to meter and account for electricity fed into to grid by an active consumer and electricity supplied from the grid. The metered data shall be processed in a standardized communication interface and/or made available via remote access to final consumers or a third party acting on their behalf. The provided information shall be displayed in an easy and understandable format to enable comparisons on a like-for-like basis. At the time of installation, consumers shall be informed of the possibilities and potentials of smart meters and security of data communication.[31]

Member States shall establish framework conditions to increase distribution and development efficiencies including congestion management of DSOs. Therefore, DSOs shall be enabled to procure services provided by distributed generators, DR, electricity storage and take into account effects of energy efficiency measures. Thus, DSOs shall establish standardized products for providers of such services to foster an effective and competitive market environment. The associated costs of such programs shall be compensated via remunerations. Distribution network development shall be based on network development plans outlining planned investments for the next five to ten years and shall be submitted to the regulatory authority every two years. These plans shall include the effects of DSM measures in comparison to alternative system expanses.[31]

2.2.9. Proposal for a Regulation (COM (2016) 861 final/2) − Regulation on the internal market for electricity

This Proposal for a Regulation targets the adaptation of existing electricity market rules, focuses on large-scale fossil-fueled power plants and addresses the low level of consumer participation. Therefore, new market rules regarding integration of RES-E, consumer participation and short-term markets are to be established. The proposal points out that consumers should be put at the heart of the energy market resulting in reduced costs for backup generation and giving consumers the opportunity to financially benefit from price fluctuations. Providing transparent real-time price signals to consumers shall tender incentives to encourage a change of their consumption patterns. New smart technologies such as electric vehicles, air conditioning and heat pumps will provide large potentials for demand response and grid services as they are able to automatically respond to price signals. To fully unlock these potentials, consumers must have access to electricity supply contracts including dynamic prices and the possibility to let a third party manage their consumption, either on a single or on an aggregated basis.[32]

The proposal especially points out the importance for a level-playing field and equal footing of generation, storage and DR at the market. As for balancing markets, either access of all market participants shall be enabled, individually or via aggregation and bidding as close to real-time as possible should be allowed. Therefore, TSOs shall provide close to real-time information on the state of and the prices in their control areas.[32]

The paper also proposes the establishment of a European entity for distribution system operators (EU DSO entity) to promote the functioning of the internal electricity market and ensure optimal coordination and operation of distribution and transmission systems. DSOs can participate in this entity and become registered members. Tasks of the EU DSO entity include coordination and planning of distribution and transmission networks, integration of RES and energy storage on distribution level, digitalization of distribution networks, data management and data protection and development of DR.[32]

2.3. Recapitulation and Thoughts

In the late 1980s, first DSM programs where emphasized by the European Union mostly utilizing existing energy efficiency potentials to decrease primary energy consumption, investments in power capacity, electricity costs, use of non-renewable resources, emissions and pollution. Increasing environmental concerns and adaptation of the Kyoto Protocol led to 1997’s White Paper declaring the promotion of RES, enabling Member States to preference RES in dispatching and targeting a share of 12% RES by 2010. The comparison of the projected and achieved RES capacity targets, stated in the White Paper, demonstrates that the adopted framework conditions and regulations where successful as the intended RES capacity levels have been achieved to a very high extent. For wind and PV, the targets were even exceeded by far and have reached unexpected high levels. Focusing on electricity, 2001s RES-E directive stated the necessity for national RES-E targets. Furthermore, a system to provide a guarantee of origin for such electricity (independent bodies) and an EU-wide framework for a RES-E support scheme, allowing RES-E to compete with conventionally generated electricity, limiting its costs and reducing its dependency on support schemes in the intermediate-term, should be installed. Member States

[32] (Proposal for a Regulation (COM (2016) 861 final/2) - Regulation on the internal market for electricity, 2017)

were obligated to continuously adopt their RES-E targets and present reports on their RES-E status every five years. A target of 22,1% RES-E by 2010 has been set. In 2012, the presently relevant directive on energy efficiency has been adopted. The directive targets a 20% reduction of primary energy consumption by 2020. To achieve this target, energy distributors and retail energy sales companies are obligated to achieve a rate of 1,5% energy savings on final customer level per annum from 2014 to 2020. The roll-out rate of smart meters shall reach 80% by 2020. The paper also points out the possibilities and benefits of DR utilizing billing information to enable energy and cost savings, the necessity to promote DR as an equal alongside generation and the requirement of certification schemes for energy service providers.

Setting the foundation for further development of the European Energy Union the Winter Package has been presented in 2016. The program is based on three pillars: Putting energy efficiency first, achieving global leadership in renewable energies and providing a fair deal for customers. Specific targets stated in the package include a reduction of carbon intensity by 43% compared to nowadays levels, a binding 30% energy efficiency target and a share of 27% RES and 50% RES-E by 2030. The paper points out the importance of active management of energy demand, suggests to extend the timeframe of the 1,5% energy savings obligation beyond 2020, focuses on the empowerment of consumers and a new electricity market design to facilitate their market participation. To further enhance consumer participation and to provide a fair deal for them, close to real-time information via smart metering, simpler energy bills, self-generation, storage and consumption will be enforced. To increase the share of RES-E, non-distortive support schemes, granting additional support besides market revenues, are found to be effective whereas priority dispatch shall not be available to newly installed generating infrastructure or generation infrastructure undergoing significant modifications or capacity increases.

On EU level, the newly proposed rules for the internal electricity market define demand response to be the change of electricity load by final consumers from their normal or current consumption in response to price and/or market signals. To establish DR in all organized markets alongside generation, technical modalities have to be defined. This includes standards to provide ancillary services as well as participation via aggregation. Dynamic electricity price contracts, access to at least one contract comparison tool, smart metering, transparent real-time price signals and smart technologies are seen as a necessity to enforce the development of DR.

The analyzed programs, directives, regulations and proposals illustrate the pathway of the European Union towards an Energy Union. Pursuing climate, economical, financial as well as political objectives ambitious targets and standards have been set, taking the global leading role regarding the clean energy transition. Due to the rapid development of RES and especially RES-E in a short time span (1995-2015) electricity infrastructure and markets are facing new challenges and obstacles demanding new approaches. DSM has been found to play a key role in the future electricity market design increasing overall system flexibility, leading to more efficient energy generation and consumption and providing final customers with the opportunity to gain financial advantages by participating in all organized electricity markets. The general framework conditions proposed by the European Union are now to be implemented and pursued to achieve our mutual targets.

3. Stakeholder Positions and Concepts for Demand Side Management

Sufficient establishment of DSM measures in Europe's electricity system and markets requires a broad and careful approach, as rash decisions can have a major impact on these systems and potentially compromise their stability. Since DSM has an impact on the overall system, involvement of all relevant stakeholders is reasonable before laying down the legislative framework. Whereas every stakeholder is an expert in its field but also pursues its own or its members' interests, a collection of recently published stakeholder views and opinions appears to have indicatory weight and value for the future development of DSM measures, framework conditions and legislations. This chapter's purpose is to present thoughts and approaches of key stakeholders and give an overview of the proposed positions and concepts.

Varying nomenclature i.e. demand side response or demand response is used according to the analyzed papers, although, both terms have the same meaning.

3.1. ENTSO-E – Demand Side Response Policy Paper

In 2014 the European Network of Transmission System Operators for Electricity (ENTSO-E) presented a policy paper on demand side response (DSR) highlighting it as a key component for the successful evolution of Europe's power system. The paper defines DSR and DSM:

> *"DSR is load demand, which can be actively changed by a trigger, whereby DSM describes the utilization of DSR".* [33]

To unlock the full potential of DSR, ENTSO-E identified five critical issues to be addressed. Those issues include setting roles and responsibilities of TSOs and DSOs, the organization of data handling procedures, security of supply, setting market mechanisms and determining a common European Framework.[33]

[33] (Demand Side Response Policy Paper, 2014)

3.1.1. Roles and Responsibilities of TSOs and DSOs

Different views of TSOs and DSOs on DSR and its use have hampered the development of DSR in Europe. As DSR will be a future key component for optimizing day-ahead and intra-day markets but also long-term portfolios, an aligned position of TSOs, DSOs and other DSR stakeholders is required. TSOs will primarily use DSR for balancing services, whereas DSOs are likely to use DSR primarily for congestion management.[33]

ENTSO-E intends to take a leading role not only in presenting information on DSR to relevant stakeholders, but also in addressing the topic of organizing different roles regarding DSR within the future electricity market design. Furthermore, promoting DSR within the TSO's system and market operations as well as TSO and DSO collaboration to enable and establish DSR in a transparent and legally applicable way within their networks and markets.[33]

3.1.2. Organization of Data Handling Procedures

To efficiently utilize DSR, data handling and management plays a crucial role. Therefore, framework conditions ensuring data access for all relevant stakeholders have to be developed. Inefficient data handling could hamper DSR as customers may be confronted with barriers when trying to switch their DSR provider or being overextended by unclear offers, complex contracts or involvement of multiple parties. The key to simplified and efficient DSR participation is clearly processed and presented data.[33]

Technologies such as smart metering as well as communication, and for that matter privacy and confidentiality issues, still are constraints hampering efficient data handling. Additionally, data is preserved by its collectors but only shared because of obligations or ad-hoc requests instead of making it generally available amongst the increasing number of stakeholders who want to utilize DSR. In addition, the question of responsibility for initiation of DSR actions and verification of DSR realization are to be addressed.[33]

ENTSO-E recommends the development of framework conditions for efficient data handling by multiple parties supported by one or more data handling bodies. It is key that the correct data is available for existing system and market needs, whereby data gathering could be done by regulated or independent companies on different hub levels. Centrally available data can have a positive impact on DSR competition by informing customers about DSR service provider's offers and facilitate new DSR market participants.[33]

3.1.3. Security of Supply

In the past, the DSR potential has not been included in planning and operation of grids, as load has been seen as an emergency-only factor. System services such as balancing were mainly accomplished using synchronous generation. To fully integrate volatile generation from RES additional control and balancing resources are required. DSR is capable to replace capacity and traditional generation, provide additional flexibility and therefore support the integration of volatile generation. Furthermore, grid expansion might be postponed due to the effects of DSR.[33]

ENTSO-E considers that performance criteria for DSR have to be ensured via legislative operations. Providing DSR should generally be conducted on a voluntary basis whereby TSOs might be required to adapt non-voluntary sources of DSR to maintain security of supply (i.e. load shedding). Planning and operational standards considering dynamic needs of users, including different levels of security of supply, are to be developed.[33]

3.1.4. Setting Market Mechanisms for Demand Side Response Integration

Efficient integration of DSR requires changes in the organization of electricity markets. Barriers hampering market entry of DSR providers, favoring only big players have to be reviewed and removed resulting in more competitive and cost effective markets. To enable cross-border trading and consumer participation common principles and rules have to be established ensuring DSR does not compromise roles and tasks of other market participants (i.e. services of BRPs).[33]

ENTSO-E recommends the allowance of appropriate price signals and incentives to facilitate DSR. Participation of DSR in all electricity markets shall be enforced to ensure and establish DSR as an equal player alongside generation and to create a level-playing field. “DSR friendly” products must be designed for wholesale and balancing markets pursuing reduced bidding size, bidding time and gate closure time. To satisfy specific TSO or DSO needs, specific demand-based products should be developed, while taking into account EU-wide standardizations to emphasis cross-border exchange. Simplicity and clarity are key factors for the acceptance of DSR by customers. Therefore, all billing information must be provided to the customer via one single bill. Neutral and independent bodies have to supervise such a system ensuring confidentiality.[33]

3.1.5. Common European Framework

Providing DSR as well as consumer participation in the electricity market is currently not common. Nowadays, DSR is limited to a small share of industrial load, whereas commercial and residential load do not play any role. Since there are no common European framework conditions for DSR, different countries emphasize different DSR products such as time-of-use tariffs, interruptible contracts, critical peak pricing, balancing services via large industrial consumers, etc. To encounter these barriers common European framework conditions are a necessity.[33]

ENTSO-E emphasizes the need for common European ground-rules to establish DSR. Such rules should be initiated on an EU level and have to be specific, while implying a certain share of flexibility to emphasize realization on national or regional levels. ENTSO-E should take a leading role in defining such ground-rules. Framework conditions shall be assessed due to their practicability to exploit the full potential of DSR. TSOs should participate in this process.[33]

3.2. ENTSO-E − Market Design for Demand Side Response

In 2015s policy paper on Market Design for Demand Side Response, ENTSO-E redefines and sharpens its policy on DSR. Within the paper, ENTSO-E presents its view of necessary characteristics of the future market design to integrate DSR in relevant electricity markets (i.e. day-ahead, intraday, balancing energy, reserve capacity). As DSR still is in an early stage of development, periods of assessing and testing different concepts and their applicability in differently organized markets are required. Gradually, properly applicable concepts will emerge.[34]

ENTSO-E states that a market model valuing demand flexibility is the key component for efficient DSR integration. Therefore, the new market design requires well-defined roles and responsibilities as well as mechanisms to enable consumers to react to market signals (i.e. prices). DSR is currently hampered by technical, financial and organizational challenges, whereas technical issues are less and less of a factor. Future market design has to tackle these challenges and unlock the full DSR potential.[34]

3.2.1. Accurate Market Price Formation

Proper short-term market prices (day-ahead, intraday, balancing) are a necessity to demonstrate the value of DSR. Therefore, DSR activation has to be based on price signals but price signals also have to reflect DSR activations. DSR participation in capacity reserve markets has the potential to take a key role by increasing competition most likely resulting in lower prices.[34]

3.2.2. Cost Reflective Consumer Prices

DSR implies the economic choice between the value of consumption and non-consumption. For consumers the value of consumption is the utilization of used energy. The value of non-consumption is represented by the value of related products (i.e. commodities, imbalances) or the value of substitutional sources of energy sources. Especially domestic and small to medium sized consumer are restricted to electricity supply contracts, which do not offer this economic choice but only enable choosing between suppliers. To overcome this DSR barrier, consumers should be able to conclude electricity supply contracts with energy prices depending on the time of consumption to facilitate consumer responses. Therefore, proper incentives have to be granted.

[34] (Market Design for Demand Side Response - Policy Paper, 2015)

As a second option, consumers could sell their flexibility on the market, either directly or via an aggregator. To ensure reliability of this flexibility (amount of actual power or energy) consensual baseline methodologies have to be agreed on. Thus, product specific metering methods are a requirement.[34]

3.2.3. Information and Physical Possibility to Act

Proper price information and the physical possibility to act are key to efficient DSR as inefficiencies can cause significant costs, especially for small customers and when complex products are involved. Simplicity and understandability of DSR products are important factors to encourage consumer participation. Another factor is consumer awareness for their own DSR potential, as it requires dedication and expertise to locate and estimate it. Reveling these potentials implicates a business opportunity for DSR companies (i.e. aggregators).[34]

There are different ways of physically acting and triggering DSR. Either customers can activate DSR manually or automatically or the activation responsibility can be assigned to a contractor (i.e. aggregator, supplier, service provider, TSO). Standardizing communication protocols can facilitate efficient activation of DSR and result in reduced cost.[34]

3.2.4. Framework Conditions for Demand Side Response

As discussed within ENTSO-E's Demand Side Response Policy Paper, common framework conditions are a necessary requirement for DSR. Such framework conditions must encourage DSR but also present regulatory stability to avoid negative effects hampering the development of DSR. As DSR affects all relevant stakeholders, possible effects jeopardizing system relevant tasks have to be considered and managed. This specially applies to the tasks of balance responsible parties, which have a key position in balancing the electricity system by balancing their own balancing group. DSR adds yet another factor to this task resulting in an even more complex system. Therefore, balance responsible parties have to be provided with all necessary information avoiding counter-balancing and enabling appropriate forecasting.[34]

3.2.5. Business Cases and Willingness for Demand Side Response

Increasing the willingness for DSR participation requires business cases to assign and measure the benefits of it. Such business cases display the effects of different economic factors i.e. electricity price volatility, installation and operational costs and the value of alternatives like non-participation or usage of different energy sources. Additionally, smooth DSR activations not effecting standard business activities as well as the positive image value of DSR, are factors, which are likely to lead to increased willingness of participation.[34]

Market competition heavily influences economic factors and therefore the willingness of DSR participation. Consumers offering their DSR potential via independent aggregators are key to realize unbundling of supply and flexibility. As consumers pursue their own economic interests by negotiating flexibility clauses of their supply or flexibility contracts, competition between suppliers and aggregators emerges, leading to optimization of the economic value of DSR.[34]

DSR has to compete on the market against other sources. Therefore, limiting potential subsidies for DSR to an absolute minimum is a necessity to benefit society as a whole. Exceptions shall only be made to meet policy targets and to kick-off DSR in the first place. Such exceptional subsidies must be designed to not cause market distortions, as this could have cross-border effects.[34]

3.2.6. Communication and Control Technology

Communication and control technologies have a key role as tools to enable DSR for small consumers. Providing and implementing these tools i.e. smart meters, is task of TSOs and DSOs. Modern control technologies and concepts could be used to establish decentralized DSR as an innovative approach for providing system reserves, assuming the high reliability requirements are achieved. Taking into account the large number of small units especially in the domestic sector, DSR could support avoiding unnecessary and high cost, though this requires careful assessments so reliability is not compromised. Ensuring reliability requirements of DSR has to be an integral part of technical, market and pre-qualification rules.[34]

3.2.7. Recommendations and Further Steps

Facilitating market integration of DSR is key to unlock its full efficiency and economic potential. To overcome emerging challenges, concrete market design measures are required. Some of these measures already exist, others are currently being implemented and tested, whereby most of them can be considered as complementary approaches.[34]

Implementation decisions of a new market design should be based on a cost-benefit analysis taking into account considerable factors like economic efficiency, competition, complexity, fairness, robustness as well as the potential of unlocking further flexibility with respect to local context. Major factors within the new market design are competition of all DSR market participants and possible market entry barriers, as those will contribute to regulatory approaches on DSR. Either DSR will be practiced only directly, via suppliers or via independent aggregators. ENTSO-E points out that lack of information due to the new market design could negatively influence forecasting and therefore the balancing quality i.e. because of commercial post-contract confidentiality for aggregators.[34]

Any implementation of DSR must not compromise the efficiency and well-functioning of electricity markets. Especially balance responsible parties play a key role, which requires appropriate information and balancing incentives. From a TSO’s point of view, ENTSO-E identifies increasing residual imbalances and the development of additional resources as the major trade-off factors when deciding on a new market design.[34]

A large share of DSR’s economic potential lies in reserve capacity markets, especially in countries with a high share of fluctuating RES generation. Unlocking this potential requires high reliability levels as well as proper data management and data security and leads to a pivotal coordination role for TSOs and customers in the market design.[34]

3.2.8. Integrating Demand Side Response in Day-Ahead, Intraday and Balancing Energy Markets

The status quo of DSR market participation varies across Europe, depending on market designs as well as existing barriers. ENTSO-E presents different approaches for market designs in day-ahead, intraday and balancing markets considering the necessity for well-functioning markets on one side and unlocking full DSR potential on the other one. Suitability of the presented market designs is dependent on national conditions and especially on the level of DSR implementation and competition in a country and/or market.[34]

Figure 2 provides an overview and classification of DSR models. It differentiates between DSR being an integral part of the electricity supply contract or not. If not, the existence of a bilateral agreement with the supplier on DSR is the differentiation criteria. Further examples of market models are based on this overview.[34]

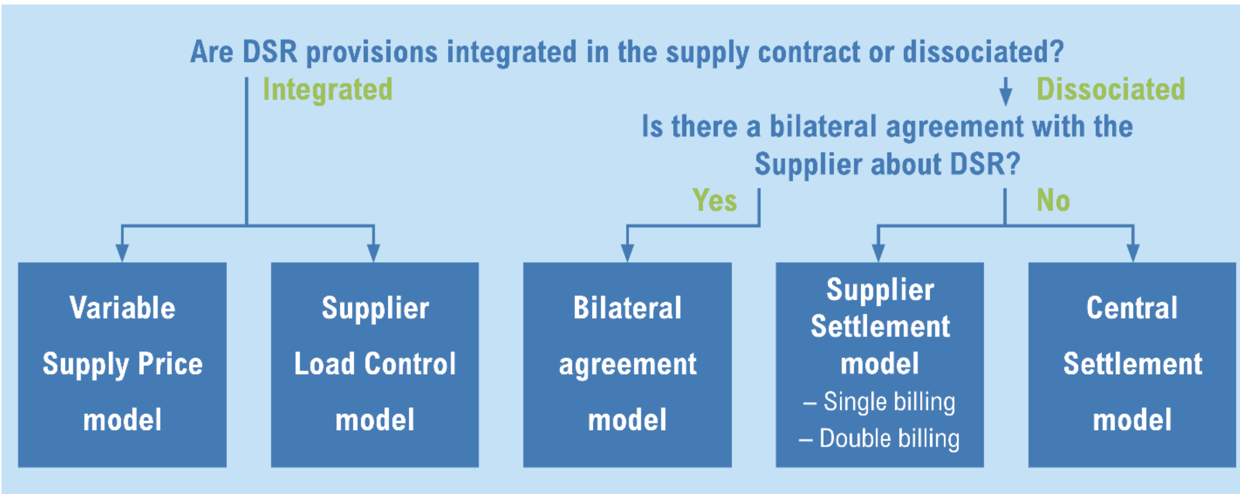

Figure 2: Overview and classification of market design options for DSR
Source: ENTSO-E [34]

Each of the presented market models is organized around the consumer who has concluded an energy supply contract with an energy supplier as shown in Figure 3.

The task of the balance responsible party source (BRP_{source}) is to source energy on the market to comply with the energy requirements of its assigned suppliers. Some markets allow consumers to pursue market activities on their own, which requires former compliance with a BRP or being pre-qualified as a balance service provider (BSP) to obtain access to the balancing market.[34]

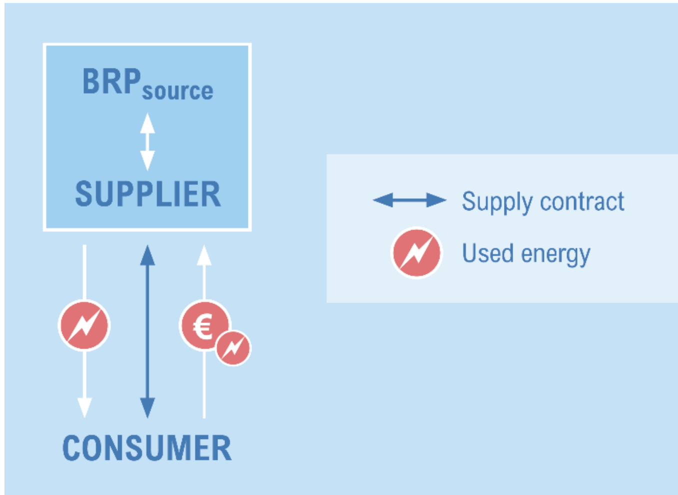

Figure 3: Basic relationship of consumer, supplier and BRP source in market models
Source: ENTSO-E [34]

3.2.8.1. Market Designs with Demand Side Response Models Integrated in Supply Contracts

Integrated market designs offer the possibility to include flexibility clauses in supply contracts (Figure 4). Consumers can profit from such flexibility clauses as they are enabled to reduce their energy bills compared to standard supply contracts, suppliers can optimize their portfolio and reduce their sourcing costs.[34]

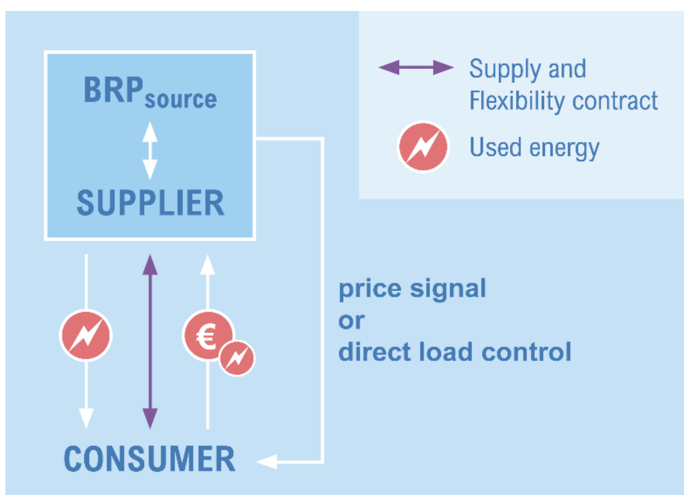

Figure 4: Market designs with DSR models integrated in supply contracts
Source: ENTSO-E [34]

This simple market design only affects the supplier and consumer who conclude a bilateral contract which sets the clauses for supply as well as DSR. It can be differentiated between market designs including price incentives or models with direct supplier load control.[34]

A. Variable Supply Price Model

The basis for this model are variable supply prices, which vary within contractually settled limits. Indexation of price signals on actual market prices encourages consumers to adapt their consumption according to price variations. Variable supply price models provide more accurate price signals, enabling consumers to economically benefit from them but also imply higher price risks, as they are more complex to manage by consumers. The consumption changes induced by price signals are anticipated by suppliers and used for balancing by the BRP source. Currently a large share of established DSR models in Europe are variable supply price models predominantly targeting small consumers equipped with smart meters.[34]

B. Supplier Load Control Model

Flexibility clauses in supplier load control models entitle suppliers to directly control the consumers load in certain situations. The contractually agreed amount of the consumer's load curtailment is requested by the supplier and can be used by the BRP source i.e. to participate in balancing markets, self-balance its portfolio or benefit from high market prices. In return for their load curtailment, consumers are provided with financial benefits. This market model predominantly targets industrial consumers.[34]

Assessment of Market Designs with DSR Models Integrated in Supply Contracts

Market designs with DSR models integrated in supply contracts represent a simple, non-interfering concept to implement DSR. Thus, this market design does not empower aggregators to act independently from suppliers, DSR potential might be hampered. Combining this approach with other market designs should be considered. Generally, significant price gaps between market and retail prices lower the economic efficiency of the variable supply price model over the supplier load control model.[34]

3.2.8.2. Market Designs with Dissociated Demand Side Response and Supply

Offering DSR in market designs with dissociated DSR requires direct access to markets for customers and/or aggregators. Organization of market access to intraday (ID) and day-ahead (DA) markets is performed by the BRP. Participation of an aggregator in the ID, DA or balancing energy market has major influences on suppliers and BRP sources. Hence, ENTSO-E identified *transfer of energy*, *risk of BRP source imbalance*, *information to suppliers and BRP sources* and *confidentiality* to be four crucial issues for market designs with dissociated DSR and supply.[34]

Transfer of energy

DSR activations by the aggregator imply an energy transfer from the BRP source or supplier to another market party via the aggregator as they are granted with direct market access. This energy transfer has to be adequately compensated by the aggregator whilst preserving balancing incentives. Adequacy issues occur as such compensations must at least cover the BRP sources' or suppliers' sourcing costs. Consequences of various sourcing strategies and variety of consumer types might be considered when determining compensations as well as not generating immense risks for aggregators. If compensation payments are not adequate, this could lead to BRP sources or suppliers adapting their sourcing strategies due to compensation prices. However, totally exposing aggregators to sourcing strategies may compromise their operability and economic survivability.[34]

Risk of BRP source imbalance

Providing DSR for the balancing energy market implies association of an aggregator with a BSP. Since balancing energy markets work on a short time scale DSR activations for that purpose cause imbalances within the balancing perimeter of the BRP source which latter cannot influence. This circumstance requires BRP sources to be compensated for the emerging costs of imbalances.[34]

Information to suppliers and BRP sources

DSR activations induce deviations from the forecasts performed by BRP sources and suppliers. To identify such deviations as DSR activations rather than changes in customer behavior the BRP source needs to be informed on DSR activities preventing it from counterbalancing them through adaption of generation. To conduct correct settlements, balancing and forecasting the BRP source requires detailed quantity and time information on performed DSR activations.[34]

Confidentiality

To facilitate competition for DSR potential between suppliers and aggregators, concluding combined flexibility and supply contracts should also be feasible in dissociated market designs. Thus, disadvantages for aggregators may occur, since suppliers can profit from the identification efforts of DSR potential performed by aggregators. As suppliers are notified on DSR activations affecting their customers, they can obtain this information for free. To encounter this issue, confidentiality principles equally applying to suppliers and aggregators need to be established, although, non-transparency might present itself as a barrier for competition amongst different DSR providers. ENTSO-E differentiates between *pre-* and *post-contract confidentiality* for flexibility contracts concluded between consumers and aggregators.[34]

Pre-contract confidentiality ensures, that concluding a flexibility contract between end-user and aggregator is not hampered by the BRP source or supplier, as they do not need to be informed about such a contract.[34]

Post-contract confidentiality implies that at no point of time the BRP source or supplier is aware of DSR activities in its portfolio. Maintaining this condition for all processes i.e. activation, notification and settlement is challenging, as changes in consumption patterns have to be made unnoticeable by manipulation of metering data.[34]

As the volume of DSR activities increases, end-users might be confronted with obligations to inform the BRP source and/or supplier of changes in their consumption patterns and to ensure no overlaps or gaps of concluded supply and flexibility contracts occur. Clauses in supply contracts, implying conditions on external flexibility contracts need to be considered by end-users. [34]

Post-contract confidentiality and *information to BRP sources and suppliers* require a trade-off decided upon by policy makers as they pursue diverging interests. Prioritizing *post-contract confidentiality* on one hand may facilitate the development of DSR, on the other hand balancing efforts for BRP sources are likely to increase. Vice versa, impacts would be archives focusing on *information to BRP sources and suppliers*. [34]

The following market designs try to tackle and solve the addressed issues though compromises and trade-offs cannot be avoided.

A. Bilateral Agreement Model

To solve the issues of a dissociated market design, the aggregator and the BRP source/supplier conclude a bilateral agreement (Figure 5). The consumer has a supply contract with the supplier and a separate flexibility contract with the aggregator (although, combined supply and flexibility contracts are also possible; supplier serves as aggregator). The aggregator performs DSR activations according to its forecast (for day-ahead and intraday markets). Information on DSR activations is passed on to the BRP source/supplier. Since DSR activities imply a transfer of energy, the aggregator receives an amount of energy equal to its DSR activations from the BRP source/supplier (the BRP sources' perimeter remains balanced). The aggregator can sell this energy on the market while the BRP source/supplier receives a compensation payment based on a price agreed upon in the bilateral agreement. The bilateral agreement also contains clauses for settling imbalances caused by DSR activations for participation in balancing energy markets. Thus, the bilateral agreement provides adequate solutions for the *transfer of energy* and *the risk of BRP source imbalance* issues, although, if the contractually set prices for settling imbalances are not appropriate, this may result in a shift of balancing responsibilities from the BRP source to the aggregator.[34]

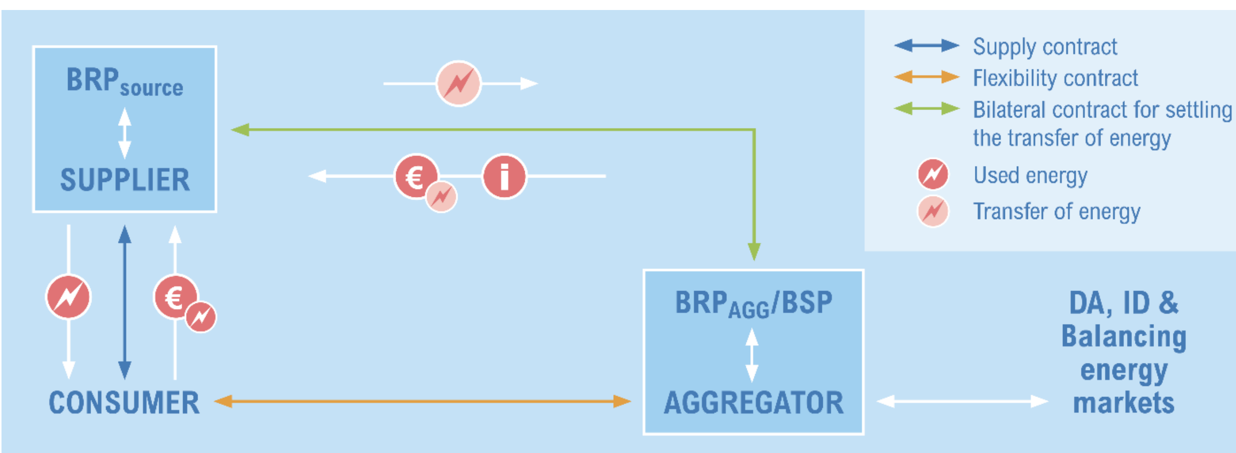

Figure 5: Operation principle of the bilateral agreement model
Source: ENTSO-E [34]

With a bilateral agreement in place, implying flow of information, the *confidentiality* issue has to be considered. Since approval of both parties is required to form a bilateral agreement, this could result in hampered competition for DSR potential due to BRP sources/suppliers only agreeing on bilateral contracts in exchange for excessive tariffs for energy transfers. To prevent this issue, standardized contracts with prizes set by regulatory entities can be used, with the benefit of simple monitoring and competition supervision.[34]

Assessment of the Bilateral Agreement Model

According to ENTSO-E, the bilateral agreement model offers a low degree of complexity for aggregators while consent on the terms of the agreement implies a high level of fairness for the BRP source/supplier and aggregator. Competition issues can be coped with by standardized enforceable contracts set by the regulatory authority and contractual prizes determine economic efficiency.[34]

B. Market Designs without Bilateral Agreement

Market designs without bilateral agreement predominantly tackle *information to supplier and BRP source and confidentiality* issues implied by the bilateral agreement. The *risk of BRP source imbalance* issue for DSR activities in DA or ID markets is resolved by adequate scheduling respectively forecasting of those DSR activities. Hence, there are no imbalances induced to the BRP source. For DSR activities in the balancing market the related imbalances induced to the BRP source are assigned to the aggregator's BRP (BRP_{AGG}) and settled according to the imbalance settlement price of the BRP source.[34]

This market design requires the *transfer of information* regarding DSR activities from the aggregator to the metering or central entity. This entity passes the information on to the BRP source to enable scheduling respectively forecasting of DSR activities and to prevent counter balancing. Although *pre-contract confidentiality* is resolved, *post-contract confidentiality* has to be considered when deciding for one of the proposed market designs.[34]

1. Supplier Settlement for Demand Side Response Activations

In the supplier settlement model (Figure 6), energy and financial transfers only occur between the supplier and consumer respectively consumer and aggregator. The supplier invoices energy associated with DSR activities to its consumer as if it had been used and on regular supply price conditions. The aggregate, which sells the flexibility on the market, compensates its consumers at least for the non-consumed energy according to the terms of the flexibility contract. Furthermore, all metering tasks (used energy as well as energy related to DSR activities) are performed by a metering entity. ENTSO-E proposes two concepts for the settlement between supplier and consumer based on the metering information the supplier receives from the metering entity.[34]

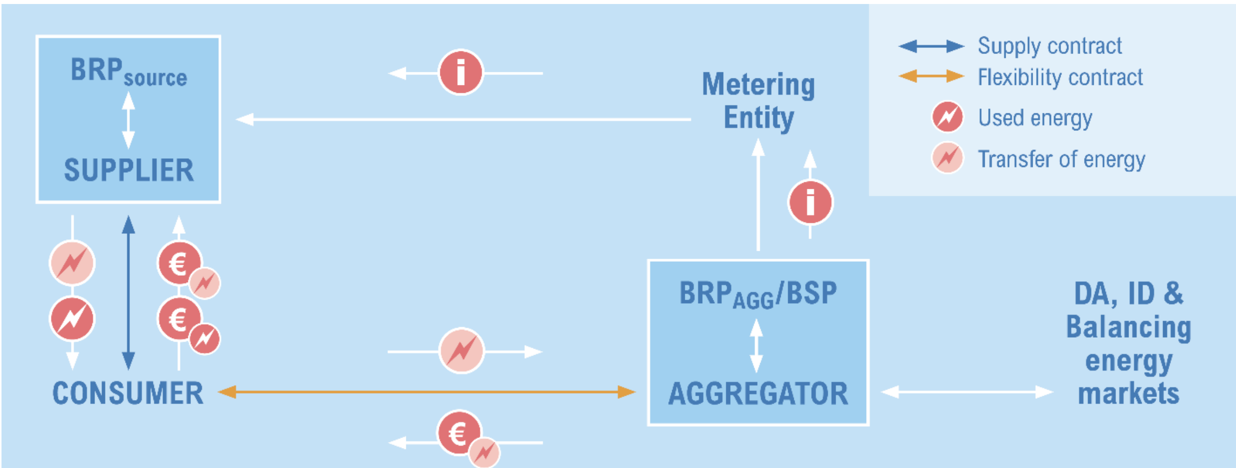

Figure 6: Supplier settlement for DSR activations
Source: ENTSO-E [34]

In the *single billing* model, the metering entity provides the supplier with merged metering data for every single consumer. Hence, the supplier can no longer differentiate between energy used and energy related to DSR activations, which ensures *post-contract confidentiality*. Although, merging metering data might not be straight forward, as it may require complex corrective processes i.e. if there are differences in taxation or grid tariffs for energy used and energy related to DSR activities.[34]

In the *double billing* model, separate metering data is provided to the supplier by the metering entity. Therefore, *post-contract confidentiality* is a concern but handling differences in taxation and grid tariffs i.e. for different categories of consumers is simplified.[34]

Both models do not cause distortions in the merit order and therefore do not influence the supplier but give the aggregator the chance to make efficient arbitrages from the value of consumption for the consumer and the market price of DSR.[34]

2. Central Settlement for Demand Side Response Activations

The central settlement model (Figure 7) works similarly to the supplier settlement model, although, a central neutral entity i.e. TSO, DSO or third party is responsible for the settlement of energy related to DSR activations. The aggregator passes the information on DSR activities on to this entity, which forwards it to the BRP source. Since this information is merged, suppliers cannot identify individual DSR potentials and *post-contract confidentiality* is ensured. The settlement process requires defined settlement prices.[34]

Settlement via *individual tariffs* is one option, although, this implicates that all individual flexibility tariffs have to be centralized at the central entity resulting in feasibility issues.[34]

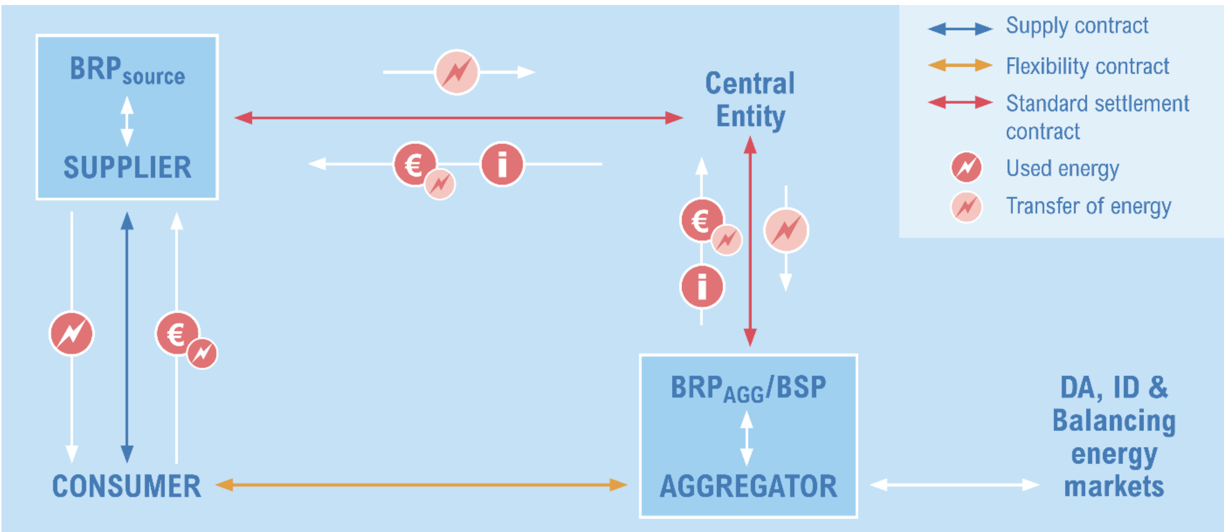

Figure 7: Central settlement for DSR activations
Source: ENTSO-E [34]

Another approach for settlement would be *regulatory set prices* i.e. prices per type of customer or prices set via a price formula.[34]

Due to the neutral central entity, the *post-contract confidentiality issue* is resolved within the central settlement model, although, *regulatory set prices* can cause economic inefficiencies if they are not cost-reflective, hamper innovative supply contracts and compromise a level-playing field.[34]

Assessment of Market Designs without Bilateral Agreement

All market designs without bilateral agreement allow aggregators to act independently from BRP sources and suppliers, ensure *pre-contract confidentiality* and in some cases even resolve the *post-contract confidentiality* issue enhancing the competition for DSR potential between aggregators and suppliers. Although economic efficiency can be ensured if prices are cost-reflective, the necessary and complex adaptions of the market design will take considerable time.[34]

3.2.9. Integration of Demand Side Response in Reserve Capacity Markets

As Europe's share of electricity from volatile RES-E increases, the demand for reserve capacity (also referred to as control capacity; implying guaranteed capacity availability), especially the secondary and tertiary reserve capacity products, rises. The control area manager (generally the TSO) procures reserve capacity within its control area via auctioning. Such markets are therefore regionally limited, implying that aggregators can only participate in reserve capacity auctions within their control area. Provided that DSR activities meet the technical requirements for those markets (i.e. ensuring availability, power slew rate and power consistency), participation in reserve capacity markets could become an additional field of application and revenues for DSR.[34, 35]

ENTSO-E states that implementing DSR in reserve capacity markets is much easier than in energy markets as no significant market adaptions are required. Furthermore, the potential capacity volume of DSR is identified to be high compared to its energy volume, at least in most countries. Assuming acceptance by all relevant stakeholders, resolving transfer of energy could be done in a pragmatic way implying no corrections in the BRP source's perimeter, which is suitable if cost benefits can be achieved due to lower complexity. This mainly applies to primary reserve capacity markets, though suitability for other capacity reserve products has to be reviewed especially in markets where capacity has a very low value and revenues are generated via the price of the energy component (i.e. joint market for negative secondary reserve capacity of Germany and Austria) as this could hamper market participation. However, the BRP source affected by DSR activities has to be compensated by the BRP source causing the imbalances (due to the need to activate reserve capacity by the control area manager).[34, 36, 37]

As a prominent example, France is currently working on the transition from an energy to a capacity based market system. One of the main pillars of this transition is the sufficient integration of DR in all market mechanism. In the context of balancing mechanisms, the French TSO RTE started an experiment in 2007, allowing offering of local generation as well as DR connected to the public distribution grid, with a minimum capacity of 1 MW. In the context of energy markets, DR is qualified as a competitive alternative to generation, utilizable to cover forecast demand. Providers of DR can either profit implicitly i.e. by portfolio-optimization according to variable supply tariffs,

[35] (APG - Balancing, 2018)
[36] (APG - Tenders for Secondary Control Power in the APG Control Area, 2018)
[37] (APG - Results of the Tenders for Control Power, 2018)

or explicitly. Since 2014, DR providers can profit directly from differences in supply and market prices during a given duration. In order to achieve smooth market integration of DR products, experimental rules, defining the conditions for trading “energy blocks“ of DR, were established.[38]

[38] (French Capacity Market - Report accompanying the draft rules, 2014)

3.3. EURELECTRIC − Demand Response Activation by Independent Aggregators as Proposed in the Draft Electricity Directive

In August 2017, the Union of the European Electricity Industry (EURELECTRIC) presented a short study conducted by DNV GL - Energy, an international service provider for advisory and testing throughout the whole energy value chain.[39, 40] The study states that DR is a valuable and versatile source of flexibility which can be used for balancing activities (TSO), congestion management (DSO) and help to reduce the need for grid extensions. Furthermore, DR might replace more expensive types of generation in the market, leading to more stable prices and help to close the gap between supply and demand due to foreseeable demand behavior causing imbalances.[41]

The paper points out, that efficient competition of DR in wholesale electricity markets requires aggregators (either suppliers or independent third parties) to source DR potential and provide it to the market. This process can be grasp as reselling of energy.[41]

The regulatory framework to enforce and enhance DR has been proposed by the European Commission in its current Proposal for a Directive on the common rules for the internal market in electricity (cf. 2.2.8). DNV GL’s study focuses on the proposal’s impacts on aggregators, their role in the market and related concerns and issues for the market as a whole.[41]

3.3.1. The Commission’s Proposal

Article 17 of the proposal entitles aggregators not to be required to compensate suppliers or generators. Compensations for BRPs are only allowed if the aggregator’s actions lead to imbalances resulting in financial costs for other market participants. This legislative approach leads to two major problems, which are likely to compromise overall efficiency of the electricity markets; the *imbalance issue* and the *bulk energy issue*.[41]

The *imbalance issue* considers imbalances within the perimeter of a BRP, which includes assigned suppliers, caused by the DR activations of aggregators. These imbalances are financially settled between the TSO and the BRB, whereby the latter assigns the imbalances to its assigned suppliers according to the cost-by-cause principle. Hence, DR related imbalances which are not corrected within the BRP perimeter cause the *imbalance issue*, with the supplier

[39] (Tapping the demand response potential, the cost efficient way, 2017)
[40] (DNV GL - Structur of the Organization, 2017)
[41] (Demand Response Activation by Independent Aggregators as Proposed in the Draft Electricity Directive, 2017)

having to bear the financial risk (cf. 3.2.8.2; *risk of BRP source imbalance, information to supplier and BRP source*).[41]

Since generation within the BRP's perimeter is based on forecast consumption, DR activations, which the suppliers are unaware of, lead to a procured but non-consumed nor payed for volume of energy. This is referred to as *bulk energy issue*. To invoice this volume of energy and recover the procurement costs, additional arrangements would be necessary (cf. 3.2.8.2; *transfer of energy, information to supplier and BRP source*). The bulk energy issue only arises for DR activities reducing the consumer's load but not if the load increases.[41]

Under the current path of the proposed directive, aggregators may exceptionally be hold financially responsible to the BRP for the imbalances they cause, though, the proposal does not include compensation for sourced energy by the supplier or BRP. Hence, aggregators have a big impact on other market participants, resulting in some form of external costs for the BRP and its assigned suppliers.[41]

3.3.2. Assessment of the Commission's Proposal

DNV GL finds, that compliance with existing EU legislative requires every market participant to be associated to a BRP, hence, this also applies to aggregators. Therefore, Article 17, stating that compensation payments for imbalances shall only be applied in exceptional situations, leaves space for interpretation on aggregators' balancing responsibilities. Without balancing responsibility, risks and costs for imbalances caused by aggregators would have to be bared by BRPs, which is likely to result in increased costs of system services for consumers and other market participants. Hence, aggregators' irresponsibility for imbalances would violate EU regulations, imply preferential treatment and compromise system stability.[41]

To tackle the *imbalance issue* whilst assuming balance responsibility for aggregators, DNV GL suggests the transfer of energy either between impacted BRP perimeters or the supplier and aggregator via forecasting respectively scheduling (Figure 8). This can either happen previous to DR activations or subsequently and should be incorporated into the Commission's proposal.[41]

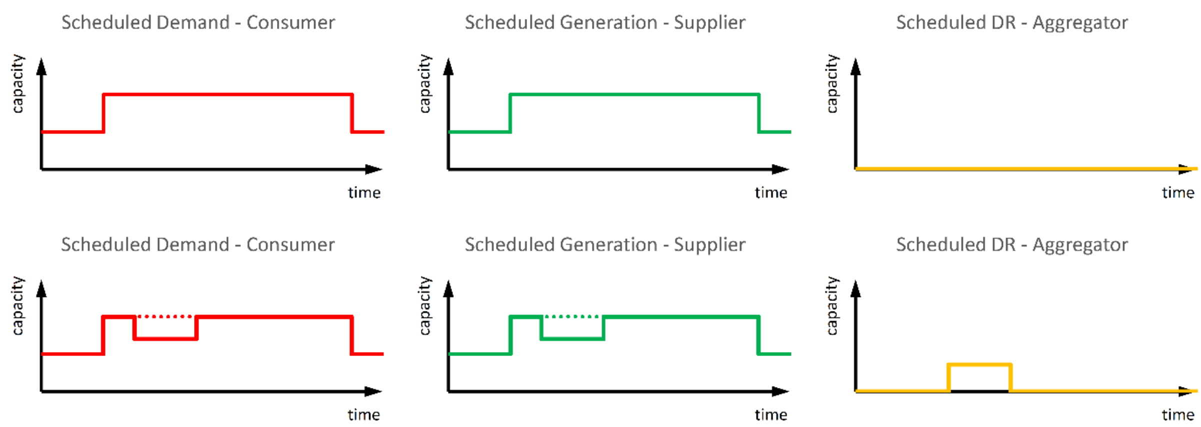

Figure 8: Energy transfer from the supplier's BRP to the aggregator's BRP with and without DR activation
Source: Own representation, based on [41]

Special thought has to be given to imbalances caused by rebounds. Rebounds occur if consumers increase their consumption after a DR activation due to processual requirement. Such rebounds can lead to imbalances only effecting suppliers since the aggregator is not obligated for them (Figure 9).[41]

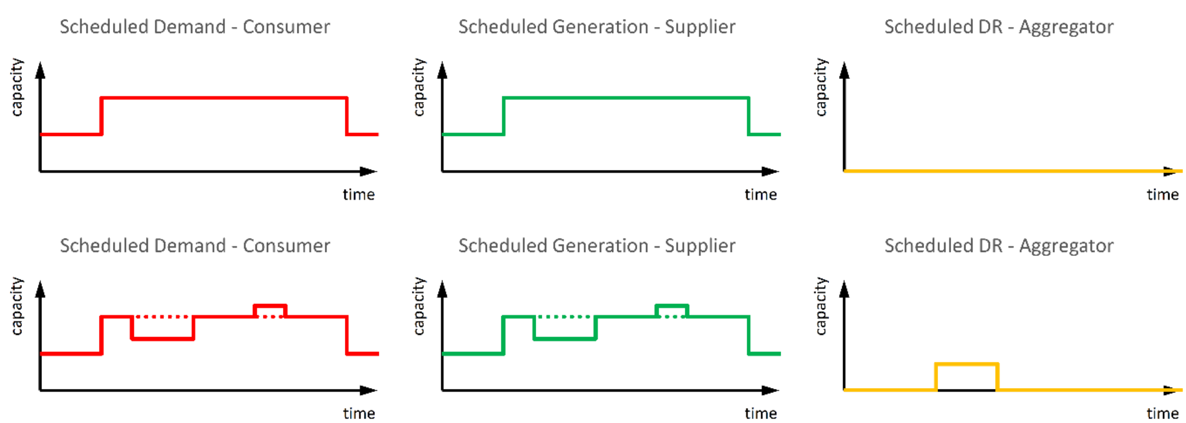

Figure 9: Energy transfer from the supplier's BRP to the aggregator's BRP with and without DR activation, considering the rebound issue
Source: Own representation, based on [41]

Resolving the *imbalance issue* does not resolve the *bulk energy issue*, as the supplier is not compensated for its sourced but non-consumed energy in case DR activations are performed. This compromises general market principles, market functioning and the overall economic efficiency.[41]

It is the supplier's tasks to procure energy to satisfy the needs of its consumers. This requires financial expenditures by the supplier (Figure 10). By executing DR actions of a specific volume, ownership of an equivalent volume of energy is shifted to the aggregator, which sells the obtained energy on the market (Figure 11). Hence, the aggregator obtains the energy for free. With this principle, the aggregator's revenues are generated at the cost of the supplier which is a violation of a basic market principle, since energy which is sold has to be bought or compensated.[41]

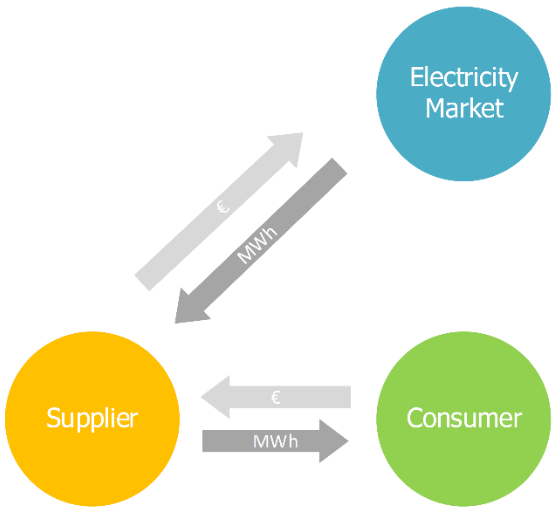

Figure 10: Basic market processes without DR activities
Source: Own representation, based on [41]

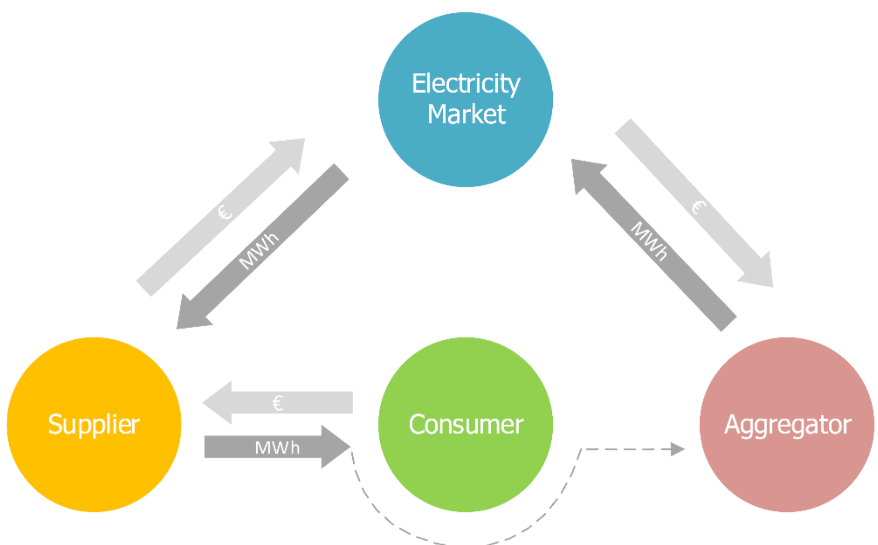

Figure 11: Market processes with DR activities but without compensation payments
Source: Own representation, based on [41]

3.3.3. Risk for Inefficiencies and Distortion of the Level-Playing Field

If aggregators are not obligated to compensate the energy they receive, economic inefficiencies can occur, not only for the supplier but also for the overall system. This happens when costs inflicted to the supplier overweigh the revenues generated by the aggregator from selling DR in the market. DNV GL identifies direct compensation for the supplier, by either the aggregator or the consumer, as suitable to ensure economic efficiency of DR. This ensures that aggregators will only offer DR at the market if the achievable prices are high enough to pay compensations and still make a profit.[41]

Nonetheless, there are voices claiming that compensation payments are not necessary, as the long-term advantages of DR (decreasing wholesale market prices due to substitution of more expensive generation alternatives by DR, which leads to lower sourcing costs) will compensate the short-term disadvantages for suppliers. However, DNV GL has concerns on this idea as the actual change in wholesale market prices and the degree of equal distribution of achieved advantages cannot be predicted. Furthermore, the actual acceptance of DR is unclear and a significant amount of DR activities is likely to be performed for balancing reasons rather than for participation in wholesale markets. Without compensation payments, it is not ensured that a level-playing field for all market participants can be maintained as decreasing wholesale prices may not compensate the financial disadvantages for certain suppliers, even in the long run.[41]

Consequently, consumers may face increasing electricity tariffs as suppliers might try to compensate their losses. Such tariff changes either will only affect consumers holding a flexibility contract with an aggregator, or be equally distributed among all consumers. Furthermore, absence of compensations does not have the same effect on small and large suppliers. Since small suppliers are likely to have higher sourcing costs (lack of access to the wholesale market or access only via an intermediary), less consumers for distributing higher electricity tariffs among, a limited consumer portfolio where single large consumers have major impacts as well as fewer means to become an aggregator on their own, effects of DR will have a bigger impact on them than on large suppliers. Latter on the other hand, will profit from lower sourcing costs via economies of scale effects respectively direct access to the wholesale market, effects of a more heterogeneous customer portfolio as well as the larger number of consumers to distribute increasing costs amongst. Hence, small suppliers may be forced to retire from retail business in the long run, resulting in fewer competition amongst the remaining large competitors which would compromise the common principles of competitive retail markets and low energy prices for consumers. The presented concerns underline the necessity for compensation payments to unlock the full effect of DR and gain overall benefits from decreasing wholesale market prices.[41]

3.3.4. Conclusion and Recommendations

From analyzing the Commission's current proposal with respect to market characteristics and the implicated issues of DR activities, DNV GL concludes that the *imbalance* and *bulk energy issue* have to be addressed consequently, as both issues compromise general market principles, overall economic efficiency of wholesale markets and competitiveness of retail markets. As for the *imbalance issue*, aggregators shall be responsible for the imbalances they cause and balance their own position. This can most appropriately be done via scheduling DR activities, which results in a transfer of energy from the supplier to the aggregator. Therefore, a time shift of energy consumption due to rebound effects needs to be considered i.e. via volume correction or the extension of energy transfer. Resolving *the bulk energy issue* requires compensation payments, either by the aggregator, by consumers with flexibility contracts exclusively or by all consumers to cover the suppliers sourcing costs. Finally, yet importantly, the actual effect of DR on wholesale prices remains uncertain. Smaller and larger suppliers are not equally affected by DR activities, which is likely to jeopardize the level-playing field and competitiveness in the retail market. Since the Commission's proposal entitles aggregators not to be required to pay compensations, this implies that compensation payments by consumers holding flexibility contracts, or even socialization of compensation via a levy, is compliable though. Overall, DR activities should not have negative impacts for suppliers.[41]

3.3.5. Pros and Cons of Different Approaches Regarding the Bulk Energy Issue

Since there are several different approaches to resolve the bulk energy issue, their pros and cons shall be discussed.[41]

If aggregators were liable for compensation payments, DR activations would only be performed when achievable wholesale prices exceed sourcing costs. This approach ensures economic efficiency, complies with general market principles and avoids shifting costs from the supplier to its consumers.[41]

Another possibility is compensation by the consumers holding flexibility contracts. In this scenario, consumers pay the contractually agreed supply price even for energy that has not been consumed due to DR activations, as if it had been consumed. As a consequence, consumers will insist on retaining their costs when concluding a flexibility contract with an aggregator. If this contract covers an amount equivalent to the consumer's costs for non-consumed energy, economic efficiency and compliance with general market is ensured, although, confidentiality about supply tariffs and flexibility contracts not covering all costs for non-consumed energy could hamper this approaches efficiency.[41]

Finally, yet importantly, an approach via socialism in form of a levy, paid by many system users rather than only by customers associated to the supplier confronted with the *bulk energy issue* could be implemented. The levy would work as a form of subsidy for aggregators. This approach only is economically efficient if the levy does not over or undercompensate sourcing costs and if (only) consumers who are paying the levy profit from decreasing electricity tariffs in the long run.[41]

3.4. EURELECTRIC − Dynamic Pricing in Electricity Supply

Up to this point, the presented positions of stakeholders (ENTSO-E & EURELECTRIC) only addressed DSR respectively DR models with more or less passive consumers, providing their flexibility to aggregators when requested. With this position paper, EURELECTRIC targets the consumer's DR potential resulting from responses to price signals provided via dynamic prices in electricity supply contracts. To clearly distinguish the two forms of DR, EURELECTRIC differentiates between *explicit* and *implicit demand response*.[42]

Explicit DR implies that the consumers' flexibility is sold either upfront in the wholesale markets or, in a short-time frame, in the balancing or reserve capacity markets. This process is performed either by the consumer itself or by an aggregator (supplier or third party). For their provided flexibility, consumers are rewarded.[42]

Implicit DR models enable consumers to conclude electricity supply contracts with time-varying prices. Such prices shall represent the actual value and costs of electricity in a given period of time, whereby different price mechanisms imply different price risks. With implicit DR, consumers can lower their electricity bill by adapting their consumption according to the price signals they receive. Using intelligent devices, this could be done with minimal effort.[42]

3.4.1. Dynamic Pricing Models

Dynamic pricing's core intention is to provide a variety of pricing models to choose from, depending on the consumer's flexibility potential and willingness to take price risks. It can be differentiated between *fixed-price offers* and *dynamic pricing models*.[42]

Consumers concluding electricity contracts based on *fixed-price offers* pay a fixed price for a defined period of time. Prices are not affected by changes of market prices, though indexation on average wholesale prices is common. With fixed prices, consumers are not at risk to experience surprises on their electricity bill. Furthermore, with *fixed-price offers* consumers can still offer their flexibility to the wholesale market either by themselves or via an aggregator.[42]

Dynamic pricing models on the other hand are effected by wholesale prices and transfer price variations to customers, at least to a certain extend. Therefore, consumers can decide to respond to price signals by changing their consumption behavior and shift consumption away from peak

[42] (Dynamic pricing in electricity supply - A EURELECTRIC position paper, 2017)

times to off-peak times. The higher the incentives for customers to do so are, the more dynamic a model is. Commonly used models are *time-of-use pricing* (TOU), *critical peak pricing* (CPP) and *real-time pricing* (RTP).[42]

With the TOU model, prices are linked to the time of consumption. This could either be realized with different tariffs for day and night time, for peak and off-peak times, which could vary throughout the day or different seasons. Normally time intervals and tariffs are known well up front.[42]

CPP models offer lower than average prices to customers throughout the year except for a limited number of days, when wholesale prices are the highest, where prices are dramatically higher. To enable customers to adapt their consumption they are notified the day before such a high price event.[42]

RTP is the most dynamic model. Consumers' electricity prices are directly linked to wholesale prices and either based on a one hour or 15-minute basis. Consumers pay for the supplied energy and a supplier margin.[42]

3.4.2. Barriers and Challenges for Dynamic Pricing Models

EURELECTRIC identifies different challenges and barriers for dynamic pricing i.e. limited availability of pricing models, awareness of savings and risks, low incentives for consumers, currently limited DR potential and costs/availability of intelligent technologies.[42]

Firstly, availability of dynamic supply contracts for commercial and residential consumers is not equally distributed across Europe, though an increasing share of RES-E and implicit volatility of generation may extend the spectrum of offers. Nordic countries and Spain are the pioneers in this field.[42]

Awareness of the savings potential as well as the risks induced by dynamic electricity contracts are crucial for the uptake on dynamic pricing models. Hence, dynamic contracts have to be designed in an easy-to-use way to enable achievability of savings while minimizing efforts to achieve them. Before concluding a dynamic contract, consumers need to be properly informed about the price risks especially of RTP models as they could encounter significant increases in their electricity bills.[42]

Sufficient shifts in consumption will only occur if incentives for consumers are considerably high. Wholesale prices might not be volatile enough to induce such shifts. Another factor is that the energy component of an average retail electricity bill only amounts to 33%. Thus, uptake of dynamic contracts might be limited. In addition, the future development of devices capable to provide sufficient DR potential is unknown. A higher share of electric vehicles and heat pumps could enhance the uptake of dynamic contracts in the residential sector but the development rate of those technologies remains uncertain.[42]

DR has to be performed automatically and without impacting the consumer’s lifestyle, otherwise shifts of consumption are unlikely. Therefore, development of smart devices and home automation is necessary, thus, the greatest barrier for the uptake of this technologies are purchase costs. Some electricity retailers are tackling this issue by providing special offers i.e. financing models to their consumers.[42]

Dynamic pricing requires continuous information on consumption on an adequate time basis, which is generally provided via a smart meter. It has to be noted, that currently only 14 EU countries have rolled out smart meters or are planning to do so and that most of these smart meters are not equipped with crucial functions for dynamic pricing i.e. dynamically identifying a certain time instant and setting critical hours. EURELECTRIC emphasizes the necessity for integration of functions like multiple tariffs options corresponding to different load curves, identification of peak and off-peak periods, etc. Integration of such functions has to be considered upfront as constant updates for smart meters are no option at the moment.[42]

3.4.3. Requirements and Recommendations for Dynamic Pricing

From EURELECTRIC’s point of view, the first step towards sufficient uptake on dynamic pricing models is customer information. If the number of consumers with dynamic contracts reaches a certain level, participation will further develop due to advertisement and increasing awareness.[42]

It should be the supplier’s choice how they design and offer dynamic pricing models. Regulatory interference i.e. regulation of the supplier’s margins on dynamic models would hamper the competiveness in the market and could result in reduced uptake on dynamic contracts limiting the overall DR potential. The required IT infrastructure to process the models, necessary data, invoices, etc. still needs to be developed which might be a considerable entry barrier especially for smaller suppliers.[42]

EURELECTRIC identifies price incentives to be key not only for dynamic pricing and DR but also for further electrification and substitution of other fuels. Therefore, fundamental changes of the overall electricity costs for consumers are suggested, targeting energy as well as network costs. In general, the levies component should be lowered and financed alternatively i.e. through taxation of other fuels. The remaining part of regulated costs should be distributed in alternative ways i.e. through TOU network tariffs charging different prices for different periods of a day or a year. Such tariffs can furthermore be extended with CPP clauses for a predefined number of days per year.[42]

Finally, access to smart meters forms the basis for the uptake on dynamic pricing. Even though consumers might have to bear the costs for a smart meter on their own, they should clearly have the right to opt for one. This ensures that smart meters are also available in countries with no intentions for a roll-out, or where the rollout is not finished yet.[42]

3.5. ACER / CEER − Whitepaper on Facilitating Flexibility

In May 2017, the Agency for the Cooperation of Energy Regulators (ACER) and National Regulatory Authorities in the Council of European Energy Regulators (CEER) responded to the Communication from the Commission - Clean Energy for all Europeans (cf. 2.2.5). The published White Paper focuses on suggestions to facilitate flexibility. For ACER/CEER it is key that participation of all consumers in all markets is ensured which includes the participation through (independent) aggregation and that undue barriers are removed to facilitate participation of all different sources of flexibility ensuring a level-playing field.[43]

From a regulator's point of view, participation of flexibility in areas of grid management (balancing, reserve capacity, etc.) shall not be restricted nor biased towards certain sources. Area-wide roll-out of smart meters is required to ensure accurate measuring for settlement processes implying data is shared with all relevant parties while maintaining protection of sensitive data. Furthermore, the following extensions are suggested to complement the Commissions Communication:[43]

Member States shall be able to implement alternatives to independent aggregators if this is found to be more efficient and effective especially if competition in retail markets is strong. Thus, costs for regulatory approaches could be avoided, leading to a higher overall efficiency.[43]

Market access of independent aggregators has to be assured by Member States preventing foreclosure by suppliers. To ensure system efficiency, ACER/CEER suggests to establish arrangements for compensations payments for resold energy related to flexibility services. The settlement process should either be performed via a central financial settlement or be included in bilateral contracts between the supplier and the consumer. Both of these approaches do not include a contractual relationship between the supplier and aggregator.[43]

Since the EU Communication finds DSOs to have a pivotal role for flexibility activities DSOs are assigned with additional responsibilities including data exchange, elaboration of network development plans featuring alternatives to grid expansion, setup of an EU wide DSO entity, etc. Those additional tasks, which are not necessarily related to DSOs core business, require sufficient regulatory observation and effective unbundling. Finally, yet importantly, coordination between TSOs and DSOs is necessary to set a level-playing field and efficient processes for all variations of flexibility.[43]

[43] (European Energy Regulators' White Paper #3 - Facilitating flexibility, 2017)

3.6. Recapitulation and Thoughts

This chapter's task was to give an overview of DSM measures proposed by stakeholders. The conducted analysis focused on stakeholders, which appeared to have the highest relevance and the most impact with respect to overall influence on electricity systems and markets. Selected stakeholders cover all market segments: ENTSO-E represents TSO's views, focusing on stability of the assigned control perimeters, balancing responsibilities respectively balancing markets, procurement of reserve capacity etc. EURELECTRIC acts as the representative sector association for the European electricity industry and operates in public affairs on its behalf.[44] Finally, yet importantly, ACER and CEER represent the national regulatory bodies, setting regulations in different fields to ensure competitiveness and overall efficiency of electricity systems, markets and for consumers.

From ENTSO-E's point of view, successful implementation of DSR requires to overcome five critical issues. First, TSO's and DSO's roles and responsibilities have to be clarified, as both parties would use DSR resources for different system tasks. Therefore, ENTSO-E intends to take a leading role in setting up clear responsibilities to enforce DSR. This also includes data access for all relevant stakeholders, generally sharing it amongst involved parties, clarification of DSR initiation responsibilities and standardized communication protocols. To ensure sufficient data handling and sharing, communication and control technologies i.e. smart meters are a necessity. Furthermore, ENTSO-E recommends to setup neutral data handling bodies. Performance criteria set up by legislative measures is key to ensure DSR's capability to increase security of supply and postpone grid development. Market mechanisms have to be adapted to support and promote DSR. This especially requires proper price signals and incentives for DSR but also the development of "DSR friendly" products with adequate bidding sizes, bidding times and gate closure times, though, subsidies inducing market distortions have to be limited to a minimum i.e. to kick-off DSR in the first place. Nowadays, most medium and small size consumers (especially residential consumers) do not have the choice between fixed or flexible supply contract allowing for price respectively time dependent adaption of consumption which represents a major barrier for the development of DSR. Likewise, offering flexibility to the market either by consumer on their own or via an aggregator shall be promoted. Latter is key to efficient utilization of DSR potential as competition between aggregators and suppliers increases DSR's economic value. ENTSO-E points out the importance for simplicity and clarity of DSR products being invoiced in one single

[44] (About EURELECTRIC, 2016)

bill combining supply and DSR costs. Finally, development of DSR requires a common European framework, setting specific regulations on an EU level while implying a certain share of flexibility for realization on national levels considering different circumstances. As DSR has an effect on the overall electricity system and brings new challenges, a common European framework has to ensure that system relevant tasks are not jeopardized.

ENTSO-E's key recommendations for the effective and efficient implementation of DSR include the development of concrete market measures based on cost-benefit analyses, sufficient competition for consumers' DSR potential and reduction of possible market entry barriers while ensuring well-functioning of electricity markets. From ENTSO-E's point of view, the largest potential for DSR lies in reserve capacity markets, especially in countries with a high share of volatile RES-E.

ENTSO-E also provides ideas and examples on how to incorporate DSR alongside suppliers, consumers and markets, taking into account different DSR models and their mutual influences. For DSR activities in retail, wholesale and balancing markets, ENTSO-E differentiates between integrated and dissociated DSR models depending on either DSR clauses are included in supply contracts or not. Integrated DSR models are basically straight forward models as they require no contractual relationship between the aggregator and the supplier. They can either be designed as variable supply price models where consumers adapt their consumption on their own due to price signals or as supplier load control models where curtailment of the consumer's is performed by the supplier. ENTSO-E points out, that such models do not allow aggregators to act independent form suppliers, wherefore they should be combined with other models. The implementation of dissociated DSR models is not straight forward, but implies different issues mainly relating to the transfer of energy form the BRP source or supplier to the aggregator, the risk of BRP source imbalances and information and confidentiality concerns. Dissociated DSR models can either include a contractual relationship between the BRP source/supplier and the aggregator (bilateral agreement) or not. Bilateral agreement models have the advantage of consent between involved parties and therefore provide a high degree of fairness including the sharing of economic risks. They solve the transfer of energy and imbalance issue to a very high extend as well as competition issues arising from exchanging information i.e. with standardized enforceable contracts set by regulators. Though it has to be noted, that the current EU communication does not obligate aggregators to compensate suppliers or BRP sources for the transfer of energy, which could be a barrier for the bilateral agreement model.

Market models without bilateral agreement especially tackle information and confidentiality issues implied by a bilateral agreement. The aggregator is responsible for deviations of its activated and sold energy. However, since there is no bilateral agreement the risk of imbalances induced by aggregators performing DSR activities is shifted to the BRP source. This requires the transfer of information on DSR activities from the aggregator to the TSO/DSO (metering entity), which passes it on to the BRP source. There are two different approaches for market designs without bilateral agreement, the supplier settlement and the central settlement model. In the supplier settlement model the transfer of energy is settled between the supplier and the consumer according to supply conditions. The additional costs for the consumer are compensated by the aggregator via the flexibility contract. Single and double billing variations determine if the BRP source/supplier receives merged or explicit metering information on DSR activations. In case of the central settlement model, not only transfer of information but also energy and compensations is managed by a central entity. In these models, either compensations for energy transfer can be settled using individual supply tariffs or a price set by the regulator. This model can resolve the post-contract confidentiality issue, although regulatory set prices could compromise the level-playing field. Models without bilateral agreement allow aggregators to act independently from suppliers, can resolve confidentiality issues and therefore enhance competition for DSR potential. However, ENTSO-E claims that implementation of such complex market designs will take considerable time.

Finally, yet importantly, reserve capacity markets could present themselves as another field of application for DSR to gain additional revenues. Besides much easier integration of DSR in reserve capacity markets than in other markets, the capacity potential of DSR is rated to be much higher than its energy potential, at least in most countries. In this case, transfer of energy due to DSR activities could be neglected and only imbalances inflicted to the BRP source would need to be compensated. However, this pragmatic approach has to be reviewed regarding its applicability in different reserve capacity markets, as the energy component can be the major source for revenues if the capacity component’s price is very low.

Being the second major stakeholder, EURELECTRIC commissioned a study performed by DNV GL to evaluate the Commission’s Communication, focusing on its impacts and especially on the necessity for compensations between suppliers respectively generators and aggregators for resold energy. The study identified two major issues if compensation between aggregators and suppliers is not required, namely the imbalance and the bulk energy issue. Their effects are comparable to the transfer of energy and risk for BRP source imbalance issues explained by

ENTSO-E. However, the information and confidentiality issues described by ENTSO-E find only little or no consideration in this paper. The paper states that the bulk energy issue only arises for DR activities, reducing the consumer's load but not if the load increases. Nevertheless, increasing load also requires additional energy procurement. Therefore, this is only true as long as the inflicted costs are passed on to the consumer in a cost-reflective way, since the aggregator could sell flexibility to the balancing market while the supplier has to source energy i.e. in a spot market. This would also affect the overall efficiency of markets.

DNV GL finds that the current EU proposal, which only implies compensation for imbalances caused by aggregators and no compensation for resold energy likely to result in increased costs of system services for consumers and other market participants. Tackling the imbalance issue should be done via transfer of energy from the impacted BRP's perimeter or the supplier to the aggregator's BRP, allowing to forecast respectively schedule DR activations. Additionally, the rebound effect, leading to unexpected consumption behavior of certain DR providers, has to be considered. The bulk energy issue is found to violate general market principles since energy, which is sold, has to be bought or compensated, which is not planed in the current proposal. This would foster economic inefficiencies as the costs inflicted to the supplier overweight the revenues generated by the aggregator in the market.

From DNV GL's point of view, the impact form DR on wholesale prices cannot be predicted sufficiently. Additionally, the study authors assume that DR will mainly be sold and used for balancing purposes, which does not correspond with ENTSO-E's predictions. Ensuring a level-playing field for all market participants i.e. competition of small and large suppliers, and keeping electricity tariffs on an optimal level, requires compensation payments.

The paper also discusses market models, which take a different approach for the bulk energy issue, via a model comparable either to ENTSO-E's supplier settlement model or via socialism, where a levy is inflicted on many system users. Such a levy would work as a subsidy for aggregators, although, this model is only economically efficient if the levy does not over or undercompensate sourcing cost and (only) consumers paying the levy profit from decreasing electricity tariffs in the long run. However, introduction of a levy, which decreases with time, could be used as an additional incentive to stimulate the development of aggregators in the first place.

Previous analyses focused on explicit DR, where consumers' flexibility is sold to wholesale, balancing or reserve capacity markets. EURELECTRIC also presented a position paper reviewing implicit DR, which offers consumers the opportunity to conclude electricity contracts with time-varying, dynamic prices. Adaption of consumption patterns and behavior as a reaction to price signals can help consumers reduce their electricity bill. There are two basic variations of such models either with fixed prices for a certain period of time i.e. day/night, season, which are not linked to wholesale prices (with this models consumers can still sell their flexibility in the market), or dynamic models linked to wholesale prices i.e. TOU, CPP, RTP. Dynamic models offer a different degree of dynamism, implying various levels of price risks for consumers, with RTP being the most dynamic model.

EURELECTRIC identified that availability of dynamic pricing models is not equally distributed across Europe and that awareness of potential savings and risks are key for the development of implicit DR. Special attention is given to the fact, that the energy component of an average retail bill only amounts to 33% and wholesale prices might not be volatile enough to sufficiently encourage consumption shifts. Furthermore, the future development of enabling technologies like smart devices, home automation and the roll-out of smart meters, which is currently only planned or performed in 14 EU countries, are crucial factors. From EURELECTRIC's point of view, suppliers should be given the choice to offer dynamic pricing models or not. Any regulatory interference could hamper competitiveness and limit the uptake on dynamic models. EURELECTRIC votes for a general change of overall electricity costs, whereby the levies component should be lowered and financed alternatively. Finally, yet importantly, consumers should have the right to opt for a smart meter, although, they might have to bear the costs themselves.

Finally, ACER's respectively CEER's views on flexibility where analyzed. Their views focus on ensuring a level-playing field for all sources of flexibility, especially in areas of grid management. Therefore, regulatory interventions should be limited to an absolute necessary minimum. The whitepaper suggests that compensation payments for resold energy should be installed. These compensations should either be settled by a central financial settlement or be included in bilateral supply contracts between suppliers and consumers. These suggestions comply with the current EU Communication's approaches on settlements. Furthermore, latter's ideas on new and additional tasks for DSOs induced by an increasing share of flexibility, are grasped to require sufficient regulatory observation and effective unbundling.

From all analyzed stakeholder concepts, ENTSO-E presented the most complex and comprehensive models, not only focusing on financial compensations for energy and imbalances but also taking into account information and confidentiality issues. They generally identified compensations to be necessary, incorporated them in all their proposed models and presented their models two years up front to the EU's proposal. EURELECTRIC also points out the necessity for compensation payments, although, their approaches on explicit DR only cover information and confidentiality issues to little or no extend. However, unlike ENTSO-E, who only brushes implicit DR models, EURELECTRIC also tackles this topic, especially pointing out issues related to low incentives for consumers and composition of overall electricity costs. Lastly, ACER/CEER represents the position to keep regulatory interventions to a minimum, leading to higher overall efficiency. ACER/CEER also supports the introduction of compensation payments either via a central financial settlement or via bilateral contracts between consumers and aggregators.

From a personal point of view, the European Commission's intentions to facilitate DR by laying down the required legal framework are much appreciated. Stakeholder contribution and cooperation imply that the willingness to facilitated DR is given. However, from a pragmatic point of view, most of the presented concepts (especially the ENTSO-E concepts) are highly sophisticated and complex. Therefore, the applicability in the residential but also commercial sector is questionable. Industrial consumers, especially energy intensive industries are likely to hold more potential for DR. Since the number of potential industry applications and equipment is limited and their power is high, utilization of industrial DR might offer fairly easily unlockable potential for DR.

4. Potential Analysis for Demand Response − Residential, Commercial and Industrial Sector

On the way to reach European energy and emission targets, Member States will facilitate the expansion of volatile RES, especially wind and photovoltaic. Since these forms of electricity generation are strongly weather-dependent, ensuring national balancing between generation and demand will be challenging. Transmission systems have a key role when integrating this volatile generation, as they imply compensation of at least some of the volatility of RES-E generation, although public acceptance for transmission system projects is low across the continent.[45] Furthermore, massive power flows in the transmission system imply relatively high losses and therefore overall inefficiencies.[46] From a financial point of view, national feed-in laws i.e. the German Erneuerbare-Energien-Gesetz (EEG) have been set up to finance and accelerate the development of RES-E in Germany.[47] As a consequence of high volatility of wind and PV generation, very low or even negative wholesale electricity prices can emerge (i.e. in the German market).[48] Thus foreign market participants, which are certainly not the financiers of RES-E, can gain financial advantages. Since cross-border power flows are physically limited, the number of redispatch measures continuously increases leading to immense costs and economic inefficiencies.[49] In 2017, the Austrian TSO APG had to perform redispatch measures on 301 days of the year, leading to cost of about 319 M€ compared to 150 M€ in 2016. As a result, system usage charges for 2018 were significantly raised, especially on network level 3 where most industries are connected to the grid.[50]

Finally, yet importantly, electricity cannot be stored directly (at least on a large-scale and with high energy density), but has to be converted into another form of energy (potential, mechanical, chemical, etc.). This fact also implies that conversion and reconversion losses occur, which leads to overall inefficiencies. Nevertheless, storage technologies will play an important role in the future electricity system, but they will not solve all challenges on their own.

[45] (The benefits of cooperation in a highly renewable European electricity network, 2017)
[46] (Finding a representative network losses model for large-scale transmission expansion planning with renewable energy sources, 2016)
[47] (German energy policy and the way to sustainability: Five controversial issues in the debate on the "Energiewende", 2016)
[48] (Negative Preise - Wie sie entstehen, was sie bedeuten, 2018)
[49] (Quartalsbericht zu Netz- und Systemsicherheitsmaßnahmen, 2017)
[50] (Stresstest: Kritische Situationen für Österreichs Stromversorgung 2017, 2018)

The impact of RES-E's volatility manifests itself especially during so-called "cold dark doldrums", which can occur during winter months. In this period, PV generation is very low due to little daylight and irradiation and wind generation is low due to doldrums. However, generally load demand is high during this period (especially in Austria). Hence, cold dark doldrums can be qualified as critical situations for the electricity system. In this context, it has to be noted, that there is no generally accepted and unified definition of the term cold dark doldrums yet.[51]

It has been assumed that the situation of cold dark doldrums occurs if electricity generation by wind power plants is less than 10% of its installed power capacity.

Diagram 1 shows the impacts of such cold dark doldrums based on an hourly resolution. From January 28, 2017 (13:00) to February 4, 2017 (01:00) the hourly wind generation in Austria was less than 10% of the installed capacity (2.649 MW at the end of 2016 [52]). During this period, average PV generation (only hours with actual generation taken into account) amounted to 66 MW, whereby maximal PV generation was 170 MW (1.096 MW_{peak} at the end of 2016 [53]). The total duration of this cold dark doldrums was 156 hours, which equals 6,5 days.

Diagram 2 illustrates the load during the considered cold dark doldrums. As assumed, the largest share of load demand during the investigated cold dark doldrums corresponds to the maximal annual load. As a consequence, this existing yet unavailable capacity has to be compensated, generally by utilizing fossil-fueled power plants.

Diagram 3 shows, that the highest 700 MW of the maximal annual load are only demanded during a ten days period, but not for the rest of the year. However, this maximal annual load determines the totally required (fossil-fueled) generation capacity.[54] Therefore, it has an impact on the overall system costs. In the Austrian case, the existent generation deficit was mostly covered utilizing gas-fired power plants and electricity imports (Diagram 4).

[51] (Identifizierung kritischer Wettersituationen im Hinblick auf die Stromerzeugung in Westeuropa - Kurzfassung, 2018)
[52] (Windenergie in Österreich - Entwicklung der Windkraft in Österreich seit 2000, 2018)
[53] (Innovative Energietechnologien in Österreich - Marktentwicklung 2016, 2017)
[54] (Potentiale und Hemmnisse für Power Demand Side Management in Österreich, 2008)

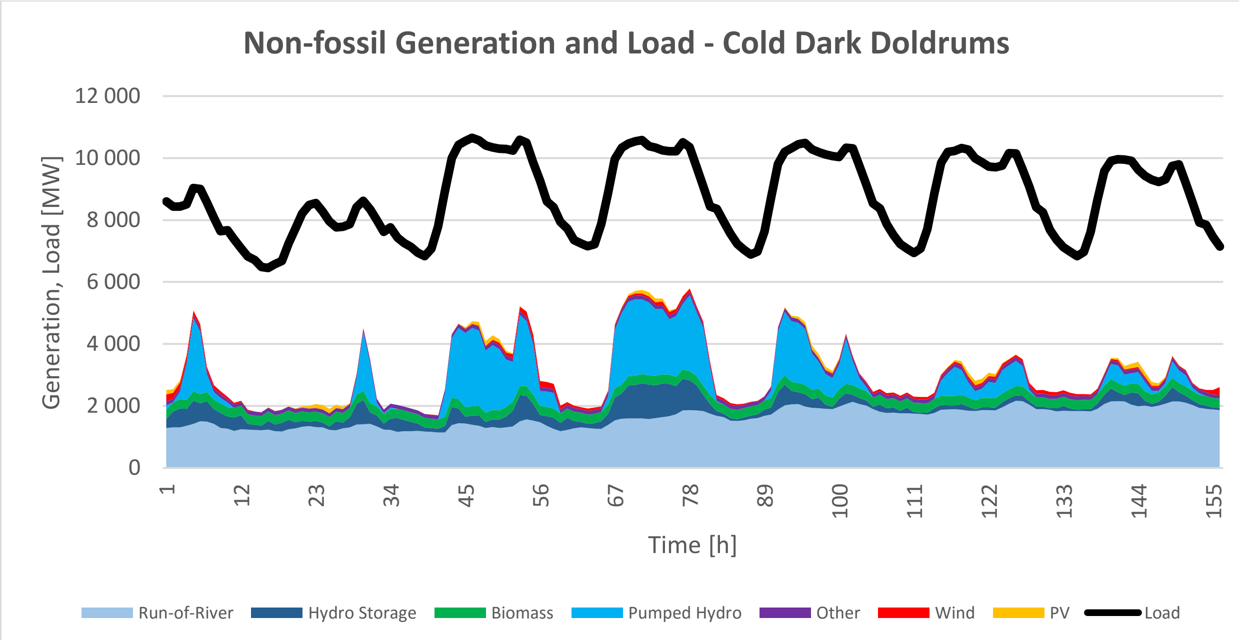

Diagram 1: Non-fossil generation and load during cold dark doldrums, January-February 2017, Austria
Source: Own representation, based on data from [55, 56, 57]

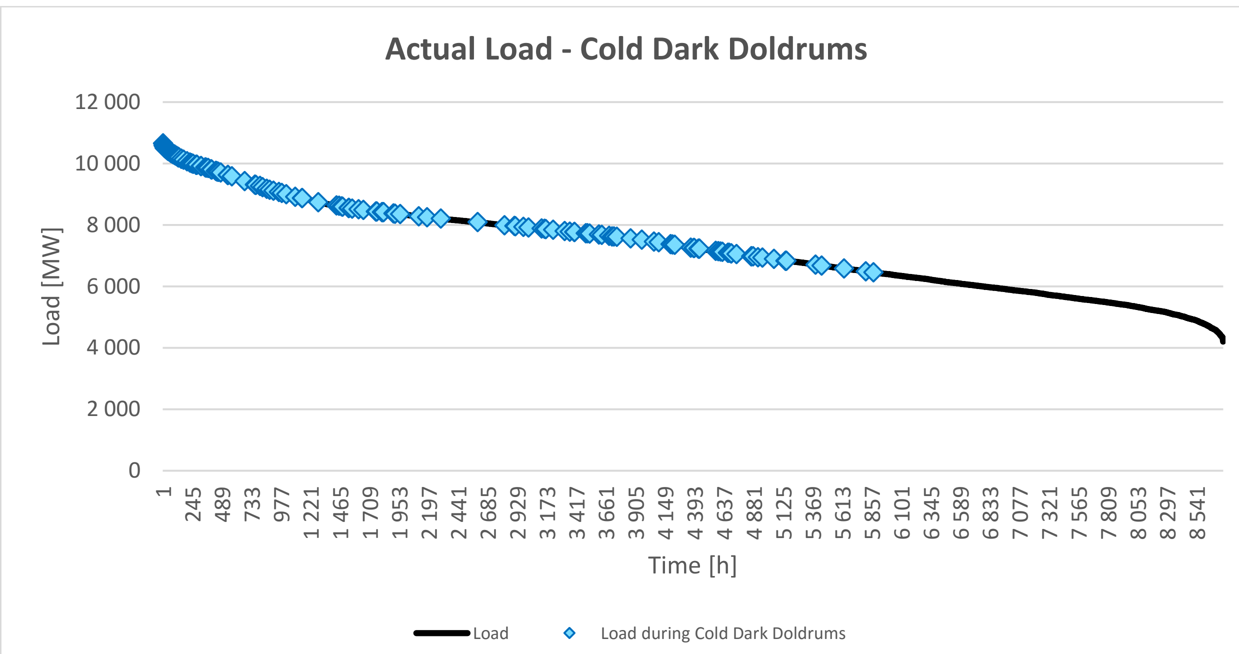

Diagram 2: Load duration curve and actual load during cold dark doldrums January-February 2017, Austria
Source: Own representation, based on data from [56, 57]

[55] Position ‘Other’ includes: geothermal, waste, other renewables and other sources
[56] (APG - Ist-Last, 2018)
[57] (APG - Erzeugung nach Typ, 2018)

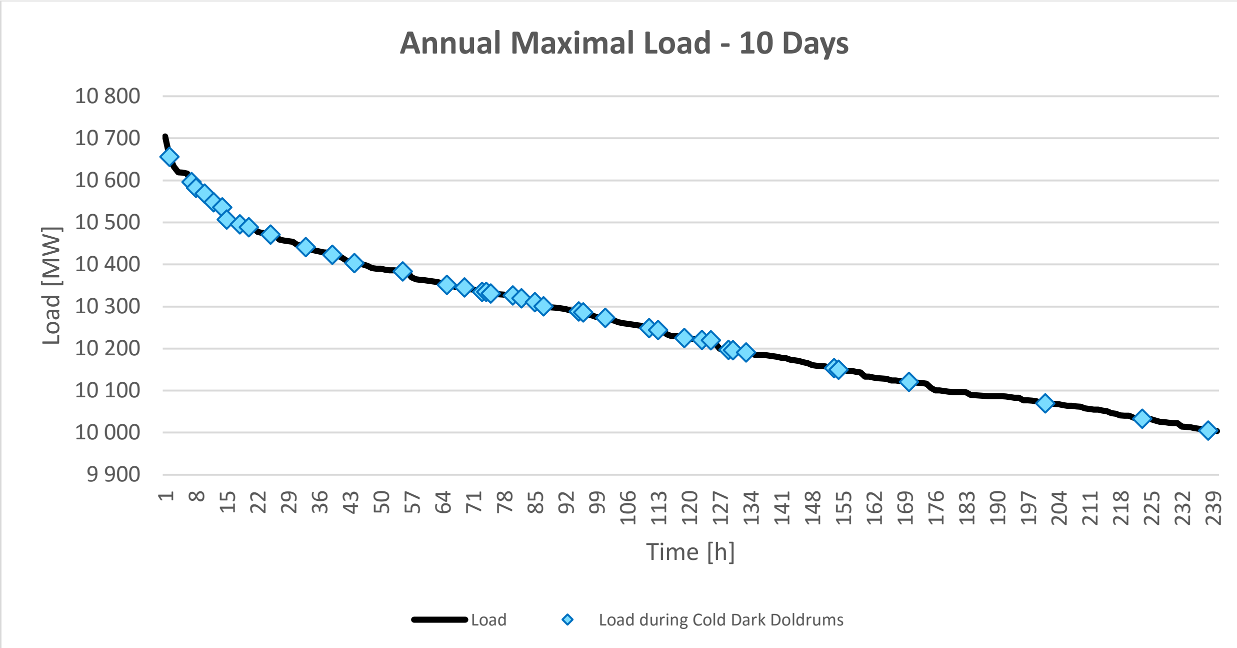

Diagram 3: Duration curve of the annual maximal load 2017, Austria
Source: Own representation, based on data from [56, 57]

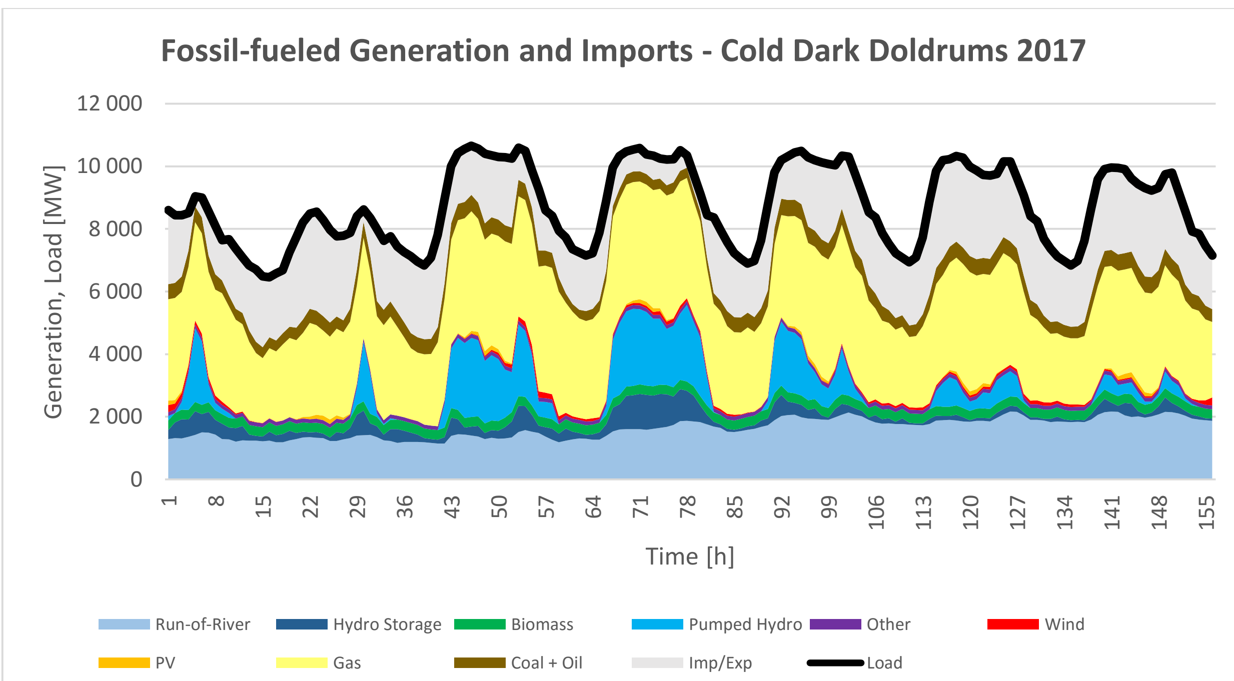

Diagram 4: Fossil-fueled generation and imports during cold dark doldrums, January-February 2017, Austria
Source: Own representation, based on data from [55, 56, 57]

Although, higher wind and PV generation would not have been able to completely substitute generation from gas-fired power plants and electricity imports, especially wind generation could have provided a major contribution taking into account the totally installed capacity.

Taking into account the illustrated issues, DR could present itself as a valid alternative to grid expansion, electricity storage and huge RES-E overcapacities. In the following chapters the potentials and impacts of different forms of DR provided by the residential, commercial and industrial sector are investigated and analyzed.

4.1. Residential Sector

Several studies focus on the identification of mostly theoretical DR potentials, either on a European or a national level. Representative for such studies, the focus is set on data which has been evaluated by Gils [58], as the calculated potentials seem to be most reasonable compared to other studies (comparison was done for Germany only).[59] Gils determined the theoretical average potential for DR in the European residential sector, utilizable via load shifting, to be 37 GW.[60] For load reduction, the minimal potential is less than 20 GW and the maximal potential is higher than 75 GW. The average residential potential for load increase is 209 GW, the minimal potential is 43 GW and the maximal potential is found to be 449 GW. Furthermore, time-of-use of different residential appliances can be either delayed, advanced or delayed and advanced. The study identified an average load reduction potential of about 0,6 GW for Austria, mainly utilizing freezers/refrigerators and heat circulation pumps. Average load increase potential is significantly higher and amounts to 3,5 GW. As a comparison, the average potential for load reduction in Germany is about 6,4 GW, the average potential for load increase is 27,4 GW.[58]

Most investigated studies have in common, that they define the two parameters maximal shifting time t_{shift} and the intervention time $t_{intervention}$ to evaluate DR potential. The maximal shifting time limits the duration until load used for DR (either by delayed or advanced utilization) has to be powered again. The intervention time limits the maximal available duration of a DR intervention. Both parameters are quantified by similar values in different studies.[59, 58, 61, 62] Representative values are shown in Table 2.

[58] (Assessment of the thoretical demand response potential in Europe, 2014)
[59] (Demand Response Potential: Available when Needed?, 2018)
[60] The study includes not only the EU-28 but also Albania, Belarus, Bosnia and Herzegovina, Liechtenstein, Macedonia, Moldova, Montenegro, Norway, Serbia and Kosovo, Switzerland, Turkey and Ukraine as well as several norther African countries: Algeria, Egypt, Libya, Morocco and Tunisia but which only have a minor impact on the statistic
[61] (Dynamische Simulation eines Lastmanagements und Integration von Windenergie in ein Elektrizitätsnetz auf Landesebene unter regelungstechnischen und Kostengesichtspunkten, 2007)
[62] (Power grid balancing of energy systems with high renewable energy penetration by demand response, 2008)

Potential DR Appliances: Residential Sector			
	DR action	**t_{shift}**	**$t_{intervention}$**
	[-]	**[h]**	**[h]**
Freezer/refrigerator	delay	2	1
Washing machine, tumble dryer, dish washer	advance/delay	6	-[63]
Residential air conditioner	delay	2	1
Residential electric storage water	advance	12	12
Residential heat circulation pumps	delay	2	1
Residential electric storage heater	advance	12	12

Table 2: Maximal shifting time and intervention duration for residential appliances with DR potential
Source: Own representation, based on data from [58]

Average, maximal but also minimal theoretical residential DR potentials, evaluated by Gils and other studies, imply that the residential sector can have a major contribution for providing DR. However, taking into account the figures presented in Table 2, residential DR potential is limited to short time spans and therefore not capable to have a major effect during cold dark doldrums. Furthermore, utilization of heating appliances is high during cold dark doldrums, which additionally limits shifting, and intervention times.

When considering the additional requirements necessary to utilize residential DR potential, it becomes apparent that this potential cannot be utilized at the moment. As described in chapter 3.4.2, enabling technologies as smart meters are only rolled-out or planned to be rolled out in 14 EU countries. This implies that dynamic pricing models, which require at least a smart meter, are also not available in most countries. As a consequence, consumers do not receive any incentives to shift their consumption. Furthermore, the availability and number of smart devices is limited at the moment. Even if those devices where available, adaption would require a considerable amount of time.

The stated issues also apply to explicit DR, since communication and control of consumer devices is not available or included yet. Possible exceptions can be hot water boilers. Furthermore, the fact that aggregators are required to conclude individual flexibility contracts with every single consumer limits the current residential DR potential.[64]

[63] No general limit can be determined

[64] (Integration of Demand-Side Response in the Swiss Ancillary Service Markets through the ENTSO-E Central Settlement Model, 2018); additional information received during the 15. Symposium Energieinnovation 2018, TU Graz; Aby Chacko, Swissgrid Ltd

4.2. Commercial Sector

Similarly, to the residential sector, theoretical DR potential in the commercial sector is high with an average of 31 GW for load reduction on a European level. The minimal load reduction potential is less than 20 GW, whereas the maximal load reduction potential is more than 75 GW. The minimal load increase potential is assumed to be 21 GW compared to a maximal load increase potential of 45 GW with an average of 33 GW. The study identified an average load reduction potential of about 0,36 GW for Austria. Table 3 presents the maximal shifting and intervention times assumed for commercial applications with DR potential.[58]

Potential DR Applications: Commercial Sector			
	DR action	**t_{shift}**	**$t_{intervention}$**
	[-]	**[h]**	**[h]**
Cooling in food retailing	delay	2	1
Cold storages	advance/delay	2	2
Cooling in restaurants and hotels	advance/delay	2	2
Commercial ventilation	delay	2	1
Commercial air conditioning	delay	2	1
Commercial storage water heater	advance	12	12
Commercial storage heater	advance	12	12
Pumps in water supply	advance/delay	2	2
Waste water treatment	advance/delay	2	2

Table 3: Maximal shifting time and intervention duration for commercial applications with DR potential
Source: Own representation, based on data from [58]

As for the residential sector, shifting and intervention times are short, wherefore the potential effects during cold dark doldrums are very limited. As for commercial applications, heating demand is high during cold dark doldrums too. However, several commercial applications with high power and a relatively low number i.e. ventilation and air conditioning in shopping centers, could be utilized for short-time DR, by increasing their load to support compensation of sudden generation spikes.

4.3. Industrial Sector

Gils states, that the annual average potential for load reduction in industry is about 25 GW and mostly constant during a year. The potential for load increases varies between 2 GW and 8 GW with an average of 5 GW. The study identified an average load reduction potential of about 0,32 GW for Austria. Table 4 presents the maximal shifting and intervention times assumed for industrial applications with DR potential.[58]

Potential DR Application: Industrial Sector			
	DR action	**t_{shift}**	**$t_{intervention}$**
	[-]	**[h]**	**[h]**
Electrolytic prod. of primary aluminum	load shedding	- [65]	4
Electrolytic refinement of copper	load shedding	- [65]	4
Electrolytic production of zinc	load shedding	- [65]	4
Electric arc furnaces for steel	load shedding	- [65]	4
Chloralkali process	load shedding	- [65]	4
Cement mills	advance/delay	24	3
Mechanical wood pulp production	advance/delay	24	3
Recycling paper	advance/delay	24	3
Paper machines	advance/delay	24	3
Calcium carbide production	advance/delay	24	3
Air liquefaction in cryogenic rectification	advance/delay	24	3
Cooling in food manufacturing	advance/delay	24	3
Ventilation	delay	2	2

Table 4: Maximal shifting time and intervention duration for industrial applications with DR potential
Source: Own representation, based on data from [58]

As Table 4 shows, industrial processes imply longer shifting durations than residential and commercial applications, although, interference times are also very limited.

[65] Load does not need to be rebalanced in case of load shedding

4.4. Potential Analysis of “Long-term” Demand Response – Industrial Sector

European circumstances, stated in chapter 4, suggest another approach towards efficient and effective industrial DR. The idea is to shut down qualified processes for a medium to long time duration (for 5-10 continuous days). The resulting load reduction can help to reduce the maximal annual load, as well as provide an opportunity to react to critical generation situations (deficit or excess generation of volatile RES-E). Table 5 presents the relevant data to calculate the annual energy and power potential of industrial DR in Europe (investigated countries are listed in the Annex). Q_{ann} describes the annual production output of each investigated branch, based on the average annual output from 2011-2015. W_{spec} is the specific energy demand per ton of output. The factor AV quantifies the availability of the process by considering revision times. UT describes the capacity utilization of a process and N_{ann} the number of hours per year.

Based on Q_{ann} and W_{spec} the total annual energy demand per process W_{ann} is calculated.

$$\mathbf{W_{ann} = Q_{ann} \cdot W_{spec}}$$

The installed power P_{inst} of each utilizable process to provide DR is derived from AV, UT, W_{ann} and N_{ann}.

$$\mathbf{P_{inst} = \frac{W_{ann}}{AV \cdot UT \cdot N_{ann}}}$$

Calculation results (see Table 5) show a European DR potential of approximately 30 GW, which corresponds to Gils’ findings of an average of 25 GW. It has to be noted, that not all countries investigated by Gils, were included in the calculations. However, it has been assumed that all processes can be shut down completely, which increases the available DR potential. Furthermore, calculations based on annual production outputs imply that some of the determined values for the installed capacity deviate from reality. However, the problem has to be approached somehow, as retrieving information from each individual industry would have gone beyond the scope of this Master’s Thesis.

This radical approach might seem inconvenient at first, but in order to substantially change our systems, intensive actions are required. However, the possibility to completely shut down industrial processes, as well as its implied consequences, can only be determined in bilateral discussions between power sector companies (PSC) and the industry. Therefore, TSOs and Regulators could take responsibility in organizing and managing such discussions.

Energy and Power Demand of DR Applications: Industrial Sector - Europe						
	Q_{ann}	W_{spec} [58]	AV [58]	UT [58]	W_{ann}	P_{inst}
	[kt/a]	[kWh/t]	[%]	[%]	[GWh/a]	[MW]
Primary aluminum electrolysis	3.544 [66]	14.000	95	95 [67]	49.613	6.275
Copper electrolysis	3.418 [68]	350	95	95	1.196	152
Zinc electrolysis	2.159 [69]	3.400	95	95 [70]	7.340	928
Steel - electric arc furnaces	71.766 [71]	525	95	75 [67]	37.677	6.037
Chloralkali process - mercury cell	2.440 [72]	3.400 [73]	95	85 [67]	8.295	1.173
Chloralkali process - diaphragm cell	1.525 [72]	2.800 [73]	95	85 [67]	4.271	604
Chloralkali process - membrane cell	5.692 [72]	2.600 [73]	95	85 [67]	14.800	2.092
Cement mills	184.876 [74]	110	95	80	20.336	3.058
Mechanical wood pulp defibration	9.859 [75]	1.500	95	80	14.789	2.224
Recycling paper process	55.713 [75]	250	95	80	13.928	1.833
Pulp and paper machines	95.857 [75]	425	95	90	40.739	5.428
Calcium carbide production	500 [76]	3.100	95	80	1.550	233
Annual DR Potential - Europe						**30.037**

Table 5: Relevant data to determine the annual energy and power potential of DR applications in Europe
Source: Own representation, based on data from [58]

Table 6 presents investigated Austrian industries with DR potential. The total installed power utilizable for DR amounts to 581 MW, which is about twice the potential stated by Gils (269 MW). Furthermore, 581 MW equals 5,43% of the maximal annual load of 2017 (Diagram 2). By utilizing this DR potential, 581 MW of generation capacity could be conserved. This capacity is only required for 168 hours per year (= 1 week).

[66] (2015 Minerals Yearbook - Aluminum, 2016)
[67] (The potential of demand-side management in energy-intensive industry for electricity markets in Germany, 2010)
[68] (2015 Minerals Yearbook - Copper, 2017)
[69] (2015 Minerals Yearbook - Zinc, 2017)
[70] Estimated value based on [58] since 100% capacity utilization is doubtful
[71] (Steel Statistical Yearbook 2016, 2016)
[72] (Chlorine Industry Review 2011/12 - 2016/17, 2012 - 2017)
[73] (Best Available Techniques (BAT) Reference Document for the Production of Chlor-alkali, 2014)
[74] (2014 Minerals Yearbook - Cement, 2017)
[75] (Forestry Production and Trade - FAOSTAT, 2018)
[76] (Emission Problems and Opportunities from Calcium Carbide Production, 2006)

Energy and Power Demand of DR Applications: Industrial Sector - Austria						
	Q_{ann}	W_{spec} [58]	AV [58]	UT [58]	W_{ann}	P_{inst}
	[kt/a]	[kWh/t]	[%]	[%]	[GWh/a]	[MW]
Steel - electric arc furnaces	677 [71]	525	95	75	355	57
Chloralkali process - membrane cell	60 [77]	2.600 [73]	95	85	156	22
Cement mills	4.464 [78, 79]	110	95	80	491	74
Mechanical wood pulp defibration	373 [75]	1.500	95	80	560	84
Pulp and paper machines	4.914 [75]	425	95	90	2.089	278
Recycling paper process	1.467 [75]	250	95	80	367	48
Calcium carbide production	38 [80]	3.100	95	80	118	18
Annual DR Potential - Austria						**581**

Table 6: Relevant data to determine the annual energy and power potential of DR applications in Austria
Source: Own representation, based on data from [58]

To avoid economic impacts of DR measures on the participating processes, losses in production quantity have to be compensated at some point of time. Coordinated scheduling of revision times could be an option to compensate these losses, although, maintenance would have to be done parallel for all processes. Since industrial processes do not work to full capacity, another option to compensate these losses could be increasing the utilization of the available capacity. Based on data presented in Table 6 the rate of capacity utilization with DR (UT_{DR}) is calculated.

$$\mathbf{UT_{DR}} = \frac{\mathbf{W_{ann}}}{\mathbf{AV} \cdot (\mathbf{N_{ann}} - \mathbf{t_{DR}}) \cdot \mathbf{P_{inst}}}$$

Table 7 shows that the required capacity utilization increment ΔUT for the assumed annual DR duration t_{DR} = 168 h varies between 1,5% and 11,9%, which should be achievable by all processes. Another approach would be to determine the minimal time required (t_{min}) to cover emerging losses in production output upfront by increasing capacity utilization to 100% and stocking the production surplus.

$$\mathbf{t_{min}} = \frac{\mathbf{UT}}{(\mathbf{1} - \mathbf{UT})} \cdot \mathbf{t_{DR}}$$

[77] (Chlorine Industry Review 2011/12 - 2016/17, 2012 - 2017); Estim. Q_{ann} based on a production capacity of 65 kt/a
[78] (Österreichs Zementindustrie: Vertrauenskrise bremst Investitionen, Jahresbilanz 2014 und Prognose 2015, 2015)
[79] (Österreichs Zementindustrie: Jahresbilanz 2015 und Prognose 2016, 2016)
[80] (Austrias National Inventory Report 2017, 2017)

The principle of stocking production surplus is called “Energy-Service Storage” (ESS). Industrial processes generally utilize electric energy to change physical or chemical properties of input factors - an energy-service is performed. Regularly, the resulting output products can be stored in ESSs, whereas electricity cannot be stored directly (cf. 4). In industry, ESS units i.e. tanks, bunkers or warehouses, frequently are available.[54] This principle supports the concept of long-term DR.

In case of some industry branches i.e. electric arc furnaces, the possibility to increase capacity utilization is very limited due to smelting respectively emptying and refilling durations.[67]

However, DR might induce some additional effects on participating industries i.e. the necessity to adapt plant and process management or additional wages for working staff. These effects are not considered in this approaches.

Required Utility Increment: Industrial Sector - Austria									
	AV	UT	W_{ann}	P_{inst}	N_{ann}	t_{DR}	UT_{DR}	ΔUT	t_{min}
	[%]	[%]	[GWh/a]	[MW]	[h/a]	[h/a]	[%]	[%]	[wk/a]
Steel - electric arc furnaces	95	75	355	57	8.760	168	76,5	1,5	-
Chloralkali process - membrane cell	95	85	156	22	8.760	168	86,7	1,7	5,7
Cement production	95	80	491	74	8.760	168	81,5	1,5	4,0
Mechanical wood pulp defibration	95	80	560	84	8.760	168	81,5	1,5	4,0
Recycling paper	95	90	367	48	8.760	168	93,1	3,1	9,0
Pulp and paper machines	95	80	2.089	278	8.760	168	91,9	11,9	4,0
Calcium carbide production	95	80	118	18	8.760	168	81,5	1,5	4,0

Table 7: Required utility increment to compensate losses in production due to DR measures
Source: Own representation, based on data from [58]

4.5. Financial Impact of "Long-term" Demand Response − Industrial Sector

Alongside the technical potential of the processes listed in Table 6, the financial impacts DR measures might have on its providers, have to be considered. Therefore, the value of lost load (VOLL), which quantifies the financial losses due to power interrupts, is determined. In general, the VOLL is the quotient of the gross value added (GVA) of a certain industry sector and its electricity demand (ED). This approach to determine the VOLL does not consider sectoral linkages.[81]

$$\mathbf{VOLL} = \frac{\mathbf{GVA}}{\mathbf{ED}}$$

According to the definition of Statistik Austria the GVA is the total value of the commodities and services generated during production processes (production value) reduced by the value of the processed and converted commodities and services (input).[82]

Table 8 shows the production value (PV), the GVA and the ED for the period from 2013 to 2015. Statistik Austria annually publishes some of the presented data (PV, GVA) on their website. However, data on the corresponding ED is only available for the main categories defined in ÖNACE 2008 (Austrian version of the European classification of economic activity [83]). To increase the VOLL's significance, more detailed information on the ED of classification subcategories would be required. Due to confidentiality reasons this information is not available.[84] Data on ED includes self-generation from PV, wind, hydro power and other plants as well as externally generated electricity. Under given circumstances, the VOLL is calculated for the superior categories instead (gray rows, Table 8). Based on this data, the VOLL of a certain year is calculated and presented in Table 9.

[81] (The Value of Lost Load for Sectoral Load Shedding Measures: The German Case with 51 Sectors, 2016)
[82] (Definition - Gross Value Added, 2003)
[83] (Classification Database, 2018)
[84] Information telephonically received from Statistik Austria

Shortcut	ÖNACE 2008	Output of DR Applications	2013			2014			2015		
			PV	GVA	ED	PV	GVA	ED	PV	GVA	ED
			[M€]	[M€]	[GWh]	[M€]	[M€]	[GWh]	[M€]	[M€]	[GWh]
Production of pulp/paper and goods from it	C17		5.699,5	1.652,2	4.437,4	5.761,5	1.775,7	4.644,3	5.790,6	1.772,5	4.437,1
Production of wood pulp, paper and pulp	C171	Wood pulp, pulp a. paper, recycling paper	3.436,3	767,3	n.a.	3.397,0	852,5	n.a.	3.404,9	855,9	n.a.
Production of chemical products	C20		13.984,7	2.134,2	3.411,1	13.652,3	2.232,4	3.580,8	12.807,2	2.656,8	3.613,4
Production of basic inorganic substances	C2013	Calcium carbide, Chlor	269,7	96,0	n.a.	267,0	93,4	n.a.	258,7	98,7	n.a.
Production of glass/-products, ceramics, etc.	C23		6.017,1	2.281,3	1.460,4	6.201,1	2.393,9	1.592,5	6.083,6	2.317,5	1.540,8
Production of cement	C2351	Cement	366,3	152,6	n.a.	376,0	155,4	n.a.	379,2	157,8	n.a.
Production and processing of metal	C24		14.768,1	3.399,4	4.919,0	14.796,2	3.540,0	5.072,1	15.544,0	3.883,4	5.061,2
Steel	C241	Crude iron and steel	7.409,2	1.653,3	n.a.	7.345,4	1.613,4	n.a.	7.475,1	1.871,7	n.a.

Table 8: Sectoral production values, gross values added and electricity demand of industrial DR applications
Source: Own representation, based on data from [85, 86]

It has to be noted, that the determined VOLL does not consider any seasonal or temporal effects influencing the production output i.e. time of day, time of power interruption, duration of power interruption, etc. Such factors have been considered in other studies i.e. by Reichl.[87]

Table 9 shows the VOLL for the years 2013 to 2015. Production of cement shows a high VOLL compared to other processes due to its relatively low specific energy demand (cf. Table 6). Since the VOLL is calculated for superior categories, it can only estimate the specific VOLL for the subcategories. Therefore, its quality of estimation is assessed. Due to the fact that the specific energy demand for the considered processes is high, the process' GVA within its superior category has to be high as well, in order to receive an estimation of the VOLL of proper quality. For quality estimation of relevant VOLLs, GVAs of all individual subcategories are sorted from largest to smallest and compared to each other.

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[85] (Leistungs- und Strukturstatistik 2013-2015, Produktion und Dienstleistungen, 2015-2017)
[86] (Energieeinsatz im Produzierenden Bereich 2013-2015, 2018)
[87] (The value of supply security: The cost of power outages in Austrian households, firms and the public sector, 2012)

Shortcut	Output of DR Applications	VOLL			
		2013 [€/kWh]	2014 [€/kWh]	2015 [€/kWh]	Quality of estimation
Production of wood pulp, paper and pulp	**Wood pulp, Pulp and paper, Recycling paper**	0,372	0,382	0,399	=
Production of chemical products	**Calcium carbide, Chlor**	0,626	0,623	0,735	<<
Production of glass/-products, ceramics, etc.	**Cement**	1,562	1,503	1,504	<
Production and processing of metal	**Steel**	0,691	0,698	0,767	=

Table 9: VOLL for industrial DR applications, 2013-2015
Source: Own representation, based on data from [85, 86]

Results show that the determined VOLL for the "production of wood pulp, paper and pulp" and for the "production and processing of metal" reflects the actual VOLL of its relevant subcategories. In case of "production of glass/ -products, ceramics, etc." the determined VOLL is likely to underestimate the actual VOLL. For the "production of chemical products" a significant underestimation has been identified.

Increasing the capacity utilization for the process of steel smelting with electric arc furnaces is difficult (cf. 4.4). Here the VOLL could be used for financial quantification of production losses, since quality of estimation has been found to be significant.

Table 10 presents the non-consumed energy during a DR action (W_{DR}) and the corresponding loss in GVA (GVA_{loss}) if the missing production output is not shifted to an earlier or later point in time. S_{DR} quantifies financial savings for non-consumed energy (based on corresponding EXAA-Spot prices; cf. Table 12) and L_{DR} the resulting losses due to a DR action. In case of the steel smelting from electric arc furnaces, assuming a DR duration of 168 hours, annual losses L_{DR} amount to 4,8 M€ (cf. 4.6).

Annual Loss in GVA per Industry								
	Ø VOLL	P_{inst}	UT	t_{DR}	W_{DR}	GVA_{loss}	S_{DR}	L_{DR}
	[€/kWh]	[MW]	[%]	[h/a]	[MWh/a]	[k€/a]	[k€/a]	[k€/a]
Wood pulp	0,385	84	80	168	11.290	4.346,5	530,8	3.815,7
Pulp and paper	0,385	278	80	168	37.363	14.384,8	1.756,8	12.628,0
Recycling paper	0,385	48	90	168	7.258	2.794,2	341,3	2.452,9
Calcium carbide	0,661	40	80	168	5.376	3.553,5	252,8	3.300,8
Chlor	0,661	22	85	168	3.142	2.076,6	147,7	1.928,9
Cement	1,523	74	80	168	9.946	15.147,1	467,6	14.679,5
Steel	0,719	57	75	168	7.182	5.163,9	337,7	4.826,2
Annual result						**47.466,6**	**3.834,7**	**43.631,9**

Table 10: Annual loss in GVA per industry if production losses cannot be compensated
Source: Own representation, based on data from [58, 85, 86]

Up to this point, only industrial load reduction potential has been analyzed. Volatility of RES-E, however, also implies massive surplus generation spikes, which can as well be qualified as critical generation situations. Since all investigated processes do not work to full capacity, available industrial capacity could be utilized to at least partially compensate such spikes. This is already done by several businesses (not necessarily energy intensive industry), which prequalified their processes for the negative control power market. In case of participation in the control power market, prequalification criteria i.e. power slew rate and power consistency have to be met (cf. 3.2.9).[36]

Load increase could also be realized through installation of additional industrial power capacity. This power capacity should be (at least partially) financed by the electricity sector, as the sector obtains economic benefits due to DR. The approach for realization of financing is explained in the following chapter.

It has to be noted that the specific investment costs required to quantify total costs for additional industrial power capacity were not investigated. This would have gone beyond the scope of this Master's Thesis.

4.6. Financial Impact of "Long-term" Demand Response − Electricity Sector

The proposed DR approaches only consider a continuous onetime DR action. However, based on the assumption that 581 MW of industrial power could be shut down during the annual peak load time, annual cost savings for power plants not required anymore are calculated. Since peak demand is mostly covered by gas-fired power plants, the costs for 581 MW of gas turbine power plants (GT) in total respectively a combined-cycle power plant (CCP) with the same power are used to illustrate potential annual cost savings. Relevant input data is presented in Table 11.

Relevant Input Data GT vs. CCP			
		GT	CCP
Installed capacity	[MW]	581	581
Time-of-use	[h]	168	168
Specific investment costs	[$€_{2011}$/MW]	656.017	1.083.422
Maintenance (capacity based)	[$€_{2011}$/MW·a]	2.780	5.085
Economically useful life	[a]	25	30
Outside capital rate	[%]	100	100
Interest rate (nominal)	[%]	4	4
Insurance	[$€_{2011}$/MW·a]	2.520	3.285
Personnel intensity	[EMP/MW]	0,03	0,08
Average salary (PSC sector in AUT) [88]	[$€_{2011}$/EMP·a]	61.703	61.703
Maintenance (generation based)	[$€_{2011}$/MWh]	5,5	3,5
CO_2 - emissions [89]	[g/kWh]	440	440
CO_2 - price (EUA), (2016-2017) [90]	[€/t]	5	5

Table 11: Relevant input data for gas turbine and combined cycle power plants
Source: Own representation, assumptions from [91]

Since economically efficient operation of gas-fired power plants is hardly possible at the moment, annual operation time is very limited (operation for redispatch measures is not considered). As a result of these circumstances even highly efficient power can be unprofitable. In some cases, it is even planned to sell power plants. If the annual operation time is assumed to be 168 hours (reference operation duration; GT: 1000 h/a; CCP: 4500 h/a [91]), achievable revenues for gas-fired power plants are very limited (Table 12). For the following calculations it has been assumed that a DR action with a duration of 168 hours is performed (January 28, 2017 (00:00) - February 4, 2017 (01:00)). This period covers the whole duration of the cold dark doldrums but also a share of the period of the annual maximal load. It has to be noted, that overlap of maximal annual load

[88] (Eurostat - Average annual gross earnings by sex and NACE, 2014)
[89] (E-Control - CO2 emissions and avoidance, 2018)
[90] (EEX - EU Emission Allowances, Secondary Market, 2018)
[91] (Institute of Electricity Economics and Innovative Energy Technologies - Internal database, 2018)

and cold dark doldrums is not ensured for every year. For the calculations maximal utilization of generation capacity has been assumed. Annual interests have been assumed to be constant. With the net present value method, more detailed quantification would be possible.

Annual Fixed Costs			
		GT	CCP
Depreciation (linear)	[k€$_{2011}$/a]	15.245,8	20.982,3
Interests	[k€$_{2011}$/a]	609,8	839,3
Maintenance (capacity based)	[k€$_{2011}$/a]	1.615,2	2.954,4
Personnel	[k€$_{2011}$/a]	1.049,0	2.776,6
Insurance	[k€$_{2011}$/a]	1.464,1	1.908,6

Variable Costs			
		GT	CCP
Generation costs	[k€$_{2011}$/a]	3.328,4	3.328,4
Maintenance (generation based)	[k€$_{2011}$/a]	536,8	341,6
CO_2 - costs	[k€$_{2011}$/a]	214,7	214,7

Assumed Market Parameters		
Ø EXAA-Spot Price (Jan-Feb 2017) [92]	[€/MWh]	47,0
Natural gas price Q3 & Q4 2016 [93]	[€/MWh]	34,1

Annual Costs, Revenues, Losses			
		GT	CCP
Total annual costs	[k€$_{2011}$/a]	**24.063,9**	**33.346,0**
Total annual revenues	[k€$_{2011}$/a]	**1.261,1**	**1.261,1**
Total annual losses	[k€$_{2011}$/a]	**22.802,8**	**32.084,9**

Table 12: Annual fixed, variable and total costs, market parameters, revenues and losses of GT and CCP power plants

Source: Own representation, based on data from [91]

Under current circumstances, annual losses of 581 MW of GT power plants amount to 22,8 M€, whereas annual losses for a CCP power plant of the same capacity amount to 32,1 M€.

Instead of building new power plants for future peak demand coverage, these costs could be saved. Part of the savings should be used to utilize the development of DR and industrial DR in particular. However, capital already invested into power plants cannot be recovered with these measures (or at least only to a low extend). Such costs are referred to as sunk costs.[94]

Part of the conserved losses presented in Table 12 could be devoted to compensate the steel industries losses (cf. Table 10). However, it has to be noted that the calculated losses L_{DR} only

[92] (EXAA - Historical market data - spot prices, 2017)
[93] (Eurostat - Natural gas price statistics, 2017)
[94] (Beitrag zur volkswirtschaftlichen Theorie der Elektrizitätswirtschaft, 2018)

reflect the loss in GVA, but do not consider the loss of actual revenues and/or profits from selling end-products at retail prices.

4.7. Recapitulation and Thoughts

This chapter's task was to determine the DR potential of the residential, commercial and industrial sector. To illustrate possible contributions DR can have in Austria, the impact of cold dark doldrums, which represent critical situations for the system, has been underlain. In late January 2017 such cold dark doldrums occurred for a continuous period of 6,5 days. During this period, generation from wind power plants was less than 10% of the installed capacity while electricity demand was around its annual peak. Subsequently, an even higher share of electricity demand than usually had to be covered by gas-fired power plants and electricity imports. Due to the absence of enabling technologies (smart meter, smart devices, etc.) as well as incentives to facilitate DR, the currently achievable DR potential in the residential and commercial sector is very limited. However, the industrial sector, and especially energy intensive industrial processes, are likely to hold bigger potential for DR. Several studies determined a maximal DR duration of 2 to 4 hours, while the potentially available time to shift load is infinite in case of load shedding or up to 24 hours if load is advanced/delayed. For the analyzed processes, complete shutdown during DR actions has been assumed. Based on the annual production output and the specific energy demand per ton of output, the installed capacity available for DR has been determined. In the Austrian case, the DR potential amounts to 581 MW. Investigated processes include steel smelting from electric arc furnaces, chloralkali processes, cement mills, mechanical wood pulp defibration, pulp and paper machines, recycling paper processes and the production of calcium carbide. In context with annual peak load, this potential implies a possible reduction of 581 MW. In 2017, the corresponding time of this reduction amounted to 168 hours which has been used as a calculation basis. However, investigation results reveal a huge gap between non-fossil generation and actual load demand. By utilizing DR, only a relatively small share of this gap can be covered. Taking into account these circumstances, achievability of the ambitious target of 100% RES-E by 2030, stated in the recently presented Austrian climate and energy strategy, is questionable.

Complete shutdown of the investigated industrial processes implies losses in production output. As the capacity utilization of all investigated processes is lower than 90%, losses in production output can be compensated over time if it is possible to increase capacity utilization. This can either be done by slightly increasing capacity utilization for the rest of the year or by increasing it to (theoretically) 100% for a short time span. Latter can be done upfront or subsequently to DR activities. The principle of ESS can be utilized to handle increased production output during a limited duration of time.

Non-utilized industrial power capacity could be used to compensate surplus generation spikes, by providing negative control power. This is already done by several businesses. To have an even bigger impact, however, installation of additional industrial power capacity, partially financed by the electricity sector, is conceivable.

For certain processes, increasing the capacity utilization is not possible (or at least only to a very low extend) i.e. steel smelting form electric arc furnaces. If the installed capacity is not increased (installation of additional electric arc furnaces), and therefore production losses cannot be compensated, the financial impact for an affected steel manufacturer can be assessed using the value of lost load. The VOLL quantifies the financial losses of power interrupts of a certain industry sector. Due to confidentiality reasons, required input data is only available for superior industry categories rather than subcategories. To estimate validity of the VOLL anyway, its quality of estimation has been determined. Based on the VOLL and an annual DR of 168 hours the annual losses in gross value added respectively net losses have been determined. For steel smelting with electric arc furnaces annual net losses would amount to 4,8 M€.

In context with generation capacity for covering peak demand, this potential implies that 581 MW, which are only required for 168 hours per year, can be conserved. During the assumed DR period, peak demand is mostly covered by gas-fired power plants. Therefore, annual fixed and variable costs for 581 MW of gas turbine power plants in total respectively a combined cycle power plant have been determined. Results show that annual losses for such power plants with very little operating time amount to 22,8 - 32,1 M€. These losses respectively power plant capacity could be conserved with coordinated DR actions. Part of the conserved losses should be used to facilitate further development of DR i.e. by provide incentives to potential participants. This should also include financing the installation of additional process capacity of well suited, fast responding processes i.e. mechanical wood pulp defibration.

From a personal point of view, the main factor currently limiting industrial DR potential is lack of communication between the electricity and industrial sector. Bilateral discussions between PSCs and the industry should be organized and managed by TSOs as well as regulators. Overcoming these barriers can reveal significant additional DR potential, as both parties gain information on the others technical limitations and possibilities as well as requirements. This also includes cooperation and coordinated management regarding conceivable additional power capacity.

5. Summary

The increasing share of electricity generated from renewable energy sources and the implied unavoidable volatility of generation enforces adaptions of future electricity systems and markets.

In the first section of this Master's Thesis, the parallel development of renewable energy sources and demand side management in the European Union is outlined. Therefore, legal framework conditions in form of EU directives and regulations, starting in the late 1980s up to recently proposed regulations, are analyzed. These define the European Union's master plan towards an Energy Union until 2030. The master plan is titled as "Clean Energy for all Europeans" and generally referred to as "Winter Package". Next to lowering carbon intensity by 43% (compared to nowadays levels), the package's key objectives target a share of 50% electricity from renewable energy sources in 2030. The Winter Package includes three directives and one directive, which (partially) amend existing legislative framework (i.e. Directive 2012/27/EU on energy efficiency). In this context, roles of market participants are redefined and presented as well as other terminologies. One terminology defines the role of an "aggregator", which is qualified to aggregate the load potential of multiple consumers as well as generated electricity for trading in energy markets or to provide it to the market in form of "Demand Response". Demand response describes the change of electricity patterns of consumers in response to different market signals.

In the second section of the Master's Thesis, demand response concepts of selected stakeholders are analyzed (ENTSO-E, EURELECTRIC and ACER/CEER). Analyzed stakeholder positions allow to draw conclusions on the organization of future electricity markets, considering impacts of aggregators and demand response. Analyzed stakeholder concepts include integrated respectively implicit as well as dissociated respectively explicit demand response models. Integrated/implicit models utilize supplier load control or dynamic electricity price models to enable demand response whereas dissociated/explicit models enable consumers to directly offer their demand response potential to the market, either on their own or via an aggregator. Analysis shows, that ENTSO-E lays its focus on dissociated/explicit demand response models as they presented three different concepts with an increasing level of complexity for each concept. Those concepts not only consider the transfer of energy and implied compensation payments between involved market participants, but also information and confidentiality issues implied by such transfers. Regarding compensation payments, EURELECTRIC has commissioned a study to evaluate their necessity, as such payments were not considered in European framework conditions. The study concludes that compensation payments are required to avoid economic distortions of electricity markets. From ENTSO-E's point of view the largest potential of dissociated/explicit demand response lays in reserve capacity markets, whereas the study commissioned by EURELECTRIC sees it in the field of balancing energy. Alongside this study, EURELECTRIC also presents detailed concepts on integrated/implicit demand response in form of dynamic pricing models. Such dynamic pricing models imply different chances but also risks for consumers depending on their dynamisms and the consumer's ability to respond to varying prices. Finally, yet importantly, ACER/CEER set their focus on ensuring a level-playing field for all sources of flexibility. Therefore, regulatory interventions should be kept to a minimum and compensation payments should be installed. Also, ACER/CEER is in support of ENTSO-E's most complex concept for demand response.

With legal framework set (at least to a certain degree) and implementation concepts proposed, the question for the available demand response potential emerges. The third section of this Master's Thesis emphasizes critical situations induced by the high share of volatile renewable energy sources, so called cold dark doldrums, which are already present today. Cold dark doldrums occur during winter time and can last for several days. In this timeframe, load demand is maximal (applies to Austria) but electricity generation form PV and wind power plants is very low. Resulting electricity deficits are mainly compensated by generation from gas-fired power plants, which are only active for a few hours per year, or via electricity imports. During such critical situations, demand response could present itself as a valid alternative. To quantify the Austrian respectively European demand response potential, electrical appliances and applications in the residential, commercial and industrial sector are investigated. The currently available demand response potential of the residential and commercial sector is determined to be relatively low. These circumstances occur, because access to required technical framework (share of smart meters, availability of smart devices, etc.), as well as dynamic electricity tariffs and aggregators is limited at the moment. However, industrial consumers, especially energy intensive industries, hold bigger potential for demand response as installed power is high but the number of potential processes is low. To achieve the maximal load reduction effect of industrial demand response, it is assumed that qualified industrial processes are completely shut down for the duration of demand response activities, in order to utilize their full capacity. The total resulting potential amounts to 581 MW for Austria. This Master's Thesis not only determines the demand response potential of industrial processes, but also addresses financial aspects. This is done by comparing costs of demand response actions (losses in gross value added) to costs for existing gas-fired power plants, which become dispensable when realizing demand response. As a consequence, prevented costs should be used to provide incentives for industrial demand response. The demand response potential of 581 MW determined in chapter 4.4, should illustrate that there are indeed valid alternatives to the construction of new fossil-fueled power plants. This Master's Thesis shall also induce rethinking in the electricity sector by considering scientific impulses for further development of demand response. This should not only be done due to economic deliberations and for profit maximization, but especially due to environmental reasons. As the basic principle is:

"The only form of clean energy is the one that's not required at all".

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Bibliography

2014 Minerals Yearbook - Cement. (2017, March). *minerals.usgs.gov.* (H. G. van Oss, Ed.) Retrieved February 28, 2018, from https://minerals.usgs.gov/minerals/pubs/commodity/cement/

2015 Minerals Yearbook - Aluminum. (2016, November). *minerals.usgs.gov.* (E. L. Bray, Ed.) Retrieved February 28, 2018, from https://minerals.usgs.gov/minerals/pubs/commodity/aluminum/index.html#myb

2015 Minerals Yearbook - Copper. (2017, October). *minerals.usgs.gov.* (M. Brininstool, & D. M. Flanagan, Eds.) Retrieved February 28, 2018, from https://minerals.usgs.gov/minerals/pubs/commodity/copper/index.html#myb

2015 Minerals Yearbook - Zinc. (2017, September). *minerals.usgs.gov.* (A. C. Tolcin, Ed.) Retrieved February 28, 2018, from https://minerals.usgs.gov/minerals/pubs/commodity/zinc/index.html#myb

A Demand Response Action Plan for Europe - Regulatory requirements and market models. (2012, June). *www.smartenergydemand.eu.* (Smart Energy Demand Coalition (SEDC), Ed.) Retrieved October 24, 2017, from http://www.smartenergydemand.eu/demand-response-action-plan-for-europe-2/

A review of demand-side management: Reconsidering theoretical framework. (2017, May 31). *www.sciencedirect.com.* (A. F. Meyabadi, & M. H. Deihimi, Eds.) Retrieved October 16, 2017, from http://www.sciencedirect.com/science/article/pii/S1364032117308481

About EURELECTRIC. (2016). *www.eurelectric.org.* (EURELECTRIC, Ed.) Retrieved January 23, 2018, from http://www.eurelectric.org/about-us/

Annual Statistical Report: 2012 European Bioenergy Outlook. (2013). (European Biomass Association (AEBIOM), Ed.) Retrieved October 23, 2017, from https://www.google.at/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=0ahUKEwjfzoe36YbXAhVF7BQKHXdLCvkQFgg1MAE&url=http%3A%2F%2Fwww.aebiom.org%2Fwp-content%2Fuploads%2F2015%2F10%2F2012-AEBIOM-Annual-Report-2013-final-version_small1.pdf&usg=AOv

APG - Balancing. (2018). *www.apg.at.* (APG, Ed.) Retrieved January 15, 2018, from https://www.apg.at/en/market/balancing

APG - Erzeugung nach Typ. (2018, February 20). *www.apg.at.* (APG, Ed.) Retrieved February 20, 2018, from https://www.apg.at/de/markt/Markttransparenz/erzeugung/Erzeugung%20pro%20Typ

APG - Ist-Last. (2018, February 20). *www.apg.at.* (APG, Ed.) Retrieved February 20, 2018, from https://www.apg.at/de/markt/Markttransparenz/last/Ist-Last

APG - Results of the Tenders for Control Power. (2018). *www.apg.at.* (APG, Ed.) Retrieved January 15, 2018, from https://www.apg.at/de/markt/netzregelung/sekundaerregelung/ausschreibungen

APG - Tenders for Secondary Control Power in the APG Control Area. (2018). *www.apg.at.* (APG, Ed.) Retrieved March 19, 2018, from https://www.apg.at/en/market/balancing/secondary-control/tenders

APG - Tenders for Secondary Control Power in the APG Control Area. (2018). *www.apg.at.* (APG, Ed.) Retrieved January 15, 2018, from https://www.apg.at/en/market/balancing/secondary-control/tenders

Assessment of the thoretical demand response potential in Europe. (2014, March 1). *www.sciencedirect.com.* (H. C. Gils, Ed.) Retrieved February 21, 2018, from https://www.sciencedirect.com/science/article/pii/S0360544214001534

Austrias National Inventory Report 2017. (2017). *www.umweltbundesamt.at.* (M. Anderl, et al., Ed.) Retrieved February 28, 2018, from http://www.umweltbundesamt.at/aktuell/publikationen/publikationssuche/publikationsdetail/?pub_id=2208

Beitrag zur volkswirtschaftlichen Theorie der Elektrizitätswirtschaft. (2018, February). *www.tugraz.at.* (H. Stigler, U. Bachhiesl, & R. Gaugl, Eds.) Retrieved March 14, 2018, from https://www.google.at/url?sa=t&rct=j&q=&esrc=s&source=web&cd=6&ved=0ahUKEwjHsKnuhezZAhVJ1ywKHUQXCIgQFghcMAU&url=https%3A%2F%2Fwww.tugraz.at%2Ffileadmin%2Fuser_upload%2FEvents%2FEninnov2018%2Ffiles%2Fkf%2FPlenum_P3%2FKF_Stigler.pdf&usg=AOvVaw3tjiqBc6cB166p

Best Available Techniques (BAT) Reference Document for the Production of Chlor-alkali. (2014). *ec.europa.eu.* (T. Brinkmann, et al., Ed.) Retrieved February 28, 2018, from https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/best-available-techniques-bat-reference-document-production-chlor-alkali-industrial

Chlorine Industry Review 2011/12 - 2016/17. (2012 - 2017). *www.eurochlor.org.* (Euro Chlor, Ed.) Retrieved February 28, 2018, from http://www.eurochlor.org/download-centre/the-chlorine-industry-review.aspx

Classification Database. (2018). *www.statistik.at.* (Statistik Austria, Ed.) Retrieved March 5, 2018, from http://www.statistik.at/KDBWeb/kdb_Einstieg.do?NAV=DE

Communication from the Commission (COM (2016) 860 final) - Clean Energy for all Europeans. (2016, November 30). *eur-lex.europa.eu.* (European Commission, Ed.) Retrieved October 30, 2017, from http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2016:860:FIN

Council Decision (89/364/EEC) - Community action programme for improving the efficiency of electricity use. (1989, June 5). *eur-lex.europa.eu.* Retrieved October 19, 2017, from http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1508396927073&uri=CELEX:31989D0364

Definition - Gross Value Added. (2003, November 21). *wko.at.* (Statistik Austria, Ed.) Retrieved March 5, 2018, from http://wko.at/ooe/Zahlen/KlassGliedSys/Def-RegProd.htm

Demand Response Activation by Independent Aggregators as Proposed in the Draft Electricity Directive. (2017, July 13). *www.eurelectric.org.* (H. Ziegler, T. Mennel, & C. Hülsen, Eds.) Retrieved January 16, 2018, from http://www.eurelectric.org/media/340062/eurelectric_dr_aggregation_final_report-2017-2521-0002-01-e.pdf

Demand Response Potential: Available when Needed? (2018, January 16). *www.sciencedirect.com.* (T. Müller, & D. Möst, Eds.) Retrieved February 21, 2018, from https://www.sciencedirect.com/science/article/pii/S0301421517308509

Demand Side Response Policy Paper. (2014, September 15). *www.entsoe.eu.* (ENTSO-E, Ed.) Retrieved December 13, 2017, from https://www.entsoe.eu/publications/position-papers/position-papers-archive/Pages/Position%20Papers/Demand-Side-Response-Policy.aspx

Directive (2001/77/EC) - Promotion of electricity produced from renewable energy sources in the internal electricity market. (2001, September 27). *eur-lex.europa.eu.* (European Parliament, & Council of the European Union, Eds.) Retrieved October 24, 2017, from http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32001L0077

Directive (2012/27/EU) - Energy efficiency. (2012, October 25). *eur-lex.europa.eu.* (European Parliament, & Council of the European Union, Eds.) Retrieved October 25, 2017, from http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32012L0027

DNV GL - Structur of the Organization. (2017). *www.dnvgl.com.* (DNV GL, Ed.) Retrieved January 16, 2018, from https://www.dnvgl.com/about/in-brief/our-organisation.html

Dynamic pricing in electricity supply - A EURELECTRIC position paper. (2017, February). *www.eurelectric.org.* (EURELECTRIC, Ed.) Retrieved January 19, 2018, from www.eurelectric.org/media/309103/dynamic_pricing_in_electricity_supply-2017-2520-0003-01-e.pdf

Dynamische Simulation eines Lastmanagements und Integration von Windenergie in ein Elektrizitätsnetz auf Landesebene unter regelungstechnischen und Kostengesichtspunkten. (2007). *publica.fraunhofer.de.* (M. Klobasa, Ed.) Retrieved February 22, 2018, from http://publica.fraunhofer.de/documents/N-68615.html

E-Control - CO2 emissions and avoidance. (2018). *www.e-control.at.* (E-Control, Ed.) Retrieved March 15, 2018, from https://www.e-control.at/en/konsumenten/oeko-energie/klima-und-umwelt/umweltauswirkungen

EEX - EU Emission Allowances, Secondary Market. (2018). *www.eex.com.* (EEX, Ed.) Retrieved March 13, 2018, from https://www.eex.com/en/market-data/environmental-markets/spot-market/european-emission-allowances#!/2018/03/13

Emission Problems and Opportunities from Calcium Carbide Production. (2006, December). *www.diva-portal.org.* (C.-E. Larsson, Ed.) Retrieved February 28, 2018, from http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A411529&dswid=-2940

Energieeinsatz im Produzierenden Bereich 2013-2015. (2018). *www.statistik.at.* (Statistik Austria, Ed.) Retrieved March 13, 2018, from Information received per email from Statistik Austria

Energy for the Future: Renewable Sources of Energy. White Paper for a Community Strategy and Action Plan. (1997, November 26). *aei.pitt.edu.* (European Commission, Ed.) Retrieved October 23, 2017, from http://aei.pitt.edu/1130/

European Energy Regulators' White Paper #3 - Facilitating flexibility. (2017, May 22). *acer.europa.eu.* (ACER, & CEER, Eds.) Retrieved January 23, 2018, from https://acer.europa.eu/Official_documents/Position_Papers/Pages/default.aspx

Eurostat - Average annual gross earnings by sex and NACE. (2014, March 24). *ec.europa.eu.* (Eurostat, Ed.) Retrieved March 13, 2018, from http://ec.europa.eu/eurostat/web/labour-market/earnings/database

Eurostat - Natural gas price statistics. (2017, November). *ec.europa.eu.* (Eurostat, Ed.) Retrieved March 13, 2018, from http://ec.europa.eu/eurostat/statistics-explained/index.php/Natural_gas_price_statistics

EXAA - Historical market data - spot prices. (2017). *www.exaa.at.* (EXAA, Ed.) Retrieved March 13, 2018, from https://www.exaa.at/de/marktdaten/historische-daten

Finding a representative network losses model for large-scale transmission expansion planning with renewable energy sources. (2016, March 24). *www.sciencedirect.com.* (D. Z. Fitiwi, et al., Ed.) Retrieved February 20, 2018, from https://www.sciencedirect.com/science/article/pii/S0360544216300573

Forestry Production and Trade - FAOSTAT. (2018). *www.fao.org.* (Food and Agriculture Organization - United Nations, Ed.) Retrieved February 28, 2018, from http://www.fao.org/faostat/en/#data/FO

French Capacity Market - Report accompanying the draft rules. (2014, April 9). *www.rte-france.com.* (Réseau de transport d’électricité (RTE), Ed.) Retrieved March 21, 2018, from http://clients.rte-france.com/lang/an/clients_traders_fournisseurs/services_clients/dispositif_mecapa.jsp

German energy policy and the way to sustainability: Five controversial issues in the debate on the "Energiewende". (2016, July 4). *www.sciencedirect.com.* (W. Fischer, et al., Ed.) Retrieved February 20, 2018, from https://www.sciencedirect.com/science/article/pii/S0360544216306867#bib7

Identifizierung kritischer Wettersituationen im Hinblick auf die Stromerzeugung in Westeuropa - Kurzfassung. (2018, February). *www.tugraz.at.* (K. Franke, et al., Ed.) Retrieved February 21, 2018, from https://www.google.at/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwjC64LZz7bZAhVNasAKHf5jAroQFggnMAA&url=https%3A%2F%2Fwww.tugraz.at%2Ffileadmin%2Fuser_upload%2FEvents%2FEninnov2018%2Ffiles%2Fkf%2FSession_B2%2FKF_Franke.pdf&usg=AOvVaw19pp8NonSSgB1e

Innovative Energietechnologien in Österreich - Marktentwicklung 2016. (2017, May). *www.pvaustria.at.* (P. Biermayr, et al., Ed.) Retrieved February 21, 2018, from http://www.pvaustria.at/meine-pv-anlage/daten-fakten/

Institute of Electricity Economics and Innovative Energy Technologies - Internal database. (2018). (Inst. of En. Economics a. Innov. En. Technologies, Ed.) Retrieved March 13, 2018

Integration of Demand-Side Response in the Swiss Ancillary Service Markets through the ENTSO-E Central Settlement Model. (2018, February). *www.tugraz.at.* (A. Chacko, et al., Ed.) Retrieved March 1, 2018, from https://www.tugraz.at/fileadmin/user_upload/Events/Eninnov2018/files/kf/Session_B5/KF_Chacko.pdf

JOULE 1 - Specific research and technological development programme (EEC) in the field of energy - non-nuclear energies and rational use of energy. (1989-1992). *cordis.europa.eu.* (European Commission, Ed.) Retrieved October 18, 2017, from http://cordis.europa.eu/programme/rcn/113_en.html

Launching the public consultation process on a new energy market design. (2015, July 15). *www.ec.europa.eu.* (European Commission, Ed.) Retrieved October 10, 2017, from http://ec.europa.eu/transparency/regdoc/?fuseaction=list&coteId=1&year=2015&number=340&language=EN

Leistungs- und Strukturstatistik 2013-2015, Produktion und Dienstleistungen. (2015-2017). (Statistik Austria, Ed.) Retrieved March 13, 2018, from https://www.statistik.at/web_de/statistiken/wirtschaft/produktion_und_bauwesen/leistungs_und_strukturdaten/index.html

Market Design for Demand Side Response - Policy Paper. (2015, November 27). *www.entsoe.eu.* (ENTSO-E, Ed.) Retrieved December 14, 2017, from https://www.entsoe.eu/publications/position-papers/position-papers-archive/Pages/Position%20Papers/market-design-for-demand-side-response.aspx

Negative Preise - Wie sie entstehen, was sie bedeuten. (2018). *www.epexspot.com.* (EPEX SPOT, Ed.) Retrieved February 20, 2018, from https://www.epexspot.com/de/Unternehmen/grundlagen_des_stromhandels/negative_preise

Optimal Demand-Side Response to Electricity Spot Prices for Storage-Type Customers. (1989, August). *www.ieeexplore.ieee.org.* (B. Daryanian, & R. E. Bohn, et al., Eds.) Retrieved October 17, 2017, from http://ieeexplore.ieee.org/document/32577/

Optimal operation of power system incorporating wind energy with demand side management. (2015, August 20). *www.sciencedirect.com.* (M. H. Alham, & M. Elshahed, et al., Eds.) Retrieved October 16, 2017, from http://www.sciencedirect.com/science/article/pii/S2090447915001094

Österreichs Zementindustrie: Jahresbilanz 2015 und Prognose 2016. (2016, May 11). *www.zement.at.* (Vereinigung der Österreichischen Zementindustrie, Ed.) Retrieved February 28, 2018, from http://www.zement.at/services/presse/45-2016/417-oesterreichs-zementindustrie-jahresbilanz-2015-und-prognose-2016

Österreichs Zementindustrie: Vertrauenskrise bremst Investitionen, Jahresbilanz 2014 und Prognose 2015. (2015). *www.zement.at.* (Vereinigung der Österreischischen Zementindustrie, Ed.) Retrieved February 28, 2018, from https://www.google.at/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwiEtrTzrMjZAhXG1hQKHe2mBnAQFggnMAA&url=http%3A%2F%2Fwww.zement.at%2Fdownloads%2Fdownloads_2015%2FGrafiken_Zementind_Bilanz_14_Prognose_15_21_05_15.pdf&usg=AOvVaw00BdQSbU8K6D530sZE0Zz

Potentiale und Hemmnisse für Power Demand Side Management in Österreich. (2008, February). *online.tugraz.at.* (C. Gutschi, & H. Stigler, Eds.) Retrieved February 26, 2018, from https://www.google.at/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&ved=0ahUKEwjNzsKoncPZAhURGuwKHeytCyoQFggxMAE&url=https%3A%2F%2Fonline.tugraz.at%2Ftu

g_online%2Fvoe_main2.getvolltext%3FpCurrPk%3D35775&usg=AOvVaw36LQTY0AL48rZWr7NysYhh

Power grid balancing of energy systems with high renewable energy penetration by demand response. (2008, February 20). *www.sciencedirect.com.* (I. Stadler, Ed.) Retrieved February 22, 2018, from https://www.sciencedirect.com/science/article/pii/S0957178707000732/pdfft?md5=689fadf65b6145273bac4cfbcaacdd5d&pid=1-s2.0-S0957178707000732-main.pdf

Primer on Demand-Side Management - With an emphasis on price-responsive programs. (2005, February). *documents.worldbank.org.* (Charles River Associates, Ed.) Retrieved October 18, 2017, from http://documents.worldbank.org/curated/en/986041468154163610/Primer-on-demand-side-management-with-an-emphasis-on-price-responsive-programs

Proposal for a Directive (COM (2016) 761 final) - Energy Efficiency. (2016, November 30). *ec.europa.eu.* (European Commission, Ed.) Retrieved October 30, 2017, from ec.europa.eu/transparency/regdoc/rep/1/2016/EN/COM-2016-761-F1-EN-MAIN-PART-1.PDF

Proposal for a Directive (COM (2016) 767 final) - Promotion of the use of energy from renewable sources. (2016, November 30). *eur-lex.europa.eu.* (European Commission, Ed.) Retrieved October 31, 2017, from http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52016PC0767&qid=1509453455762&from=EN

Proposal for a Directive (COM (2016) 864/2) - Common rules for the internal market in electricity. (2017, February 23). *eur-lex.europa.eu.* (European Commission, Ed.) Retrieved November 8, 2017, from http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52016PC0864R%2801%29

Proposal for a Regulation (COM (2016) 861 final/2) - Regulation on the internal market for electricity. (2017, February 23). *ec.europa.eu.* (European Commission, Ed.) Retrieved December 11, 2017, from ec.europa.eu/transparency/.../COM-2016-861-F2-EN-MAIN-PART-1.PDF

PV Status Report 2011. (2011, July). *publications.europa.eu.* (Joint Research Center (JRC), Ed.) Retrieved October 23, 2017, from https://publications.europa.eu/en/publication-detail/-/publication/e5bce0fc-cdb0-4d7c-a717-a026342bfbe1

Quartalsbericht zu Netz- und Systemsicherheitsmaßnahmen. (2017, May 29). *www.bundesnetzagentur.de.* (Bundesnetzagentur für Elektrizität, Gas, etc., Ed.) Retrieved February 20, 2018, from https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Allgemeines/Bundesnetzagentur/Publikationen/Berichte/2017/Quartalsbericht_Q4_Gesamt_2016.pdf?__blob=publicationFile&v=2

Renewable Energy in Europe - Markets, trends and technologies. (2010). (European Renewable Energy Council (EREC), Ed.) Retrieved October 23, 2017, from https://www.google.at/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwjG6N-6_IbXAhUPlxQKHWWmBLYQFggrMAA&url=http%3A%2F%2Fwww.shirazedc.co.ir%2FDorsaPax%2Fuserfiles%2Ffile%2FEbook%2FRenewable%2520Energy%2520in%2520Europe%2520-%2520Markets%2CTrends%2520

Renewable Energy Progress in EU 27 2005-2020. (2013). *ec.europa.eu.* (M. Banja, & N. Scarlat, et al., Eds.) Retrieved October 23, 2017, from https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/renewable-energy-progress-eu-27-2005-2020

SAVE 1 - Promotion of energy efficiency in the Community. (1991-1995). *cordis.europa.eu.* (European Commission, Ed.) Retrieved October 18, 2017, from http://cordis.europa.eu/programme/rcn/281_en.html

Sixth Community Environment Action Programme. (2002, July 22). *eur-lex.europa-eu.* (European Parliament, & European Council, Eds.) Retrieved October 20, 2017, from http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32002D1600

Solar Power from Europe's Sun Belt. (2009, June). *www.solarthermalworld.org.* (Europ. Solar Thermal Electr. Association (ESTELA), Ed.) Retrieved October 24, 2017, from https://www.google.at/url?sa=t&rct=j&q=&esrc=s&source=web&cd=3&ved=0ahUKEwiGrrmH1YjXAhUEI1AKHUFQAdEQFgg_MAI&url=http%3A%2F%2Fwww.solarthermalworld.org%2Fsites%2Fgstec%2Ffiles%2Festela%2520sunbelt.pdf&usg=AOvVaw1ZIdfcK-pp7lgMyY6vdj1g

Steel Statistical Yearbook 2016. (2016, October). *www.worldsteel.org.* (World Steel Association, Ed.) Retrieved February 28, 2018, from https://www.worldsteel.org/steel-by-topic/statistics/steel-statistical-yearbook-.html

Stresstest: Kritische Situationen für Österreichs Stromversorgung 2017. (2018, January). *www.energieinstitut.net.* (Energieinstitut der Wirtschaft GmbH, Ed.) Retrieved February 21, 2018, from https://www.google.at/url?sa=t&rct=j&q=&esrc=s&source=web&cd=30&cad=rja&uact=8&ved=0ahUKEwjkseH5vbbZAhXOGuwKHeevALU4FBAWCE4wCQ&url=http%3A%2F%2Fwww.energieinstitut.net%2Fde%2Fsystem%2Ffiles%2Feiw_insights_stresstest_18_01.pdf&usg=AOvVaw1xGBOvcwbIlPnJ6eBon

Tapping the demand response potential, the cost efficient way. (2017, August 29). *www.eurelectric.org.* (EURELECTRIC, Ed.) Retrieved January 16, 2018, from http://www.eurelectric.org/news/2017/tapping-the-demand-response-potential-the-cost-efficient-way/

The benefits of cooperation in a highly renewable European electricity network. (2017, June 6). *www.sciencedirect.com.* (D. P. Schlachtberger, et al., Ed.) Retrieved February 20, 2018, from https://www.sciencedirect.com/science/article/pii/S0360544217309969#bib1

The Concept of Demand-Side Management for Electric Utilities. (1985, October 10). *www.ieeeexplore.ieee.org.* (C. W. Gellings, Ed.) Retrieved October 16, 2017, from http://ieeexplore.ieee.org/document/1457586/

The potential of demand-side management in energy-intensive industry for electricity markets in Germany. (2010, April 14). *www.sciencedirect.com.* (M. Paulus, et al., Ed.) Retrieved March 9, 2018, from https://www.sciencedirect.com/science/article/pii/S0306261910000814?via%3Dihub

The Value of Lost Load for Sectoral Load Shedding Measures: The German Case with 51 Sectors. (2016, February 19). *publications.rwth-aachen.de.* (A. Praktiknjo, Ed.) Retrieved March 5, 2018, from https://publications.rwth-aachen.de/record/570165

The value of supply security: The cost of power outages in Austrian households, firms and the public sector. (2012, September 15). *www.sciencedirect.com.* (J. Reichl, et al., Ed.) Retrieved March 5, 2018, from https://www.sciencedirect.com/science/article/pii/S0140988312002149

United Nations Framework Convention on Climate Change - Kyoto Protocol. (11. December 1997). *www.unfccc.int.* Abgerufen am 11. October 2017 von http://unfccc.int/kyoto_protocol/items/2830.php

United Nations Framework Convention on Climate Change - Paris Agreement. (12. December 2015). *www.unfccc.int.* Abgerufen am 11. October 2017 von http://unfccc.int/paris_agreement/items/9485.php

United Nations Framework Convention on Climate Change. (9. May 1992). *www.unfccc.int.* Abgerufen am 11. October 2017 von http://unfccc.int/essential_background/convention/items/6036.php

USA steigen aus Pariser Klimaabkommen aus. (2017, June 1). *diepresse.com.* (Die Presse, Ed.) Retrieved March 19, 2018, from https://diepresse.com/home/ausland/aussenpolitik/5228231/USA-steigen-aus-Pariser-Klimaabkommen-aus

Utility Demand-Side Management Experience and Potential - A Critical Review. (1992, November 1). *www.annualreviews.org.* (S. Nadel, Ed.) Retrieved October 17, 2017, from http://www.annualreviews.org/doi/10.1146/annurev.eg.17.110192.002451

White Paper: An Energy Policy for the European Union. (1995, December 13). *aei.pitt.edu.* (European Commission, Ed.) Retrieved October 19, 2017, from http://aei.pitt.edu/1129/

Wind in power: 2010 European statistics. (2011, February). *windeurope.org.* (The European Wind Energy Association (EWEA), Ed.) Retrieved October 23, 2017, from https://windeurope.org/about-wind/statistics/european/wind-in-power-2010/

Windenergie in Österreich - Entwicklung der Windkraft in Österreich seit 2000. (2018). *www.igwindkraft.at.* (Interessengemeinschaft Windkraft Österreich, Ed.) Retrieved February 21, 2018, from https://www.igwindkraft.at/fakten/?xmlval_ID_KEY%5B0%5D=1234

Annex

	Electrolytic prod. of primary aluminum	Electrolytic refinement of copper	Electrolytic production of zinc	Electric arc furnaces for steel	Chloalkali process	Cement production	Mechanical wood pulp production	Recycling paper	Pulp and paper machines	Calcium carbide production
Albania				x		x				n.a.
Austria				x	x	x	x	x	x	n.a.
Belgium		x	x	x	x	x	x	x	x	n.a.
Bosnia and Herzegovina	x			x		x		x	x	n.a.
Bulgaria		x	x	x		x	x	x	x	n.a.
Croatia				x		x	x	x	x	n.a.
Cyprus		x				x				n.a.
Czech Republic				x	x	x	x	x	x	n.a.
Denmark						x	x	x	x	n.a.
Estonia						x	x	x	x	n.a.
Finland		x	x	x	x	x	x	x	x	n.a.
France	x		x	x	x	x	x	x	x	n.a.
Germany	x	x	x	x	x	x	x	x	x	n.a.
Greece	x			x	x	x		x	x	n.a.
Hungary				x	x	x			x	n.a.
Ireland								x	x	n.a.
Italy	x		x	x	x	x	x	x	x	n.a.

Table 13: European countries (A - I) with an output in the investigated industries; relevant for Q_{ann} in Table 5
Source: Own representation, based on data from [66, 68, 69, 71, 72, 74, 75, 76]

	Electrolytic prod. of primary aluminum	Electrolytic refinement of copper	Electrolytic production of zinc	Electric arc furnaces for steel	Chloralkali process	Cement production	Mechanical wood pulp production	Recycling paper	Pulp and paper machines	Calcium carbide production
Latvia				x		x		x	x	n.a.
Lithuania						x		x	x	n.a.
Luxembourg				x		x		x	x	n.a.
Macedonia		x		x		x		x	x	n.a.
Montenegro	x			x				x	x	n.a.
Netherlands	x		x	x	x	x	x	x	x	n.a.
Norway	x	x	x	x	x	x	x	x	x	n.a.
Poland		x	x	x	x	x	x	x	x	n.a.
Portugal				x	x	x		x	x	n.a.
Republic of Moldova						x		x	x	n.a.
Romania	x			x	x	x		x	x	n.a.
Serbia		x				x		x	x	n.a.
Slovakia	x			x	x	x	x	x	x	n.a.
Slovenia				x		x	x	x	x	n.a.
Spain	x	x	x	x	x	x	x	x	x	n.a.
Sweden	x	x		x	x	x	x	x	x	n.a.
Switzerland				x	x	x	x	x	x	n.a.
United Kingdom				x		x	x	x	x	n.a.

Table 14: European countries (L - U) with an output in the investigated industries; relevant for Q_{ann} in Table 5
Source: Own representation, based on data from [66, 68, 69, 71, 72, 74, 75, 76]