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THE POTENTIAL OF DEMAND RESPONSE FOR EEX AND MIBEL ELECTRICITY MARKETS

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For my parents,
For Pedro,

"There is a driving force more powerful than steam, electricity and nuclear power: the will."

Albert Einstein

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ABSTRACT

The demanding European Union (EU) environmental targets and lower greenhouse gas (GHG) emissions force an increasing electrification of the economy and a growing share of electricity generation from renewable energy sources. The new opportunities and challenges for all market participants impose a more sophisticated market design and operation to maximize the gains offered by this new reality. Electricity markets were established based on the premise that short run price elasticity of demand is small, due to electricity importance, convenience and low cost. Nevertheless, demand and the supply are constantly changing according with the period of the day, week, month or year but consumers are unaware of this reality and may tend to overconsume in periods of expensive production and to under consume in periods of inexpensive production. Demand Response (DR) may be used as a tool to increase electricity consumer flexibility. By rescheduling loads or by accepting load reductions, end-user consumers may reduce power system constraints and trigger electricity prices reduction due to a more efficient operation of the electricity markets. The literature about the potentiality for DR in electricity markets with different designs is scarce, namely, in what regards comparing market designs either with or without bid caps or floor mechanisms, such is the case of the EEX and the MIBEL. Appropriate modelling can be developed to allow the evaluation of different variables impact in the DR potential.

This work aims to enrich and contribute to the existing scientific knowledge and literature, specifically regarding the potential for DR in EEX and MIBEL day-ahead wholesale markets and to identify if there is a market design structure more suitable for DR initiatives. The research results should clearly contribute to improve the debate on DR policies, providing indications for the development of future energy market design structures. Results demonstrate that the variables found in the literature such as seasonality and characteristics of supply generators, influence the potential for DR in MIBEL and EEX. The literature indicates that energy markets dominated by non-controllable energy sources, such as renewable energy sources (RES), with high fixed costs and marginal costs that tend for zero, have a lower tendency for DR potentials. This is the case of energy markets dominated by hydropower facilities, such as Portugal. Nevertheless, in this study, Portugal results tend to be more favorable in what concerns DR potential while, *per* opposition, Germany tends to be a less favorable market for implementing DR on the energy market. According to the results found,

MIBEL would experience a more positive impact on prices resultant from load flexibility than EEX, seeing that in more hours it would be economically viable to perform DR. This study results also reveals that load-shift optimization on different markets does not necessarily correspond to a general decrease on wholesale energy market prices. For all the three markets, results demonstrate that a small amount of load shifting allow to obtain nearly the same economic potential to perform DR. According with this study findings, market design characteristics have implications for DR future implementation. Negative prices, generation portfolios dominated by non-fossil technologies, peak hours, week days and months with lower temperatures are variables associated to lower potential to perform DR, while generation portfolios dominated by fossil technologies, off-peak hours, weekends and months with mild temperatures are associated to higher number of hours to perform DR potential, emerging a problem since a significant part of the benefits associated to DR mechanisms on energy markets consists in smoothing peak loads and incorporate the full potential of RES production. The ongoing increase of renewable energy production pretends primarily to reduce GHG emissions, particularly if its integration is fully achieved, and DR appears as mechanism towards RES inclusion on markets. If DR does not achieve the necessary impact, particularly in what regards to the renewables integration, it might have a negligible or negative impact on emissions, depending on the marginal emissions factors of the power system. The first model results lead to the development of an unconventional approach in order to allow DR implementation during peak-load periods. Instead of reducing non-renewable production during peak-hours, the concept was developed in the opposite manner. Once it is expected during peak-hours the load average consumption is still going to be higher than in non-peak hours, a non-renewable percentage of the load during off-peak hours should be shifted to peak hours of non-renewable production, avoiding non-renewable production during peak hours.

Keywords: Demand Response Potential, Electricity Markets Design, Spot Prices, CO₂ emissions

RESUMO

De modo a cumprir os objetivos ambientais da EU para diminuir as emissões de gases com efeito de estufa, é expectável um aumento da eletrificação da economia devido ao contínuo aumento da integração de eletricidade proveniente de fontes de energias renováveis. Novas oportunidades e desafios irão surgir para todas as partes envolvidas no mercado, para a estrutura e operação do mercado de forma a adaptarem-se a esta nova realidade. Os mercados de eletricidade baseiam-se na premissa que a eletricidade imediata dos preços da procura é diminuta, devido à importância, conveniência e baixo custo da eletricidade. No entanto quer a procura quer a oferta estão permanentemente a mudar ao longo do dia, semana, mês e/ou ano, mas os consumidores são alheios a tal realidade podem tender a consumir em excesso durante períodos de produção mais dispendiosa e consumir por defeito em períodos de produção mais barata. Neste contexto, a DR pode ser utilizada como uma ferramenta para aumentar a flexibilidade dos consumidores. Através da alteração dos consumos ou da redução dos mesmos, os consumidores finais podem reduzir estrangulamentos no sistema e despoletar a redução dos preços de eletricidade devido a um funcionamento mais eficiente do mercado de eletricidade. A literatura relativa ao potencial para DR no mercado de eletricidade é diminuta, particularmente, acerca da comparação de diferentes estruturas de mercado nomeadamente com e sem limites de propostas máximas e mínimas tal como é o caso do EEX e do MIBEL. O desenvolvimento de modelação apropriada pode ser desenvolvido de forma a avaliar o impacto de diferentes variáveis no potencial para efetuar DR. Este trabalho pretende contribuir para a literatura e conhecimento científico relativamente ao potencial para efetuar DR nos mercados grossistas do dia seguintes do MIBEL e EEX e identificar se existe uma estrutura de mercado mais favorável para as iniciativas de DR. Os resultados desta pesquisa contribuem para melhorar o debate nas implicações políticas relativas a DR, dando indicações para o futuro desenvolvimento da estrutura de mercados de energia. Os resultados demonstram que as variáveis identificadas na literatura científica, como a sazonalidade e as características associadas à geração influenciam o potencial de DR no MIBEL e EEX. De acordo com a literatura os mercados de energia dominados por fontes de energia não controláveis, como as FER, com custos fixos elevados e custos marginais que tendem para zero, apresentam tendência para um potencial de DR menor. Este é o caso de mercados de energia dominados por centrais hidroelétricas, como é o caso de Portugal. No entanto, de acordo com os

resultados deste estudo, Portugal tende a ter resultados mais favoráveis no que respeita ao potencial de DR enquanto, que por oposição, a Alemanha tende a ter resultados menos favoráveis para a implementação de DR no mercado de energia. De acordo com os resultados obtidos, o MIBEL teria um impacto tendencialmente mais positivo nos preços decorrente da flexibilidade de consumo do que o EEX, pois seria economicamente viável realizar DR durante um maior número de horas. Os resultados deste estudo também revelam que a otimização da alteração do consumo nos diferentes mercados não corresponde necessariamente a uma diminuição geral nos preços do mercado grossista de energia. Os resultados demonstram que para os três mercados, com uma pequena quantidade de alteração de carga é possível obter praticamente o mesmo potencial económico para realizar DR. Os resultados demonstram que as características da estrutura de cada mercado têm implicações para a futura implementação de DR. Preços negativos, portfólios de geração dominados por tecnologias renováveis, horas de pico, dias de semana e meses com temperaturas mais baixas tendem a estar associados a um menor potencial para realizar DR, enquanto portfólios de geração dominados por tecnologias fósseis, horas de vazio, fins de semana e feriados e meses com temperaturas amenas estão associadas a um maior potencial para realizar DR, surgindo um problema paradoxal, pois uma parte significativa dos benefícios associados à integração de mecanismos de DR nos mercados de energia diz respeito à suavização dos picos de carga e do potencial de aproveitamento da produção de fontes renováveis de energia. As emissões de GEE associadas à produção de eletricidade são altamente dependentes da tecnologia de produção de eletricidade. No entanto, a literatura afirma que a implementação de DR não implica necessariamente uma redução do consumo de energia. Caso a implementação de DR não atinja o impacto necessário, particularmente no que diz respeito à integração de FER, pode ter um impacto negligenciável ou até negativo nas emissões, dependendo dos fatores de emissão marginais do sistema elétrico. Os resultados do primeiro modelo levam ao desenvolvimento de uma abordagem não convencional para permitir a implementação de DR durante os períodos de pico. Em vez de reduzir a produção não renovável durante os horários de pico, o conceito foi desenvolvido de maneira oposta. Uma vez que se espera que durante as horas de pico o consumo de carga médio seja maior do que fora das horas de pico, uma certa percentagem de carga não renovável produzida fora das horas de pico deve ser transferida para a parte de produção não renovável das horas de pico, evitando a produção não renovável nas horas de pico.

Palavras-Chave: Potencial Demand Response, Estrutura de Mercados de Eletricidade, Preços Spot, Emissões CO₂

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LIST OF ABBREVIATIONS AND ACRONYMS

GGS – Global System Management

EED – Energy Efficiency Directive

AMI – Advanced Metering Infrastructure

EE – Energy Efficiency

EC – Energy Conservation

LR – Literature Review

IEA – International Energy Agency

GHG – Greenhouse Gas

VRES – Variable Renewable Energy Sources

VRE – Variable Renewable Energy

CO₂ – Carbon Dioxide

USA – United States of America

CH₄ – Methane

SO₂ – Sulfur dioxide

NO_x – Nitrogen oxide

N₂O – Nitrous oxide

SF₆ – Sulfur hexafluoride

HFC – Hydrofluorocarbons

PFC – Perfluorocarbons

EU ET – European Union Emission Trading

PRTR – Registro Estatal de Emisiones y Fuentes Contaminantes

CPS – Carbon Price Support

EU ETS – European Union Emissions Trading Scheme

NF₃ – Nitrogen trifluoride

UN – United Nations

CCS – Carbon capture and storage

IPCC – Intergovernmental Panel on Climate Change

GDP – Gross domestic product

RES-I – Renewable Energy Sources Integration

APA – Agência Portuguesa do Ambiente

CT – Combustion Turbines

PWR – Pressurized Water Reactors

AA-CAES – Advanced Adiabatic Compressed Air Energy Storage

NEB – Northern European and the Baltics

CEE – Central-eastern European countries

CWE – Central-western European countries

SSEE – South and South-eastern European countries

EEA – European Environment Agency

VOLL – Value of lost load

WCED – World Commission on Environment and Development

EU – European Union

DERs – Distributed Energy Sources

IRENA – International Renewable Energy Agency

EEX – European Energy Exchange

RES – Renewable Energy Sources

MOE – Merit Order Effect

DR – Demand Response

RES-E – Renewable Energy Sources for Electricity

PV – Photovoltaics

EV – Electric Vehicles

MIBEL – Mercado Ibérico de Electricidade

DSM – Demand side management

VAR – Vector Autoregressive

VECM – Vector Error Correlation Models

LMP – Locational Marginal Prices

PJM – Pennsylvania-New Jersey-Maryland Interconnection

SWF – Social Welfare Function

SW – Social Welfare

UE – União Europeia

EU – European Union

PT – Portugal

RE – Renewable Energy

GB – Great Britain

UK – United Kingdom

ES – Spain

SVAR – Structural Vector Autoregressive

DE – Germany

ISO – Independent System Operator

MO – Market Operator

TSO – Transmission System Operators

DSO – Distribution System Operators

DSR – Demand Side Response

SM – Smart Metering

ICT – Information and Communication Technologies

EED – European Efficiency Directive

IBP – Incentive Based Programs

TBR – Time Based Rate Programs

HVAC – Heating, Ventilation, and Air Conditioning

AMI – Advanced Metering Infrastructure

TOU – Time-of-Use

RTP – Real Time Pricing

DLC – Direct Load Control

CAP – Capacity Market Program

I/S – Interruptible/Curtailable Service

DA – Day-ahead

ID – Intra-day

DB – Demand Bidding

CPP – Critical Peak Pricing

EDRP – Emergency Demand Response Program

A/S – Ancillary Services

IBP – Incentive Based Programs

EDP – Extreme Day Pricing

ED-CCP – Extreme Day CCP

ACs – Air conditioners

MISO – Midcontinent ISO

IBDR – Incentive Based Demand Response (Programs)

DoE – United States Department of Energy

LSES – Load Serving Entities

U.S. – United States (of America)

EUR or € – Euros

IEEE – Institute of Electrical and Electronics Engineers

EEI – Edison Electric Institute

OTC – Over-the-counter

OMIE – Operador do Mercado Ibérico de Eletricidade

REE – Red Electrica de España

REN – Redes Energéticas Nacionais

EPEX – European Power Exchange

ENTSO – European Network of Transmission System Operators

CHP – Combined Heat and Power

IAEA – International Atomic Energy Agency

C2ES – Center for Climate and Energy Solutions

CCGT – Combined Cycle Gas Turbines

DAM – Day-ahead market

ERCOT – Electric Reliability Council of Texas

AD – Active Demand

ADR – Active Demand Response

MADM – Multi Attribute Decision Making

TOPSIS – Technique for Order Preference by Similarity to Ideal Solution

OCGT – Open Cycle Gas Turbine

VRES APC – Active Power Control of Renewable Power Plants

ICE – Internal Combustion Engines

ENTSO-E – European Network of Transmission System Operators for Electricity

HHI – Herfindahle Hirschman Index

APX – Amsterdam Power Exchange

OECD – The Organisation for Economic Co-operation and Development

ERSE – Entidade Reguladora dos Serviços Energéticos

FCR – Frequency Containment Reserves

FRR – Frequency Restoration Reserve

aFRR – Automatic frequency regulating reserve

mFRR – Manual Frequency Restoration Reserve

RR – Replacement Reserve

DSR – Demand Side Response

CBA – Cost-benefit analysis

1

INTRODUCTION

1.1. CONTEXT AND MOTIVATION

The liberalization process of the electricity market has taken place in most European countries and led to the creation of competitive wholesale markets. According to Pellini, E. G. (2014), wholesale electricity trading includes bilateral (bespoke) trading, over-the-counter (OTC) transactions and power exchanges. This includes major competitive markets such as APX Power NL (Netherlands), APX Power UK (Great Britain), EEX (Austria, Deutschland and Switzerland), MIBEL (Spain and Portugal), NordPool (Norway, Sweden, Finland and Denmark) and Powernext (France).

Two competing market models have been established in the design of liberalized electricity markets, the pool model and the power exchange model as a way to introduce competition in the sector and organize the relations between generator entities and distributors or large consumers (Ockenfels et al., 2008).

To be reliable, an electricity power system needs to operate in a perfect equilibrium between supply and demand in real time (Aryandoust and Lilliestam, 2017). To supply the energy needs that may vary hourly, daily and seasonally, generation capacity is expected to assure maximum peak-periods. With the unbundling of the electric sector, the system will be considered efficient if the fluctuations on the demand side remain insignificant (Albadi and El-Saadany, 2007). However, due to the introduction of large amounts of variable renewable generation sources with variable output, the balance between supply and demand is complex to manage. Wind power peak is more likely to occur in off-peak hours, which can be challenging for system

operators and may be the cause for disturbances in transmission and distribution assets that might increase total electricity costs (Parvania et al., 2012). According to Albadi and El-Saadany (2007) Demand Response (DR) or the adaptation of electricity consumption to generation, is considered to be one of the cheapest resources available to operate the system according to the new electric sector paradigm. *“However, active participation in these markets by the demand-side remains minimal.”* (Kirschen, 2003). Therefore, the capability and potential from household consumers to participate in short term markets through Demand Response, is a rising research interest topic, such as the performed in the Spanish short-term electricity markets by Valencia-Salazar et al. (2011).

According to Ockenfels et al. (2008) in a perfect competition market, prices should be determined by the demand side’s willingness to pay generation capacity to fulfill the load avoiding short-term outage. In some day-ahead spot market auctions, there is a bid cap and a price floor mechanism therefore, possible bids have a lower and an upper limit. In the day ahead electricity market auction on the EEX, marginal costs can become negative in certain hours, since power plants with very high costs of starting-up and shutting down and low variable costs of production can produce at negative marginal cost.

Through a flexible use in electricity consumption, by rescheduling loads or by accepting load reductions, end-user consumers may reduce power system constraints and trigger electricity prices reduction due to a more efficient operation of the electricity markets (Liu, 2018). Demand Response benefits are numerous, including the relative and absolute reductions in electricity demand, which could reduce environmental impact and improve security of supply associated to power systems, as it allows to optimize the investment in the efficiency of the distribution network and to reduce losses; to reduce transmission network investment by reducing congestion of the network and avoiding transmission network reinforcement; to facilitate connection of more distributed generation, providing greater flexibility in balancing the system, higher standby reserve and balancing for wind, and providing reserve for emergencies or unpredicted events; to provide short run marginal cost savings from using Demand Response (DR) to shift peak demand and avoiding investment in electricity infrastructure from new power plants to transmission and distribution lines (Bradley et al., 2013).

In the study performed by Klaassen et al. (2017) the following demand-response strategies are quantified: potential benefits of the grid based, energy market based and energy market based with capacity constraints. The same study shows that from a system perspective, a demand-response strategy that is energy market based with capacity constraints is most effective in terms of realizing system benefits from residential flexibility. The reduction of such inefficient electricity production will not only reduce the cost of generation but also will have a positive environmental effect since most of these plants use fossil fuels producing higher levels of greenhouse-gases emissions. In the study performed by Conchado et al. (2016) a combination of two simulation models to estimate the joint benefits of a DR program for the generation, distribution network and demand components of an electricity system was done to estimate the economic and environmental benefits of a demand-response electricity program for Spain. Other performed studies also aimed to assess the environmental impact of energy markets. Stoll et al. (2014) conducted a study that aimed to know if there was a correlation between the dynamic CO₂ intensity and the electricity market price using data from Great Britain, Ontario and Sweden electricity market. Kara et al. (2008) studied the impacts of European Union CO₂ emissions trading on electricity markets and on electricity consumers in Finland using the VTT electricity market model and the TIMES energy system. It was concluded that expanded nuclear power generation could limit the increases in the prices of electricity to one-third compared to those in the base case.

Electricity risk premia are considered to be a payment for the exposure to the spikes in electricity spot prices and for the instability in prices and demand. In a study performed by Viehmann (2011) hourly price data of the European Energy Exchange (EEX) auction and of the continuous over-the-counter (OTC) market which takes place prior to the EEX auction were compared by an empirical analysis of prices and premiums paid on the German day-ahead power market. The results showed that market participants behave like risk-averse rational economic agents. They are willing to pay significant negative risk premia in periods of low demand and positive risk premia during peak hours. A similar study performed by Valitov (2019) using the same methodology employed by Viehmann (2011) but with the aim of analyzing the impact of negative prices on risk premia, confirms the presence of risk premia in the German day-ahead electricity market. There is evidence that the mean yearly risk premium exhibits a highly unstable pattern over time. In this last study a variety of variables that affect electricity premia have been identified, such as the risk of unexpected price changes, the

uncertainty concerning the electricity demand and the risk that the electricity transmission system reaches its capacity limit. “*It is conjectured that a positive relationship exists between emission allowance spot returns and electricity risk premia within the European Union Emissions Trading Scheme.*” (Daskalakis and Markellos, 2009). This study performed in the EEX, Nord Pool and Powernext markets by Daskalakis and Markellos (2009) aimed to find out if the electricity risk premia is affected by emission allowance prices. Empirical analysis investigated both short and long-term risk premia which were estimated using, respectively, day-ahead forward prices and monthly futures prices. This study suggests that electricity risk premia should account a “*carbon component*” for pricing electricity forwards and futures based on equilibrium models.

According to the literature, some studies concerning Demand Response in electricity markets were already performed. However, few were focused in studying the potentialities for Demand Response considering the electricity market design. By the performed review, there are no studies focusing the potentiality for DR in electricity markets with different designs, namely, in what regards comparing market designs either with or without bid caps or floor mechanisms, such is the case of the EEX and the MIBEL market designs, respectively.

1.2. RESEARCH QUESTIONS

This research work examines whether the Portuguese, Spanish and Germany electricity markets would successfully integrate DR. In particular, the conducted research addresses three main groups of research questions. The first group is focused on listing variables identified on the literature with possible impact on spot prices and markets. The second group focus the economic potential for DR in the selected countries, considering a wide spectrum of dimensions from the effects of load shifting effects on prices to specific market design characteristics. The third group aims to answer if the DR load flexibility would have representative impact on CO₂ emissions. Along this work, including in some research questions, both potential for DR and DR potential were used expressions having the same meaning, however, there is a language abuse thus the present work does not aim to quantify the MWh/day but rather to assess the viability for economic DR.

- Group 1:

According to the literature, which market design (MIBEL or EEX) is friendlier to DR potential initiatives? Does the literature identify indicators which affect energy prices on these markets? Which indicators affect DR?

- Group 2:

The increasing penetration of flexible loads in the energy market is commonly associated to an increase in prices elasticity. Research questions from Group 2, were divided into four main groups: Flexible Loads vs Market Prices, Market Design, DR Potential Constraints and Policy Implications.

Flexible Loads vs Market Prices

- Does the increasing penetration of flexible loads correspond to a general decrease on wholesale energy market prices?
- Does a higher flexibility load level correspond to a significant decrease on prices, or does lower flexibility levels would produce a similar price variation?

Market Design

- Is there any tendency pattern for the potential levels in the analyzed markets along the years?
- Do the three markets prices react in the same way to flexible loads? If markets respond in a different way, which tend to be more favorable and which tend to be less favorable to DR?
- Do the negative prices practiced in EEX have an impact on DR potentials? Which type of impact does EEX negative price have on DR potentials, an increasing or decreasing tendency in spot prices setting?

DR Potential Constraints

- What are the causes that tend to conditionate DR potentials? Are the identified conditioning causes common to the three energy markets or not?
- Does the energy technology portfolio in the three markets affect DR potentials?
- Does energy market concurrency levels influentiate DR potentials? In which way?

Policy Implications

- Which implications have the results found regarding the aggregators regulation framework in each of the three energy markets?
- Which implications have the results found regarding future DR implementation, particularly in less favorable potential DR markets?

- Group 3:

According to the literature are DR benefits related to the CO₂ emissions decrease? Do the results found support that DR implementation on electricity markets correspond to a general decrease on CO₂ emissions?

1.3. CONTRIBUTIONS

This thesis contributes to the knowledge on DR potential. The existing literature emphasizes that the potential impact of Demand Response is often not considered (McKenna and Darby, 2017). Even though DR programs for consumers' participation in wholesale markets are already in practice in some parts of the world such as Pennsylvania-New Jersey-Maryland Interconnection (PJM), in Europe the situation is different. Actually, there are still important and relevant participation opportunities for consumers, mostly due to the lack of necessary regulatory framework development.

DR full implementation still have some barriers, but the DR benefits of wholesale markets would promote a positive effect for all parts. Benefits will emerge if both the economic and technical potential for DR can be fulfilled. Additionally, DR should help to integrate larger

Renewable Energy Sources for Electricity (RES-E). If this last condition is not achieved, DR may be considered redundant and according to some authors it might even represent a negative impact. This is a complex issue, due to the large number of variables involved both on technical and economic DR potential perspectives but if properly regulated a positive welfare gain can be obtained from this integration. In order to contribute to the scientific knowledge and discussion on this challenging topic it was an aim of this investigation to study:

- To identify the variables, disperse in the literature review;
- In what way load-shifting mechanisms would economically impact peak and off-peak spot prices in the three selected countries, through assessing price variations per unit of load;
- To assess the emission impact associated to load-shifting mechanisms.

Concerning the first part, different energy market design characteristics such as market mechanisms, supply properties and renewables integration set the mote to study and analyse different energy markets. The literature about the economic potentiality for DR in electricity markets comparing different design is scare. When choosing the energy markets, MIBEL and EEX, particularly Germany bidding area were chosen. The existence of negative spot prices is possibly the most remarkable difference between Germany and MIBEL bidding zones, reason why the research was focus on these. The analysis was conducted from from 1st January 2015 till 30th June 2020. From the 6th July 2021 also, Portugal and Spain will introduce negative prices in day-ahead spot markets. It is thus expected that in the future, the variables that affect risk premia in EEX concerning negative prices will also affect MIBEL.

According to DR definition, DR aims changes on consumption patterns to induce lower electricity use at times of high market prices and reduce both spikes and instability. Electricity risk premia is considered to be the payment for the risk of spikes in spot prices and instability. In this way the variables that affect one will also affect other. The results of the literature analysis demonstrate that some variables were common to all market designs. But other variables differ according to specific market structure characteristics, such as seasonal volatility in MIBEL or negative prices in EEX. The variables found in the literature associated to risk premia such as seasonality and generation of the supply, may also influentiate the potential for DR both in MIBEL and EEX.

With these variables in mind, a model was developed to evaluate the economic impact of performing load shifting from one hour to any of the 23 hours left, considering a total day period. The model was assumed to be an analytic function and was written as a first order of Taylor Series, considering the price variation per unit of load during load-shifting process from a peak hour to a non-peak. In total, considering all the bidding zones, years, and scenarios more than 6 million hours of prices were simulated. Results indicate an equilibrium in all countries and even between load-shifting reference scenarios, or in other words, the number of hours in which was economic viable to perform DR is very similar to the number of hours in which was not economic viable to perform DR. Moreover, negative prices, generation portfolios dominated by non-fossil technologies, peak hours, weak days and months with lower temperatures were variables associated to lower potential to perform DR while generation portfolios dominated by fossil technologies, non-peak hours, weekends months with mild temperatures were associated to higher number of hours to perform DR potential. The model results and the economic analysis are in accordance with the variables found in the literature such as seasonality and characteristics of generation. However, from these results, emerges a paradox thus a significant part of the benefits associated to DR integration on energy markets concern with smoothing peak loads and incorporate renewable energy production.

According to the economic model results is more viable to perform load shifting from non-peak hours to peak-hours than the opposite, thus during peak -hours price volatility is lower. In order to obtain the total mass of CO₂ emissions per hour, the sum of the generation of each power plant type weighted according to the average CO₂ emission factor was calculated. The results indicate the avoided mass of CO₂ emissions per hour due to load shifting mechanism.

DR may be used as source control source, if DR mechanisms aim to target emissions reduction. Nevertheless, it assumed that non-renewable production will always be necessary to produce at peak hours. The emission model assumes that instead producing all the non-renewable load at peak hours a part of it could be transferred from peak to non-peak hours. In this way, the economic model results could be potentiated and a certain amount of the non-renewable production would be offset at peak hours. However, this is an optimistic perspective, thus if the generation produces null emissions at the shifting hour, the load shifting process does not contribute to CO₂ emissions reduction.

In the future, changes on supply in the day-ahead market are expected to happen, caused by generation seasonality. It is expected that peak load periods occur during specific hours or

during some specific months or times of the year with extreme temperatures, high demand solicitations may occur. Seasonality associated to demand or to climatic conditions also modify the composition of generation technology supply in the day-ahead market, with impact both on market clearance prices and risk. Thus, energy markets need to adapt to this reality to accommodate these characteristics. The research performed demonstrate that further studies are still necessary to improve knowledge on the load shifting effects on the spot market prices.

1.4. THESIS ORGANIZATION

This document is organised as the following: after this 1st chapter, the thesis is constituted by four chapters, each one describing the findings on the research questions previously enumerated. Briefly summarizing the remaining chapters: Chapter II concerns to answer the first group of research questions; Chapter III has the same goal concerning the second group of research questions, as well as Chapter IV for the third group of research questions. Chapter V presents the main conclusions from the previous chapters and further work to develop.

Chapter II – This chapter presents an extended literature review of the scientific knowledge to the present. This chapter methodology comprises a critical survey of the literature supporting the discussion on this challenging topic and is subdivided into seven main issues: The Importance of Demand Response Value, the Concepts and Definitions for Demand Response, Demand Response Programs Classification and Research Studies, DR Regulation Status, Benefits and Barriers to Demand Response, Demand Response and Electricity Markets and the Impact Indicators in Day-ahead Wholesale Prices.

While the first part of this chapter is focused in more broadly concepts of DR, such as definitions, the regulation status and the literature identified opportunities and barriers to DR, in the second part is done an in-depth research about the variables that potentially affect the spot prices in MIBEL and EEX. Moreover, the performed research aimed to found out if the identified variables were common to the three analysed markets and if according to the existing literature a more favourable DR potential energy market design structure was identified.

Chapter III – This chapter is divided into five main subchapters: The Introduction, the performance of the Modelling Review, the description of the Model, the presentation and Discussion of the results found for Portugal, Spain and Germany and the final Conclusions. Chapter III research and methodology aimed to answer to the second group of research questions that is the larger one.

After the performed review of literature and identification of the variables that could potentially affect the spot prices in MIBEL and EEX, a mathematical model was tested in order to assess if the increasing penetration of flexible loads correspond to a general decrease on wholesale energy market prices. The model was simulated using real market data both from MIBEL and EPEX Spot using real historical data retrieved from the ENTSO-E (European Network of Transmission System Operators for Electricity) Transparency Platform (ENTSO-E, 2020). The model was simulated for a continuous period of 24 hours from 1st January 2015 till 30th June 2020, corresponding to 1108968 simulated hourly clearing prices for a single market scenario. Considering Portugal, Spain and Germany country analysis for a 5% and 15% load shifting scenario there was a total of 6653808 number of hours simulated.

Chapter IV – This chapter aimed to answer the last group of research questions and estimate the impact on the CO₂ emission for the DR established scenarios. It is divided into a similar structure to the previous one, with five main subchapters: The Introduction, the performance of the Modelling Review, the description of the Model, the presentation and Discussion of the results found for Portugal and Spain and the final conclusions. Public data concerning this topic was not available for Germany.

Finally, in Chapter V – In this chapter, are summarized the main results of the research. The conclusions and policy implications of the research work are presented as well as suggestions regarding further work to be performed.

1.5. REFERENCES

Albadi, M. H., & El-Saadany, E. F., 2007, June. Demand response in electricity markets: An overview. In 2007 IEEE power engineering society general meeting (pp. 1-5). IEEE. <https://doi.org/10.1109/PES.2007.385728>

Aryandoust, A., & Lilliestam, J., 2017. The potential and usefulness of demand response to provide electricity system services. *Applied Energy*, 204, 749-766. <https://doi.org/10.1016/j.apenergy.2017.07.034>

Bradley, P., Leach, M., & Torriti, J., 2013. A review of the costs and benefits of demand response for electricity in the UK. *Energy Policy*, 52, 312-327. <https://doi.org/10.1016/j.enpol.2012.09.039>

Conchado, A., Linares, P., Lago, O., & Santamaría, A., 2016. An estimation of the economic and environmental benefits of a demand-response electricity program for Spain. *Sustainable Production and Consumption*, 8, 108-119. <https://doi.org/10.1016/j.spc.2016.09.004>

Daskalakis, G., & Markellos, R. N., 2009. Are electricity risk premia affected by emission allowance prices? Evidence from the EEX, Nord Pool and Powernext. *Energy Policy*, 37(7), 2594-2604. <https://doi.org/10.1016/j.enpol.2009.02.010>

ENTSO-E, 2020. ENTSO-E Transparency Platform. Retrieved from: <https://transparency.entsoe.eu/transmission-domain/r2/dayAheadPrices/show> (accessed 10th January 2020).

Kara, M., Syri, S., Lehtilä, A., Helynen, S., Kekkonen, V., Ruska, M., & Forsström, J., 2008. The impacts of EU CO₂ emissions trading on electricity markets and electricity consumers in Finland. *Energy Economics*, 30(2), 193-211. <https://doi.org/10.1016/j.eneco.2006.04.001>

Kirschen, D. S., 2003. Demand-side view of electricity markets. *IEEE Transactions on power systems*, 18(2), 520-527. <https://doi.org/10.1109/TPWRS.2003.810692>

Klaassen, E. A. M., Van Gerwen, R. J. F., Frunt, J., & Slootweg, J. G., 2017. A methodology to assess demand response benefits from a system perspective: A Dutch case study. *Utilities Policy*, 44, 25-37. <https://doi.org/10.1016/j.jup.2016.11.001>

Liu, Z., 2018. Integrated Demand and Supply Side Management and Smart Pricing for Electricity Market. The University of Manchester (United Kingdom). Retrieved from: <https://www.research.manchester.ac.uk/portal/en/theses/integrated-demand-and-supply-side->

[management-and-smart-pricing-for-electricity-market\(2d675c1f-9dc1-469d-9a86-b4c4398154de\).html](https://www.eex.com/blob/7282/2689162f6461d4245cd85c582e06061d/04-20080807-gutachten-eex-ockenfels-engl-data.pdf) (accessed 10th December 2020).

McKenna, E., & Darby, S. J., 2017. How much could domestic demand response technologies reduce CO₂ emissions?. European Council for an Energy-Efficiency Economy. Retrieved from: https://www.eceee.org/library/conference_proceedings/eceee_Summer_Studies/2017/2-policy-governance-design-implementation-and-evaluation-challenges/how-much-could-domestic-demand-response-technologies-reduce-co2-emissions/ (accessed 10th December 2020).

Ockenfels, A., Grimm, V., & Zoettl, G., 2008. Electricity market design. Expertise commissioned by EEX for submission to the Saxon Exchange Supervisory Authority, 13, 46-51. Retrieved from: <https://www.eex.com/blob/7282/2689162f6461d4245cd85c582e06061d/04-20080807-gutachten-eex-ockenfels-engl-data.pdf> (accessed 2nd January 2020).

Parvania, M., Fotuhi-Firuzabad, M., & Shahidehpour, M., 2012, July. Demand response participation in wholesale energy markets. In 2012 IEEE Power and Energy Society General Meeting (pp. 1-4). IEEE. <https://doi.org/10.1109/PESGM.2012.6344591>

Pellini, E. G., 2014. Essays on European electricity market integration (Doctoral dissertation, University of Surrey). Retrieved from: <https://seec.surrey.ac.uk/wp-content/uploads/2018/10/2014ElisabettaPelliniThesis.pdf> (accessed 10th December 2020).

Stoll, P., Brandt, N., & Nordström, L., 2014. Including dynamic CO₂ intensity with demand response. Energy Policy, 65, 490-500. <https://doi.org/10.1016/j.enpol.2013.10.044>

Valencia-Salazar, I., Alvarez, C., Escrivá-Escrivá, G., & Alcázar-Ortega, M., 2011. Simulation of demand side participation in Spanish short term electricity markets. Energy conversion and management, 52(7), 2705-2711. <https://doi.org/10.1016/j.enconman.2011.02.005>

Valitov, N., 2019. Risk premia in the German day-ahead electricity market revisited: The impact of negative prices. *Energy Economics*, 82, 70-77. <https://doi.org/10.1016/j.eneco.2018.01.020>

Viehmann, J., 2011. Risk premiums in the German day-ahead Electricity Market. *Energy policy*, 39(1), 386-394. <https://doi.org/10.1016/j.enpol.2010.10.016>

2

LITERATURE REVIEW

2.1. THE IMPORTANCE OF DEMAND RESPONSE VALUE

Electric system utilities operate under different paradigms. In some developing economies the electrical system is operated within a traditional vertically integrated structure with the assets from generation to retailing being operated in a monopoly regime. In monopolistic vertically-integrated electricity systems, prices are generally regulated and the absence of competition leads to an inefficient management and to a fragile reliability of the power systems if there is a continuous growing demand (Foley et al., 2010; IEA Staff, 2003). In order to increase power systems reliability, a large number of countries have chosen a different paradigm throughout the unbundle of the electrical vertically integrated structure, typically introducing competition in generation, distribution and retail activities while keeping transmission network as a regulated monopoly. The electricity price for end-user is the main reason given for introducing competitive electricity markets (Nillesen and Pollitt, 2019). The liberalization and new entrants intensified the competition in some of the power system activities leading to the transaction of energy in a wholesale power market. In Portugal in the last decades, the electric system was unbundling with the introduction of electricity markets. In the recent past a vertically integrated company had the responsibility to control the overall electric system from generation till the end-user. In order to introduce the promotion of competition mechanisms in the energy markets, a new paradigm has arisen with the unbundle of the integrated vertically electricity structure namely, generation, transmission, distribution and retail activities. The main purpose for unbundling the electric system vertical structure was to introduce competition and assure an equal access and rules for all participants (Gugler and Schmitt, 2013). After the liberalization process of the electricity system, competition was for the first time introduced in the generation

and retailing activities while transmission network and distribution were kept as regulated monopolies (Nillesen and Pollitt, 2019). In liberalized systems, the balance between supply and demand is performed in “*market time*” or “*real-time*”, and is signaled by electricity prices (IEA Staff, 2003).

Electricity market liberalization policies are aimed to increase electricity sector economic efficiency and reliability inducing a continuous improvement. Moreover, it aimed to increase transparency in price setting for consumer protection. However, most electricity customers are not aware that electricity production costs are permanently changing, thus, they are not exposed to production prices fluctuations as real-time price signals are not passed on to final consumers, but are regulated into a fixed price that is set for relatively long periods regardless of the real supply-demand balance in the market what may limit competition and discourage investments (Møller Andersen et al., 2006).

Both the demand and the supply are volatile and may change according to the period of the day, week, month and year. Due to consumer unawareness these may tend to overconsume in periods of expensive production and to under consume in periods of inexpensive production. Electricity is not economically storable, forcing supply and demand to be synchronized in real time Møller Andersen et al. (2006). With the unbundling of the electric sector, the system will be considered efficient, if the fluctuations between supply and demand side remain insignificant (Albadi and El-Saadany, 2007). Thus, excessive fluctuations may cause several disturbances in power systems, such as: capacity constraints, outages, transmission bottlenecks, “*peaky*” demands and the potential exercise of market power (IEA Staff, 2003). Moreover, the introduction of large amounts of renewable generation sources with variable output, it may difficult the balance between supply and demand. Moreover, increasing RES penetration on energy markets may led to negative prices (Newbery et al., 2018). If real time price signals are communicated in a transparent manner to consumer, their participation individually - or through third party agents such as aggregators - will contribute for the integration of electricity from renewable sources and increase power system flexibility. For this reality to be achieved, consumers need to have access to smart systems and new business models and products such as electricity supply contracts with dynamic prices linked to the spot market in order to benefit from DR opportunities (IEA Staff, 2003).

Demand Response allows for the management of the demand side of electricity markets by shifting power demand according to the fluctuating supply side (Feuerriegel and Neumann, 2016). Therefore, a tariff or program must be established to motivate changes in electric use by end-use customers in response to changes in the price of electricity over time. It could include to give incentive payments designed to induce lower electricity use at times of high market prices or when grid reliability is jeopardized. When integrated into electricity markets, Demand Response can be used for load shifting and as a replacement for both control reserve and balancing and energy (Feuerriegel and Neumann, 2016; Qdr, 2006). During contingencies DR may act as a reserve capacity, offering load reductions to solve short-term constraints in the system, e.g. lack of generation or transmission capacity. DR value is dependent on the flexibility both of supply and demand, that perform economic benefits analysis based on different considerations and issues (Figure 2.1). DR value is recognized only when both supply and demand flexibility economic benefits are positive.

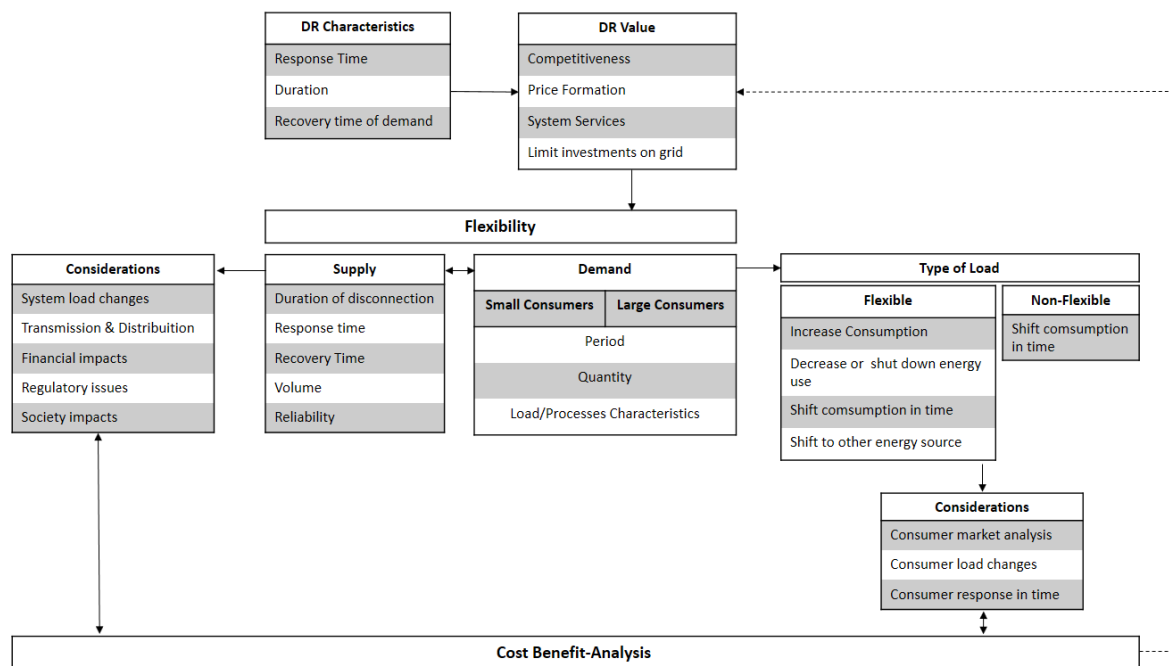


Figure 2.1 – Demand and supply flexibility cost-analysis. Source: From the author

According to Qdr (2006), DR offers financial and operational benefits both for demand (electricity customers) and supply side (load-serving entities), thus, it allows:

- To reduce electricity consumption in peak periods with the benefits of reducing the amount of generation and transmission assets required to provide electric service.
- To reduce demand in response to high prices (particularly market clearing prices in an organized regional spot market) to reduce the costs of electricity production and hold down prices in electricity spot markets.
- To reduce demand in response to system reliability problems by enhancing operators' ability to manage the electric grid - the network that transmits electricity from generators to consumers - and reduces the potential for forced outages or full-scale blackouts.
- To increase security of supply by giving consumers an incentive to react in critical situations.

2.2. CONCEPTS AND DEFINITIONS FOR DEMAND RESPONSE

2.2.1. DEMAND SIDE MANAGEMENT

The concept of demand side management (DSM) has arisen in the United States of America at the end of the 20th century and was initially focused on an “*electricity utility*” driven economic perspective, thus it aimed to modify load curves shape in an advantaged approach for utilities through production and delivery costs reduction and through the postpone or avoidance expansion investments (Eto, 1996; Lampropoulos et al., 2013). Despite the initial focus on electricity, DSM scope is larger thus it includes all forms at energy at the demand side. Demand side management policies and its classification into fundamental and broader concepts and its components are summarized in Figure 2.2.

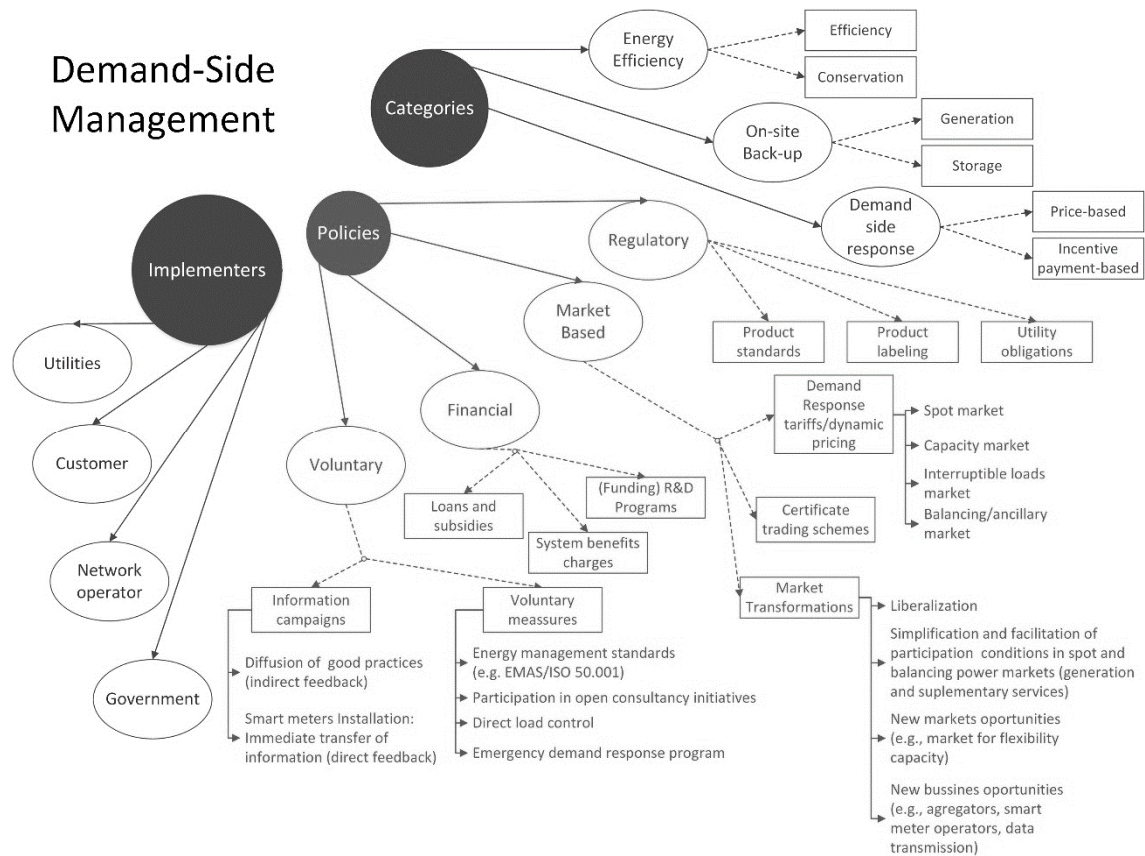


Figure 2.2 – Management of energy demand and its components. Source: Valdes et al. (2019)

Demand side management definition has been evolving since the 1980s till nowadays. Demand-side load management is the most primitive term and dates back to 1981 when it was firstly introduced by Clack W. Gellings. Then, to reflect an extensive range of planning processes used by utilities, the term was upgraded to demand-side planning in 1982 at a meeting in Edison Electric Institute (EEI). In 1985 the same author defined demand side management in the paper published in proceedings of the IEEE as follows Gellings (1985): “*Demand-side management (DSM) is the planning and implementation of those electric utility activities designed to influence customer uses of electricity in ways that will produce desired changes in the utility's load shape.*”. Further, Kreith (2008) defines DSM as an extensive concept that “*encompasses the planning and implementation of utility sponsored programs that influence the amount of timing of customers' energy use*” and Stötzer et al. (2015) describe DSM “*as the direct influence on the load by increasing or decreasing the energy demand at a certain time*”. Boshell and Veloza (2008), divide into three categories the measures to manage the demand: Demand Response, Energy Efficiency (EE) and Energy Conservation (EC). In a similar categorization,

Gellings (2009) divides demand side management into energy efficiency, savings, self-generation and load management. The initial “*utility driven*” meaning of DSM evolved to incorporate both efficiency and load profile management (Spees and Lave, 2007).

2.2.2. DEMAND RESPONSE, ENERGY EFFICIENCY AND ENERGY CONSERVATION

2.2.2.1. DEFINING DEMAND RESPONSE

The U.S. Department of Energy (DoE), defines Demand Response as the “*changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized*” which is one of the most broadly accepted definitions in the literature as referred by Møller Andersen et al. (2006), Qdr (2006), Albadi and El-Saadany (2007), Albadi and El-Saadany (2008), Mathieu et al. (2012), Shen et al. (2014), Feuerriegel and Neumann (2016), Asadinejad and Tomsovic (2017).

Demand Response may be implemented through tariffs or programs designed with specific objectives (Qdr, 2006). There is a wide range of Demand Response definitions reflecting short to long-run measures. According to Greening (2010): “*Demand response includes both modifications of electricity consumption by consumers in response to price and the implementation of more energy efficient technologies.*”. Further Feuerriegel and Neumann (2016) describes Demand Response as “*the management of the demand side of electricity markets by shifting power demand according to the fluctuating supply side*” and Albadi and El-Saadany (2008) defines Demand Response “*as the changes in electricity usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time.*”. For Annala et al. (2018) per one side “*DR means reduction of electricity consumption as a result both of insufficient generation supply due to renewable generation intermittency or network capacity*” but per other side “*It can also mean shifting of loads to times when power is available or when networks are less congested*”. Moreover, Demand Response is described by IEA Staff (2003) as “*a set of strategies which can be used in competitive electricity markets to increase the participation of the demand-side, or end-use customers, in setting prices and clearing the market.*”, and European Commission (2013) defines it “*as voluntary changes by end-consumers of their usual electricity use patterns - in response to*

market signals (such as time-variable electricity prices or incentive payments) or following the acceptance of consumers' bids (on their own or through aggregation) to sell in organized energy electricity markets their will to change their demand for electricity at a given point in time.”. Gómez et al. (2010) defines DR or demand side response (DSR) as “programs and activities designed to encourage consumers to change their electricity usage patterns, including timing and level of electricity demand, covering all load shape and customer objectives. DR includes time-off use and dynamic rates or pricing, reliability programs such as direct load control of devices and instantaneous interruptible load, and other market options for demand changes (like demand side bidding).”

Meanwhile the Directive (EU) 2019/944 of the European Parliament and of the Council of 5th June 2019 on common rules for the internal market for electricity EU (2019) defines DR as *“means the change of electricity load by final customers from their normal or current consumption patterns in response to market signals, including in response to time-variable electricity prices or incentive payments, or in response to the acceptance of the final customer's bid to sell demand reduction or increase at a price in an organised market as defined in point (4) of Article 2 of Commission Implementing Regulation (EU) No 1348/2014, whether alone or through aggregation”*. Also, DR market related definitions exist such as the one of Nordic power market where: *“Demand response (DR) is a voluntary temporary adjustment of electricity demand as a response to a price signal or a reliability-based action”* (Møller Andersen et al., 2006).

According to the numerous DR definitions in the literature, it is a wide concept that reflects consumer's changes in load consumption patterns as a reaction response to economic signals. However, DR also refers to storage, distributed electricity generation and backup generation (Farmad and Biglar, 2012). Moreover, in most definitions, DR corresponds to an effective reaction from consumers to economic incentives while the willingness to change electricity consumption patterns are a response to economic signals, such as market prices, price incentives in grid tariffs or other incentives, which may be defined as demand flexibility according to Nordic Council of Ministers (2014). Eid et al. (2016) also refer that DR can be defined as a flexibility service that is specified by:

- *Direction* (upward or downward);

- *Size* (kWh and kW);
- *Time*;
- *Location* (zone or node).

2.2.2.2. DEFINING ENERGY EFFICIENCY AND ENERGY CONSERVATION

Energy Efficiency is defined by Smith et al. (2008) as the “*effectiveness with which energy resources are converted into usable work*” including technologies with less spending of energy in a permanent approach. Kreith (2008) denotes Energy Conservation by “*doing actions without giving up amenities to save energy.*”, whereas, EC is mostly driven by behavioral measures, such as turning down the thermostat temperature or choosing public transportation instead of the own car for transportation are some examples of EC measures.

2.2.3. LOAD MANAGEMENT TECHNIQUES

Most electricity consumers are not exposed to short-term time-varying costs of electricity production. The exposition to fixed tariffs do not aware consumers for real time electricity varying costs of production and consumers tend to over-consume during periods with high production costs and to under-consume during periods with low production costs in an inefficient system load operation (Qdr, 2006).

The initial DSM concept is evolving into a “*customer driven*” activity and Demand Response plays an important role thus in some energy markets electricity consumers already have the possibility to, individually or through third-party, actively participate in energy markets through responding to system operator signals. An “*active consumer*” is defined in the previously referred Directive (EU) 2019/944 as “*means a final customer, or a group of jointly acting final customers, who consumes or stores electricity generated within its premises located within confined boundaries or, where permitted by a Member State, within other premises, or who sells self-generated electricity or participates in flexibility or energy efficiency schemes, provided that those activities do not constitute its primary commercial or professional activity*”.

Also, the increasing renewable energy generation integration, together with distributed generation, which is possible due to smart grid concept and grid enabling technologies advances such as the implementation of Information and Communications Technology (ICT) are

developing DR interest, thus a more efficient run of the power system, allowing high-cost generators to operate during reduced periods (Siano, 2014; European Commission, 2013; Møller Andersen et al., 2006). Moreover, it allows a more efficient use of fuels, with positive impacts in environment due to emissions reduction but also in increasing productivity due to lower production costs. DSM techniques for influencing and reducing energy consumption may be achieved through DR load managing techniques presented in Table 2.1.

Table 2.1 – DSM categories, and DR load management techniques. Source: From the author

Demand Side Management	Demand Response	Classic load management techniques	Peak clipping Valley filling Load shifting
		Non-classic load management techniques	Strategic load growth Flexible load shape Strategic conservation
		Energy Efficiency	
		Energy Conservation	

Demand Response may be seen as a flexible resource in order to maintain the balance in power systems and to enable intermittent generation dispatch. To change patterns of electricity consumption, different load management techniques may be used with different perspectives and objectives. According to Smith et al. (2008) load management from utilities perspective implies minimizing peak load demands in order to minimize utility investments in peak power capacity and reduce operational costs with expensive generator units, while from consumer perspective it implies to minimize electric demand both at peak and off-peak periods to minimize overall electric costs. Load shifting desired impact may be achieved through DSM programs that consider the load techniques with that objective. DR programs frequently are designed for load reduction or curtailing, but DR programs can be used to increase consumption when large amounts of renewable generation resources are available thus consumers that increase their electricity consumption benefit of low wholesale prices (Braithwait and Eakin, 2002). According to Baitch et al. (2007) Demand Response load shaping techniques aim to:

- Reduce peak demand;
- Fill the valleys of off-peak demand;

- Shift load;
- Induce variations in demand in order to obtain a flexible load shape.

Table 2.2 summarizes load management techniques definition and objectives, as well as the most common methodology for its implementation, the loads with most impact due to its application and the possible advantages mainly from the utility perspective.

Table 2.2 – Load management techniques definition, objectives, methodology for implementation and potential advantages on target loads. Source: From the author based on Gellings and Parmenter (2008)

	Load management techniques	Definition	Objective(s)	Methodology	Target Load or Processes	Advantages
Classic load management techniques	Peak clipping	Reduction of system peak loads by using direct load control	Direct load control may be used by utilities to reduce operating and dependence on critical fuels by economic dispatch	Utility directly controls consumers load appliances	Loads or processes that may be interrupted or reduced	Reduces increasing generation capacity Reduces or avoids utility investments Minimizes utility operational costs Reduces dependence on critical fuel
	Valley filling	Increase system loads during off-peak periods	Is the opposite load management technique to peak clipping, it aims to encompass	Utility directly controls consumers load appliances Through thermal energy storage	Processes or appliances with excess capacity	Renewable energy sources integration Generation production more constant Reduces dependence

			system off-peak loads	Electric vehicles charging		on critical fuel
	Load shifting	Involves shifting load from on-peak to off-peak periods	Load shifting combines the two previous load management techniques peak clipping and valley filling in order to stimulate consumers to change their energy consumption patterns from peak to off-peak periods	Utility directly controls consumers load appliances Through thermal energy storage Electric vehicles charging	Loads or processes with inertia, such as hot water tanks for tap water or heating. Loads or processes with storage, such as batteries. Processes or appliances with excess capacity	Reduces increasing generation capacity Reduces or avoids utility investments Minimizes utility operational costs Renewable energy sources integration Generation production more constant Reduces dependence on critical fuel
Non-Classic load management techniques	Strategic conservation	Changes in the pattern of use that result in a modification of the load shape due to the decrease in consumption	Reflects a reduction in consumption due to a change in the pattern of load consumption	Through appliance efficiency improvement	Loads or processes that may be reduced, as a result of more efficient technologies such as thermal insulation in buildings.	Reduces increasing generation capacity Reduces or avoids utility investments Minimizes utility operational costs Reduces dependence

						on critical fuel
	Strategic load growth	Changes in the pattern of use that result in a modification of the load shape due to the increase in sales	Reflects an increase in consumption due to a change in the pattern of load consumption	Through promotional rates, electrification or marketing campaigns	Loads or processes that may be increased. Loads or processes with storage.	Pollutant emissions can be reduced by the use of electrical appliances Reduces dependence on critical fuels Renewable energy sources integration May rise electric energy intensity and overall productivity due to fossil fuels reduction
	Flexible load shape	System reliability is considered as a planning constraint and load shape flexibility is seen as a tool for suppress	Customers have the possibility to offer load curtailing or service constrains in exchange for incentives in moments of reliability constraints of the system.	Through attribution of incentives and subsidies to consumers that are load flexible.	All the target load and processes referred above	Reduces increasing generation capacity Reduces or avoids utility investments Minimizes utility operational costs Renewable energy

		forecast errors				sources integration Helps the system operator to maintain system reliability
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Load management techniques, may have three different impacts on power supply according to consumer's changes in their electricity patterns as represented in Figure 2.3. Sæle and Grande (2011) identified the following ones, foregoing shifting and onsite generation, respectively:

- Reducing electricity demand during peak-price periods, without consuming it later.
- Shifting demand in peak-price periods to low-price periods through rescheduling.
- Using onsite generation or backup emergency generators to supply consumer needs.

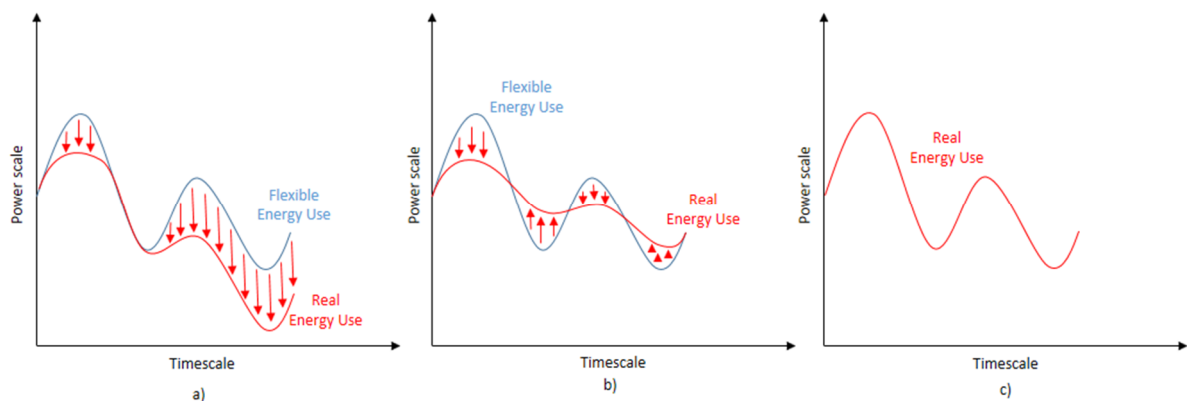


Figure 2.3 – Load management techniques. Source: From the author

The first situation in Figure 2.3 consists to decrease or shut down energy use, in which load consumption for given period is partially or totally decreased due to load curtailing, through shutting down or shifting to other energy sources. Peak clipping, strategic conservation and flexible load shape are examples of load management techniques with energy use decrease impact that may be applied during periods of high electricity prices. The other impact is to shift load consumption in time, which can be considered a particular case of decrease or shut down energy use, while load shifting is a combination between peak clipping and valley filling

techniques, though, its purpose is to change consumption from peak to off-peak periods. In this case, total power consumption is not reduced thus loads are allocated to other periods of the day, while in peak clipping the load is reduced or not consumed. The most widely known load technique is load shifting, but it may be a limited technique due to the characteristics of load Nordic Council of Ministers (2014). Moreover, load management techniques may also imply increasing load during periods of low electricity prices. In this situation, consumption increases for given period and per opposition to high electricity prices periods, and for that reason energy sources processes can be shifted to electricity. Valley filling, strategic load growth and flexible load shape are examples of load management techniques with energy use increase impact that may be applied during periods of low electricity prices.

Figure 2.4 summarizes DR techniques in function of different levels of load management, such as the period of intervention, the intention regarding load purposes, the goals regarding energy use and the period of intervention based on the classification performed by Kostková et al. (2013).

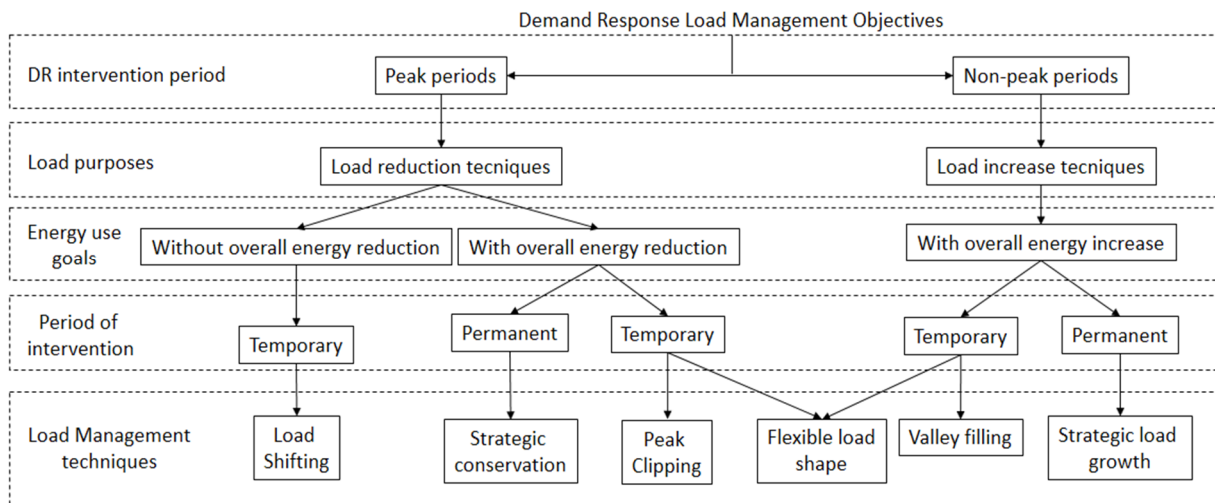


Figure 2.4 – DR load management objectives and levels. Source: From the author

Demand Response load control may be executed through “*automatic*” load control or “*dynamic control*” or through “*intentional*” load control. According to Jamasb and Pollitt (2011) in “*automatic*” load control the utility directly controls consumer appliances without a direct involvement of end-user. While in “*intentional*” load control the consumer is directly involved and controls appliances rather than utilities, in response to price signals or others communicated

through smart metering technology. Both forms of load control may co-exist and end-users may have both an active and passive role based on electricity price or the time of day. Load control is also associated with loads flexibility and with the period of disconnection that may range between hours and days, weeks and longer periods. Moreover, it depends on the load characteristics, if industrial processes are reduced or completely stopped, production economic losses may not be compensated by incentives. Load flexibility from demand is therefore particularly relevant during high electricity prices, when alternative sources of energy are either available or it is possible to shift consumption.

2.3. DEMAND RESPONSE PROGRAMS CLASSIFICATION AND RESEARCH STUDIES

DR program energy market users may be divided according to different criteria, from average energy consumption levels to socio-economic categories. The reviewed literature divides these users according to their profiles, namely, residential, commercial and industrial users (Atkinson et al., 2007; Arias et al., 2018; Ponds et al., 2018). In the first group, residential consumer's participation in DR programs are limited to their flexibility to shift or curtail loads and to the household energy needs. The residential loads more suitable for DR programs, are HVAC, water heaters and pool pumps. Commercial users may participate in DR programs and respond to price signals through lighting, washing machines, dryers, HVAC, refrigeration systems, water heaters, and pool pumps load control and in industry loads such as lighting, heating ventilation and HVAC, are the ones with highest potential for load curtailment. In Industry, where the use of energy is linked to the conversion of commodities into capital good, some specific industrial processes may allow a complete shut down to participate in a DR programs.

Individual consumers and industries with the capacity to respond to system signals in order to curtailing their energy demand or shifting specified loads in exchange for an incentive or reward, are allowed to participate directly or indirectly in energy markets through two types of DR programs categories: incentive-based programs (IBP) and time-based rate (TBR) programs (Mohajeryami et al., 2017).

The first program is also known as Explicit Demand Response, thus consumers individually or collectively, through the services of aggregators (can either be a third-party aggregator or the

customer's retailer), reduce their energy consumption during a certain period of time according to operator requirements and compete directly with supply in the wholesale, balancing and ancillary services markets. In these contracts, customers are offered a fixed discount or incentive payment in return for curtailed load during emergency or high-cost conditions (Bertoldi et al., 2016). Generally, both residential and small commercial consumers are set apart and not allowed to participate directly on the wholesale energy market. Such discrimination is based on the spot market time-frames price formation. Time-frames are set every hour, every half-hour or every 15 min what compels consumers to record the consumption for each period and to be informed in advance of the prices for each period. This type of operation requires the necessary expertise to contribute effectively to such a complex market functioning and the ability to manage information, that small-end consumers generally do not have. Belgium and France have both defined the roles and responsibilities for independent aggregation and in Europe France has been the first country to open its wholesale market to aggregated Demand Response. Also, some other energy markets such as PJM in the United States already give small-end consumers the opportunity to participate through third party aggregators (Walawalkar et al., 2010). Aggregators and large consumers such as industry, are direct sources of Demand Response when integrated into the wholesale energy markets, being Demand Response used for load shifting and for providing ancillary services (Figure 2.5).

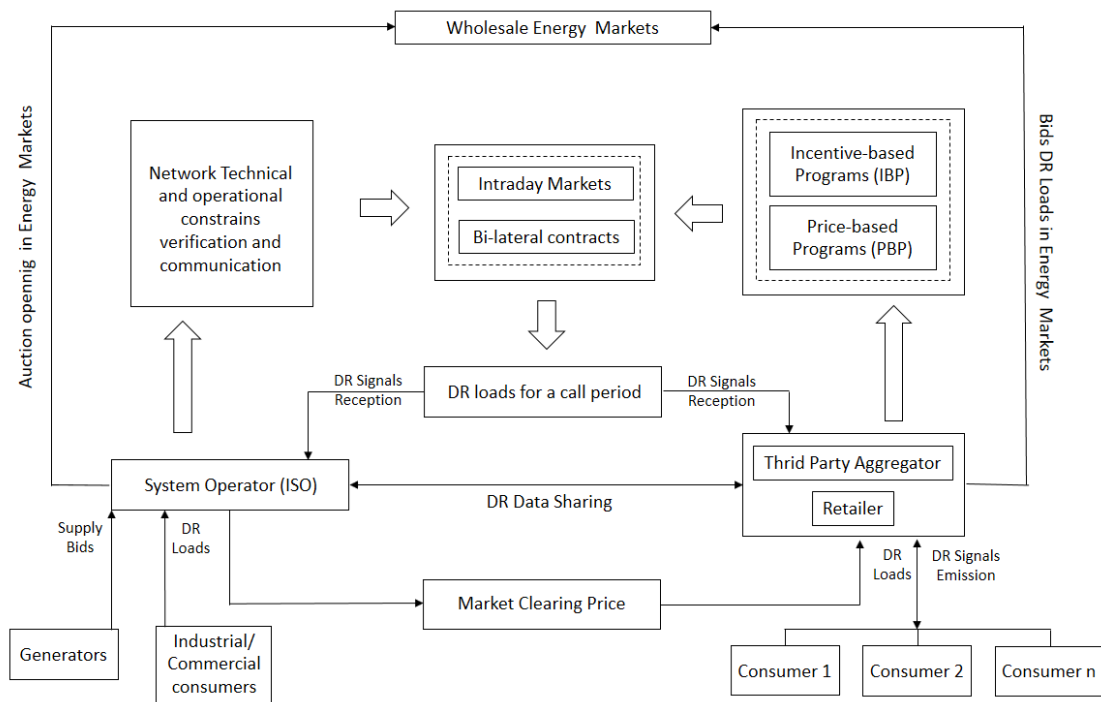


Figure 2.5 – Aggregators role on wholesale market. Source: An adaptation of Ponds et al. (2018).

Without aggregating the demand Steen et al. (2012) conclude it is necessary to combine different options for optimal Demand Response, being real-time pricing (RTP) programs the apparent most suitable for integrating large amount of renewable energy generation. RTP programs are considered Implicit Demand Response.

In Implicit Demand Response, consumers have the choice to react according with price dynamics established by the network operator or the energy market and be exposed to time-varying electricity prices or time-varying network tariffs (or both). *Per* the contrary, in Explicit Demand Response, there is no commitment and consumers may react to price changes according with their availability to participate in the program. However, in this situation demand is not allowed to compete with supply (or generation) or to participate in the balancing or ancillary services markets, thus for most capacity markets it does not represent a dispatchable resource that provides a valuable and reliable operational tool for system operators (Bertoldi et al., 2016). Furthermore, implicit DR and explicit DR programs do not have the same consumer reach. In order to allow consumers to participate and fully take advantage from their flexibility both price-based and incentive-based mechanisms should be combined in hybrid DR programs

variants (Arias et al. 2018). The transition towards flexible energy systems and the participation in DR programs is conditioned by enabling technologies such as advanced metering infrastructure (AMI) and information and communication technologies (ICT) development that will allow an effective control of consumer loads and enable communication abilities, which are necessary requisites for consumers to shift specific loads during peak or high priced trading periods and access DR programs (Mohajeryami et al., 2017; Chakrabarti, et al., 2012). The types of DR incentive-based programs (IBP) and time-based rate (TBR) programs are summarized in Table 2.3.

Table 2.3 – DR Programs Classification and their advantages and disadvantages. Source:
From the author

		Advantages	Disadvantages
Demand Response (DR) Programs	Time Based Programs	Time-of-Use (TOU) + Planning possibilities for small customers. + Easy to implement. + Tends to reduced peak demand.	– Limited integration of renewable energy sources (RES). – Time periods defined by the utility – Does not reflect total peak demand
		Real-Time Pricing (RTP) + Reduced peak demand + Support integration of renewable energy sources (RES). + Day-ahead or hour-ahead prices information; planning possibilities for customers.	– Requires customers' prompt response – Price volatility is increased – Need for communication and metering – Rebound-effect in off-peak hours.
		Critical Peak Pricing (CPP) + Reduce the total power system peak	– Limited number of hours to be used – Communicated in a very short notice by utility – Preset price levels. – Local impact on the peak demand. – No support for RES integration.
	Incentive Based Programs (IBP)		
		+ Easy to implement. + Reduce peak demand	
		Voluntary Programs Direct Load Control (DLC)	– Limited number of hours to be used. – Managed by a utility or system operator – Consumers comfort may be affected – Cold load pick-up. – No support for RES integration
		Emergency Demand Response Program (EDRP)	+ Reduce peak demand – No support for RES integration
		Mandatory Programs Capacity Market Program (CAP)	+ Reduce peak demand – No support for RES integration – pre-specified load reductions usually for large costumers – Customers may face penalties
		Interruptible/Curtailable (I/C) Service	+ Reduce peak demand – Limited number of hours to be used. – No support for RES integration. – Need for communication and metering. – Customers may face penalties

Market Clearing Programs	Demand Bidding (DB) + Reduce peak demand– Need for communication and metering. + Boosts consumers to actively participate in wholesale market
	Ancillary Service (A/S)+ Reduce peak demand– Limited number of hours to be used. Markets – Managed by a utility or system operator – Consumers comfort may be affected

In price-based or time-sensitive pricing DR programs, consumers respond to price signals in order to flatten the demand curve by offering higher prices during peak periods and lower prices during off-peak periods, while incentive-based or dispatchable DR programs offer consumers payments in exchange of loads reduction to pre-defined values and allow system operators to directly control electric appliances during peak or emergency periods (Shariatzadeh et al., 2015; Paterakis et al., 2017). Customer savings consist both on incentives received and lower prices. Both incentive-based and price-based DR programs are voluntary programs. However, in some incentive-based DR program consumers may face penalties when not responding during a peak or emergency period.

The most common Time-Based Programs mentioned in literature include three types of DR programs: Time of Use (TOU), Real Time Pricing (RTP) and Critical Peak Pricing (CPP). Other Time-Based Programs such as Extreme Day Pricing (EDP) and Extreme Day CPP (ED-CPP), were also identified by Albadi and El-Saadany (2008). These programs have the purpose of offering a high price during peak periods and lower prices during off-peak periods in order to flatten the demand curve. Each one of the DR programs Time-Based Programs are detailed below:

Time-of-use tariffs (TOU): Time-of-use tariffs design aims to reflect electricity price variations during different periods. It depends on the time of the day when electricity is consumed without reflecting real-time electricity prices volatility. A typical TOU rate structure includes two time blocks: the peak and the off-peak, for time periods defined by the utility. TOU tariffs only reflect about 14% of the wholesale price variation when compared to RTP prices, reflecting only a part of peak demand (Borenstein et al., 2002).

Real-time pricing (RTP): In Real-time pricing (RTP) programs customers are directly exposed to the hourly fluctuating prices reflecting prices variability in the wholesale market or to the changes in locational or zonal marginal prices. These rates link hourly prices to day-ahead or

hour-ahead changes. RTP customers are informed about the prices on a day-ahead or hour-ahead basis before the actual power delivery, by independent system operator (ISO) in energy markets such as PJM and Midcontinent ISO (MISO).

Critical peak pricing (CPP): According to Paterakis et al. (2017) “*The CPP tariff stands for the superimposition of a time-independent high rate on TOU or flat rates*” which are triggered by utility in an event, such as unavailability of reserves, or extreme weather conditions, and it is communicated in a very short notice. Extreme Day Pricing (EDP) and the Extreme Day CPP are two variants of CPP that use peak and off-peak rates and are applied on extreme days’ conditions while in the remaining days a flat rate is applied.

Incentive Based Programs may be classified into voluntary, mandatory or market clearing DR programs. The first type of programs includes Direct Load Control (DLC) and Emergency Demand Response Program (EDRP), the second group of programs includes Capacity Market Program (CAP) and Interruptible/Curtailable (I/C) Service and the Market Clearing Programs include both Demand Bidding (DB) and Ancillary Service (A/S) Markets programs. Parvania et al. (2012) identifies three DR programs in electricity markets: Energy Market DR (EMDR) programs, Ancillary Service Market DR (ASDR) programs and Capacity Market DR (CMDR) programs. According to this author, EMDR can be divided into non-dispatchable and dispatchable programs. While in dispatchable EMDR programs consumers are allowed to explicitly participate on the wholesale market through bidding, in non-dispatchable EMDR programs this is not allowed and consumers are exposed to time-varying rates such as: Time-of-use (TOU) rates, critical peak pricing (CPP), and real-time pricing (RTP). Both non-dispatchable and dispatchable EMDR programs are designed to reduce system peak load mainly through demand shifting or demand reduction actions.

In what concerns the Incentive Based DR Programs, their respective description is done below:

Direct load control (DLC): DLC programs are managed by a utility or system operator that might activate them due to economic or reliability (system or local) events. Utilities may temporarily control specific consumer’s electrical appliances but not to compromise consumers comfort, usually the number and the duration of interruptions are defined. Air conditioners (ACs), lighting, water heaters, pool pumps include some of the loads that can be remotely

controlled. Consumers' participation in this type of DR program is rewarded through upfront incentive payments or electricity bill credits.

Emergency Demand Response Program (EDRP): Consumers that agree to reduce or curtail load during reliability events are paid incentives for measured load reductions during the emergency conditions. Per opposition to curtailable load program, this is not a mandatory program and, in this case, customers load curtailment is voluntary.

Capacity Market Program (CAP): This program is mentioned for customers that are able to providing pre-specified load reductions during system contingencies arise. Participants usually receive a day-ahead notice of events and if they fail to commit to calls for the pre-specified load reductions, they may face penalties thus this is a mandatory program.

Interruptible/Curtailable (I/C) Service: In Curtailable load program participants respond to utility calls to reduce specific loads during system contingencies. Utilities may temporarily request consumers for load curtailments in reliability events but also for trading in the energy market. Consumers' agreement to reduce or curtail load is rewarded through incentive payment or electricity bill credits. However, if customers fail to respond to a DR event they may face penalties thus this is a mandatory program.

Demand Bidding (DB): Demand Bidding or Buyback programs boost consumers to actively participate in wholesale market through providing load reduction at a price that they would be willing to accept to be curtailed. Large customers may directly participate in the market while small consumers can participate through third-party aggregators, such as utilities or independent Load Serving Entities (LSE), to bid load into day-ahead or hour-ahead wholesale energy markets (Paterakis et al., 2017). PJM, ISO New England, the New York ISO and the California ISO, are some examples of demand bidding programs that have been offered to consumers (Shariatzadeh et al., 2015).

Demand bids may be simple or complex. Simple demand bids participate in a single market structure incorporating price-quantity information, while complex bids may participate in different energy markets and may incorporate technical conditions such as minimum energy consumption (D_{min}), maximum energy consumption (D_{max}), total energy over the considered horizon (e.g. daily), load pickup and drop rates, etc. When a demand bid is accepted, load

reductions are scheduled and dispatched in the same way. Then, generators and customers must curtail the market traded amount of load specified in the bid, or face penalties. Customers that have agreed to a simple spot pricing contract do not receive any incentive from the supplier to reduce loads thus they have the incentive of adjusting their consumption to the value traded on wholesale markets (Braithwait and Eakin, 2002).

Ancillary Service (A/S) Markets: Consumers may bid load curtailment in the spot market as operating reserve. Participants are paid for committing to be on standby and if their load curtailment is required, they are payed the spot market price.

DR programs are deployed to make power grids more efficient and improve reliability through load shaping. The most traditional DR programs have been load management programs such as DLC, and interruptible load programs. Most programs have been designed as substitutes for peaking capacity and are operated only occasionally during periods of unusually high loads or system emergencies. In Table 2.4 are summarized both DR incentive-based programs (IBP) and time-based rate (TBR) programs that have been identified in the literature. Investigation is still working on DR potential effects. Paiho et al. (2018) enumerate different factors for DR potential, such as the type of load and duration of the call, response time to request, time in advance of the request, communication and technological evolution and development of different contracts according with user's profile. The success of a DR program also depends on consumer's awareness, attitude, and behavioral adaptation (Sirin and Gonul, 2016; Bartusch et al., 2011).

Table 2.4 – DR Research Studies. Source: From the author

		Reference	Description
Time Based Rate (TBR) Programs	Time of Use (TOU)	Mohajeryami et al. (2016)	Proposes an economic optimization model applied to a TOU demand response program that aims to maximize the utility of the consumer. An algorithm is proposed for explaining the individual consumer's consumption pattern.
		Datchanamoorthy et al. (2011).	An algorithm for finding an optimum an optimum TOU pricing scheme for use in monopoly utility markets is proposed in order to maximize the societal benefits

	Real Time Pricing (RTP)	Mohajeryami et al. (2017)	Used a demand-price elasticity based model to simulate the customer reaction function in the presence of a real time pricing.
		Savolainen and Svento (2012)	Simulated the impact of RTP in the Nordic Power markets. Analyzing effects on the need for total peak demand, prices, peak demand hours, and economic welfare of electricity on the need for long-run capacities.
		Yu et al. (2011)	Developed a model to maximize users' benefits by considering both load utilities and real-time electricity price.
		Lujano-Rojas et al. (2012)	Proposes an optimal load management strategy for residential consumers and analyzes two study cases of a residential consumer in a real-time pricing demand response in the Iberian Peninsula
		Faria and Vale (2011)	The use of a demand response simulator by a retailer in a situation of energy shortage in order to study demand response actions and schemes. Non-linear programming is used to maximize the retailer's profit, determining the optimal solution for each load reduction supported by real time pricing.
		Mohajeryami et al. (2017)	An algorithm in order to study the impact of DR on price volatility through a demand-price elasticity based model was developed in order to simulate the customer reaction function in the presence of a real time pricing DR program.
		VanderKley et al. (2014)	A real time pricing model is presented that promotes the selection of electricity fees based on the risk that customers are willing to assume.
		Yang et al. (2013)	A statistical elasticity model was developed in order to maximize social welfare and calculate the optimal RTP incentive
	Critical Peak Pricing (CPP)	Herter (2007)	Investigates how critical-peak pricing (CPP) affects households with different usage and income levels

		Time of Use (TOU) & Real Time Pricing (RTP) & Critical Peak Pricing (CPP)	Aalami et al. (2008)	DR time-based programs are reviewed first, and then Multi Attribute Decision Making (MADM) methods, Entropy Ranking Technique (ERT) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), are discussed. Then, using the customer benefit function and the sensitivity coefficients, the demand response will be modeled and based on the results in a typical market considering some of the DSM important criteria, decision matrix will be produced.
Incentive Based Programs (IBP)	Voluntary Programs	Direct Load Control (DLC)	Yu et al. (2012)	Proposes a demand-price elasticity model to explain the customer reaction function in the direct load control (DLC) program.
		Emergency Demand Response Programs (EDRP)	Aalami et al. (2008)	DR is modeled considering the electricity spot price (TOU) and EDRP using the single and multi-period load models, based on the load elasticity concept.
			Yousefi et al. (2008)	Using an economic load model, the amount of customer participations in EDRP program is determined considering its economic and reliability criteria viewpoints. EDRP program has been considered as one of the spinning reserve resources.
	Mandatory Programs	Capacity Market Program (CAP)	AESO (2017)	The capacity market designs in six jurisdictions, the four jurisdictions in the United States (US) that operate centralized capacity markets - New York ISO (NYISO), the New England ISO (ISO-NE), the Midcontinent ISO (MISO) and the PJM Interconnection (PJM) - and the Great Britain (GB) and Ireland markets is reviewed.
		Interruptible/Curtailable (I/C) Service	Oren and Smith (1992)	Proposes a methodology to develop operational tools for dispatching customer loads through simulation based on historical data.
	Market Clearing Programs	Demand Bidding/ Buyback (DB)	Chakrabarti et al. (2012)	Dispatchable energy bids to accommodate DR in the energy, contingency and regulating reserve markets in the NZEM, were considered through a mathematical optimization

				model based on a linear programming method.
			Su and Kirschen (2009)	Proposes a centralized complex-bid market-clearing mechanism that allow consumers to submit complex bids and considers load shifting behavior of consumers who do submit price-sensitive bids.
			Ottesen et al. (2018)	An optimal bidding model considering aggregators participation in three sequential markets.
			Su and Kirschen (2007)	Formulated demand-shifting bids for industrial consumers to participate directly pool market
		Ancillary service (A/S) Markets	Abgottspon and Andersson (2012)	Provides a methodology based on a two-stage stochastic program to include the ability of offering secondary control in a seasonal medium-term self-scheduling of a price-taker hydro power producer with pumped storage.
Hybrid DR Programs Time Based Rate (TBR) Programs & Incentive Based Programs (IBP)			Aalami et al. (2010)	A comprehensive load economic model is developed for TOU, CPP, RTP, EDRP, DLC and I/C and CAP programs which, include penalties for customers in case of no responding to load reduction. The developed model is based on the price elasticity of demand and it takes into account the both incentives and penalties of DR programs effects as well as customer economic benefits.
			Asadinejad and Tomsovic (2016)	Proposes an optimization problem improve integration of renewable outputs based on incentive-based DR programs
			Moghaddam et al. (2011)	An economic model of price responsive loads has been is developed for TOU, CPP, RTP, EDRP, DLC and I/C and CAP programs by using the concepts of “ <i>price elasticity of demand</i> ”, and “ <i>customer benefit function</i> ”.
			Asadinejad and Tomsovic (2017)	A demand-price elasticity model based on scheme designed using both price-based (considering TOU program) and incentive-based DR programs for designing an optimum scheme for obtaining the maximum benefit of DR.

2.4. DR REGULATION STATUS

2.4.1. EUROPEAN REGULATION STATUS

Europe is the second world region that has done more significant progress towards the full deployment of Demand Response through the creation of legal framework that allows policy-makers, regulators, network operators and energy businesses to enhance a future wider promotion and participation of DR in energy markets: *“European households and businesses should be enabled to lower their bills and obtain further benefits if they help relieving pressures in the energy system by simply adapting their demand so as to consume energy in periods when it is relatively cheap or available in abundance.”* (European Commission, 2013). To achieve this purpose, demand side programs are being created within the wholesale electricity market. Moreover, energy markets, such as in UK, Belgium, France and Germany have an increasing number of aggregators, essentially operating in ancillary services and balancing markets (Barbero et al., 2018). France is also developing industrial load balancing programs. Nonetheless, significant barriers still remain until these resources contribute in a significant way to system operation and a redraw of market design is needed to cross the boundaries between wholesale and retail markets. A well performing European energy market, with harmonized rules across countries rather than dispersed regulations, is decisive for the development of a new market design with price signals communication to consumers and for a DR resources significant contribution.

Despite the acknowledged relevance of DR to future electrical power systems challenges such as stochastic renewable generation integration, increasing electrification and decreasing the share of fossil fuels as primary-energy sources, EU has no DR harmonized policy or DR EU-wide implemented programs (Annala et al., 2018; Vallés et al., 2016; Torriti et al., 2010). To fulfil EU environmental commitments, and decarbonizing the power system, the share of electricity from renewable energy sources (RES-E) is projected to continue to increase and market design and operation of the system should adapt to its characteristics. This brings new opportunities and challenges for all market participants, namely new forms of participation for consumer, cross-border cooperation among member states and direct revenues for local community.

Some energy markets in North American have already clarified the role of DR resources through specifications and clear trading parameters of Demand Response resources, resulting in leading participation. In what regards the development and deployment of DR programs, North America is the world leading region accounting for a significant 80% of the global market share (Paterakis et al., 2017). In US electricity market, Demand Response is responsible for generating approximately \$2.2 billion per year in direct revenues for local community (SEDC, 2014).

Despite pilot DR programs and initiatives are already being implemented in some European countries it is not possible to affirm that DR is completely implemented in Europe and some countries still not consider DR. The absence of such policy may be explained by historical reasons concerning the first energy policies and environmental measures that were taken after the 1970s oil shocks. Since then demand side management policies particularly energy efficiency (EE) policies development become an EU energy and environmental driving force due to oil dependency and more recently due to climate change concerns (Torriti et al., 2010).

Regardless the absence of a harmonized policy, the EU recognized DR importance through addressing Demand Response in a set of Directives, namely, Directive 2009/72/EC concerning common rules for the internal market in electricity, Directive 2012/27/EU concerning Energy Efficiency Directive (EED) and on Clean Energy Package from May 2019. These orientations represent a significant step towards Demand Response deployment in Europe.

The recast proposal of Directive 2009/72/EC concerning common rules for internal market in electricity, introduced a new range of definitions such as “*active customer*”, “*aggregator*”, “*dynamic electricity price contract*” and defined the concept of “*demand response*” as previously mentioned. Moreover, the recast of Electricity directive recognizes Demand Response positive effects regarding climate change and environmental issues, on security of supply, on reducing primary energy consumption and controlling peak loads in (EU, 2016). Consumers rights should be guaranteed thus these should be able to engage in Demand Response, self-generation and self-consumption, according to the proposal recast of Electricity Directive (EU, 2016). All customer groups (industrial, commercial and households) should be encouraged to have an active participation role in energy markets to trade their flexibility and self-generated electricity. For that reason, their contracts should reflect the dynamic prices of

electricity on spot markets thus currently they have no incentive to respond to changing market prices, being not aware of real-time price signals. Moreover, all participants should have access to balancing, day-ahead or intraday markets in a non-discriminatory basis, and without the need for other participant's consent. According to the proposal recast of the Electricity Directive (EU, 2016): *“All consumers should be able to benefit from directly participating in the market, in particular by adjusting their consumption according to market signals and in return benefit from lower electricity prices or other incentive payments. (...). Consumers should be enabled to participate in all forms of demand response (...). This should allow them to adjust their consumption according to real time price signals that reflect the value and cost of electricity or transportation in different time periods, (...). Member States should also ensure that those consumers who choose not to actively engage in the market are not penalised but instead their informed decision making on the options available to them should be facilitated in the manner that is the most suitable for domestic market conditions”*. Also, distribution system operators *“should be enabled and incentivised to use services such as demand response and energy storage, based on market procedures, in order to efficiently operate their networks and avoid costly network expansions”* (EU, 2016).

Energy Efficiency Directive (Directive 2012/27/EU) focus DR in Article 15.4 that requires Member States to *“Ensure the removal of those incentives in transmission and distribution tariffs (...) that might hamper participation of Demand Response, in balancing markets and ancillary services procurement”* and to *“Ensure (...) that tariffs allow retailers to improve consumer participation in system efficiency, including Demand Response, depending on national circumstances”* (EU, 2012). Furthermore, Article 15.8 of the Directive clearly establishes consumer access to energy markets, either individually or through aggregators, as the Article mentions: member states shall *“ensure that national regulatory authorities encourage demand side resources, such as Demand Response, to participate alongside supply in wholesale and retail markets.”* and *“Subject to technical constraints inherent in managing networks, Member States shall ensure that transmission system operators and distribution system operators, in meeting requirements for balancing and ancillary services, treat Demand Response providers, including aggregators, in a non-discriminatory manner, on the basis of their technical capabilities.”* and *“Member States shall promote access to and participation of Demand Response in balancing, reserves and other system services markets, inter alia by requiring national regulatory authorities (...) in close cooperation with demand service*

providers and consumers, to define technical modalities for participation in these markets on the basis of the technical requirements of these markets and the capabilities of Demand Response. Such specifications shall include the participation of aggregators.” (EU, 2012).

In november 2016 the European Commission launched the Clean Energy Package which included eight different important legislative proposals that may represent the regulatory launch for Demand Response in Europe. If EU guidelines are implemented across all Member States, conditions for still DR barriers be overcome are introduced thus Demand Response together with storage and generation is perceived as a market resource (EU, 2016b).

EU Demand Response market is getting advances due to the promotion of Demand Response in EU regulation and directives. Despite demand side participation in energy markets is considered to have significant advantages and benefits being considered as an asset both for the retail and the wholesale markets, Demand Response implementation in wholesale energy markets has been progressing slowly in the EU and in other world regions (European Commission, 2013; Chakrabarti et al., 2012, May).

Despite the existing barriers to Demand Response resources to participate in real-time markets, with the transposition of the Energy Efficiency Directive 2012/27/EU, and the establishment of a legal framework for Demand Response development and deployment in European energy markets some countries are taking significant advances for its fully integration into the markets. Significant discrepancy between the different market structures remains regardless of European guidelines towards liberalization and harmonization of electricity markets (Paiho et al., 2018). Demand Response implementation is quite different across member states and regions and still not accepted as a resource in the balancing, capacity or wholesale markets or is limited within some ancillary services as summarized in Table 2.5.

According to Barbero et al. (2018) European Network of Transmission System Operators for Electricity (ENTSO-E) terminology divides ancillary services into three groups in order of timing of activation:

- Frequency Containment Reserve (FCR) is the first to be activated and represents the active power reserves available to contain system frequency after the occurrence of an imbalance;

- Frequency Restoration Reserve (FRR) is the second to be activated and represents the active power reserves available to restore system frequency to the nominal frequency. aFRR and mFRR represents respectively the reserves activated automatically and activated manually;
- Replacement Reserve (RR) is the third to be activated and represents the active power reserves available to restore or support the required level of FRR to be prepared for additional system imbalances, including operating reserves.

Table 2.5 – Summary of Demand Response Access to Markets in Europe. Source: SEDC (2014)

	Wholesale Market			Balancing and ancillary services		
	Load Access & Participation	Aggregated Load Accepted	Aggregated Generation	Load Access & Participation	Aggregated Load Accepted	Aggregated Generation
Belgium	Day Ahead	X	N/A	FCR	FCR	N/A
				mFRR	mFRR	N/A
				RR	RR	N/A
Finland	Day Ahead	Day Ahead	Day Ahead	FCR	FCR	FCR
	Intraday	Intraday	Intraday	mFRR	mFRR	mFRR
France	Day Ahead	Day Ahead	Day Ahead	FCR	FCR	FCR
	Intraday	Intraday	Intraday	aFRR	aFRR	aFRR
				mFRR	mFRR	mFRR
				RR	RR	RR
				DSR - RR	DSR - RR	N/A
Great Britain	X	X	Day Ahead	FRR	FRR	FRR
			Intraday	RR	RR	RR
				FCR	FCR	FCR
				Capacity Mechanism	Capacity Mechanism	Capacity Mechanism
				Transitional arrangements	Transitional arrangements	Transitional arrangements
				Triad avoidance	Triad avoidance	Triad avoidance
				Red Zone Management	Red Zone Management	Red Zone Management
Ireland	N/A	Day Ahead	Day Ahead	RR	X	X
	N/A	Intraday	Intraday	Interruptible loads	Interruptible loads	X
				Price-based capacity provision	Price-based capacity provision	Price-based capacity provision
				Other ancillary services	Other ancillary services	Other ancillary services
				Capacity mech.	Capacity mech. (if any)	Capacity mech. (if any)
Switzerland	Day Ahead	Day Ahead	Day Ahead	FCR	FCR	FCR
	Intraday	Intraday	Intraday	FRR	FRR	FRR

				RR	RR	RR
Austria	X	X	Day Ahead	aFRR	aFRR	aFRR
			Intraday	mFRR	mFRR	mFRR
Denmark	Day Ahead	Day Ahead	Day Ahead	FCR	FCR	FCR
	Intraday	Intraday	Intraday	aFRR	aFRR	aFRR
				FCR-N	FCR-N	FCR-N
				FCR-D	FCR-D	FCR-D
				mFRR	mFRR	mFRR
Germany	Day Ahead	Day Ahead	Day Ahead	RR	RR	RR
	Intraday	Intraday	Intraday	FCR	FCR	FCR
				aFRR	aFRR	aFRR
				mFRR	mFRR	mFRR
				Interruptible loads	Interruptible loads	DR only programme
Netherlands	Day Ahead	Day Ahead	Day Ahead			
	Intraday	Intraday	Intraday	aFRR	aFRR	aFRR
Norway	Day Ahead	Day Ahead	Day Ahead	mFRR	mFRR	mFRR
	Intraday	Intraday	Intraday	FCR	FCR	FCR
				aFRR	aFRR	aFRR
Sweden	Day Ahead	Day Ahead	Day Ahead	mFRR	mFRR	mFRR
	Intraday	Intraday	Intraday	RR	RR	RR
				FCR	FCR	FCR
				aFRR	aFRR	aFRR
Poland	Day Ahead	Day Ahead	Day Ahead	mFRR	mFRR	mFRR
	Intraday	Intraday	Intraday	RR	RR	RR
Slovenia	X	X	X	Emergency Demand Response Programme	Emergency Demand Response Programme	X
				Balancing Market	X	Balancing Market
Estonia	X	X	X	FCR	X	X
				FRR Secondary Reserve	FRR Secondary Reserve	X
				FRR Tertiary Reserve	FRR Tertiary Reserve	FRR Tertiary Reserve
Italy	X	X	X	X	mFRR	mFRR
Portugal	X	X	X	X	X	X
Spain	X	X	X	RR Tertiary Control	RR Tertiary Control	RR Tertiary Control
				X	Technical Constraints	X
				X	Real-Time Constraints	X

The internal energy market situation has been advancing but the barriers to DR implementation are subsistent (Torriti et al., 2010). France, Belgium, Ireland and the UK are the countries where Directive transposition into national regulatory structures to enable demand side resources to participate in energy markets is currently in a more advanced status (Bertoldi et al., 2016). However, not all the European countries have the same reality in what this matter concerns. In

Portugal, Spain, Italy, Greece, Croatia, Czech Republic, Bulgaria, Romania, Poland, Baltic countries, Slovenia, Slovakia, Cyprus and Malta, EU Directives may have been transposed but in fact, these countries have not enabled DR. Thus, national regulators consider complex the regulatory changes for DR implementation into wholesale energy markets (Bertoldi et al., 2016). Moreover, in 2017, electricity markets at Portugal, Spain, Italy and Estonia were completely closed to explicit Demand Response resources as represented in Figure 2.6 (SEDC, 2014).

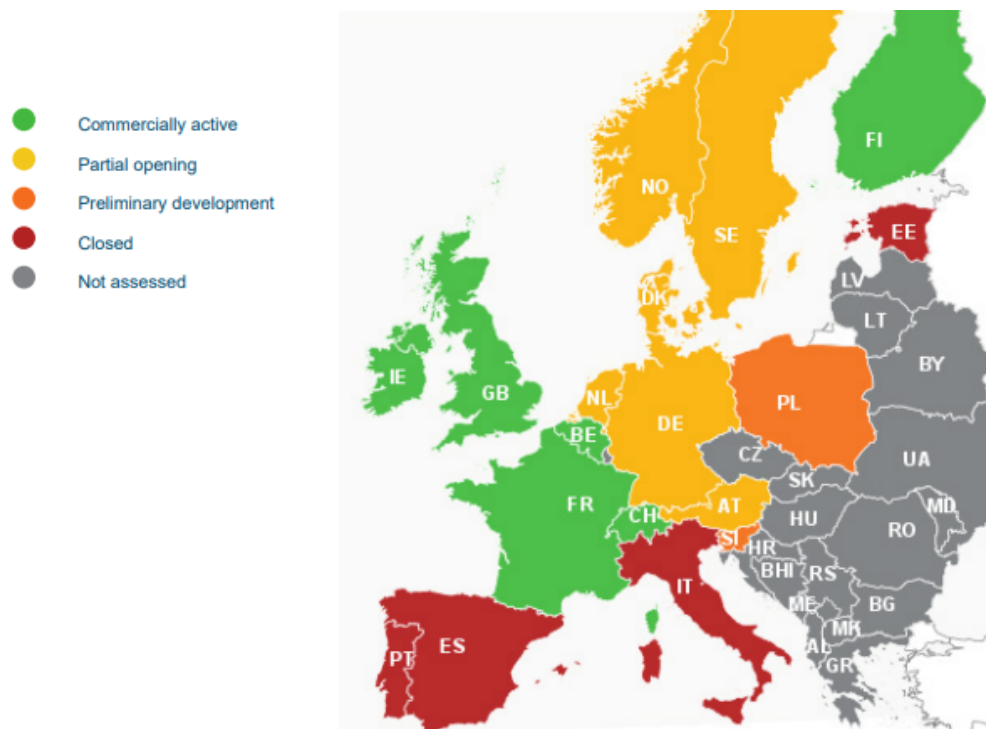


Figure 2.6 – Explicit Demand Response development in Europe. Source: SEDC (2017)

2.4.2. PORTUGUESE AND SPANISH REGULATION STATUS

Portugal has recently taken initial steps towards DR by approving smart grid pilot projects framework regulation focussing on the development of Explicit Demand Response for large consumers. This regulation framework is also expected to develop Implicit Demand Response. Both Portugal and Spain:

- Rely on hydro power and gas flexibility resources for achieving demand peak-load;

- Are developing a distributed energy generation with an increasing need for flexibility (SEDC, 2014).

The Portuguese electricity market does not recognize DR as product in wholesale markets, including both day-ahead and intra-day markets. Flexibility resources participation in the wholesale market are limited to a few large consumers, who act as their own retailer. In what concerns Balancing Markets in the 2nd April 2019 a Pilot-project started with a year duration, with the goal of assuring the participation of enabled consumers in regulation reserve markets. This project is according to Directive n. °4/2019. According to REN (2020) during Project-Pilot duration more energy was mobilized in the increasing consumption way (10 527,6 MWh) than in the decreasing consumption way (900,6 MWh).

There is an absence of a regulatory framework for consumer participation in DR energy markets, including different stakeholder's roles and responsibilities, measuring procedures and consumption shifts remuneration and incentives (SEDC, 2014). Nevertheless, initiatives have been carried out to overcome the existing barriers, such as Directive 4/2019 that establishes the rules for a Pilot-Project concerning the participation of consumption in reserve market. Furthermore, the Directive 4/2019 imposed criteria that limit the number of eligible entities to a few large consumers, such as industrial customers. Thus, according to the proposed pilot project rules, demand participation is limited to consumption facilities that both have the capacity to supply 1 MW or more and demonstrate the necessary technical and operational capacity to provide the regulation reserve from the Transmission System Operator, in its Global System Management (GGS) activity. Eligible consumption facilities need to have metering and reading equipment, with hourly discrimination, to enable the GGS to verify compliance with the regulatory reserve mobilization orders sent. In this context, Directive 4/2019 outcomes and results are expected to be useful for an extended participation of other type of consumer, such as domestic customers, through the consumption aggregators in the demand side (ERSE, 2019). Until 15th February 2019, a public consultation, from the Portuguese regulator ERSE, was in progress to discuss the foundations for the new regulatory framework for smart grid service public. Smart metering and network technological advances are crucial for DR development and implementation. Despite the structures for Demand Response have yet to be put in place, the creation of the necessary framework for DR enabling technology may help to define further regulations in the DR framework.

In Spain, similarly to Portugal, aggregated Demand Response does not have access to the balancing market, neither to ancillary services. Nonetheless, in the Tertiary Control Market, Demand Response is seen as a product and aggregators can participate. Despite the concept of aggregator for Demand Response is still not foreseen in the Spanish regulation, individual customers can directly participate in the wholesale market (SEDC, 2014). In pair with the Portuguese reality, Demand Response participation is eligible only for large industrial consumers and Interruptible Load program is the only scheme that allows Explicit Demand Response (SEDC, 2014).

2.4.3. SWITZERLAND, GERMANY AND AUSTRIA REGULATION STATUS

Despite demand-side resources in some countries, such as in Austria, where it is already allowed to participate in the day-ahead market, there is no Demand Response participation on the EPEX spot market from Switzerland, Austria and Germany.

In contrast with Switzerland, that permits load aggregation without barriers, both Germany and Austria still have to remove barriers in order to allow the full potential of demand-side flexibility. These countries reality differs significantly. In Switzerland, regulation provides clear roles and responsibility for all parties mitigating the costs and risks, while in Austria Aggregators can only attract customers with large amounts of flexible load and in Germany Demand Response Aggregators are unable to participate in day-ahead and intraday markets, due to a number of reasons such as: lack of standardized processes thus there is no framework in place to defining the interactions between energy retailer and independent aggregators, network tariff design that discourages consumers from participating, and low market prices. In Germany consumers that want to sell their flexibility in the day-ahead and Intra-day markets can only do it through their electricity retailer.

While in Switzerland all balancing market programs and ancillary services are open to Demand Response including Primary (3 MW), Secondary (10 MW mainly coming from household boilers) and Tertiary Control Power (from various industries provides about 49 MW of tertiary reserve), in Austria the only market open for DR is the FCR (Primary control), despite efforts made since 2014 to increase the participation of consumers, such as: the preconditions for the prequalification to ease the aggregation of demand resources, open the balancing market to Demand Response and new technologies. In the same country, balancing market and ancillary

services are “*pay as bid*” but if consumers fail the prequalification requirements, are subject to penalties such as: suspension of capacity and energy payment (SEDC, 2014). Due to high prices and a number of activations, the tertiary and the secondary control in Austria are the most appealing for Demand Respond flexibility resources, respectively, from a technical and from an economic point of view.

In Germany, Demand Response and aggregation are legally allowed to participate in German wholesale and balancing reserve markets. However, due to the existing barriers, only large-scale industrial consumers (more than 100 MWh / per year) participate in these markets, despite Germany potential to increase decentralized energy generation and flexibility due to the phasing out of nuclear power by 2022 and the goal to achieve 35% of renewable electricity supply by 2020 (SEDC, 2014).

2.5. BENEFITS AND BARRIERS TO DEMAND RESPONSE

The EU commitment to reduce greenhouse gas emissions to 80–95% below 1990s levels by 2050, created a new paradigm and triggered several challenges in power systems across Europe in order to be more environmentally friendly and reduce fossil fuel dependence to achieve the proposed milestone. Electrification associated with the decarbonization of the power sector is a direct, effective and efficient way to decrease fossil fuel dependence and meeting EU environmental targets and increasing power system economic efficiency benefiting society as a whole (Vallés et al., 2016). According to future scenarios, electricity demand in Europe will continue to increase, even in the highest energy efficiency scenario and is expected to represent about 36 to 39% of total energy demand in 2050 (European Commission, 2012). To fulfil a continuous demand for electricity, assuring sustainability, security of supply and system operation efficiency, an undergoing decarbonization of the power generation system is necessary. In 2030, it is expected a 57 to 65% decarbonization level, and, in 2050, this will be almost complete (96 to 99%). Renewable technologies are vital towards decarbonization of the energy system and are expected to be predominant in future (European Commission, 2012). According to EU decarbonization scenarios, in 2030 and 2050, the import of fossil fuel will fall, respectively, to 35 and 45%, having less representativeness in the European energy mix

and as a consequence, fuel price volatility is expected to decrease (European Commission, 2012).

The continuous growth of renewable penetration, the development of smart grids and decentralized generation, and the integration of energy markets across Europe, will influence the power system and the power markets and future energy prices should better reflect costs thus actual energy prices are artificial due to regulations and subsidies. However, there is some uncertainty related to the evolution of energy prices in a future where renewables predominate in the energy mix. Different scenarios suggest a continuous rise in electricity prices till 2030, due to high capital costs and high needs for balancing capacity, storage and grid investments assumptions (European Commission, 2012). As European scenarios project electricity prices to continue to rise, financial incentives from Demand Response program participation may represent a future possibility to offset the increasing energy costs.

Demand Response potentials and benefits constitute a largely unexploited resource in Europe. The European Commission, in the communication *“Incorporating demand side flexibility, in particular demand response, in electricity markets”* considers there are three main intervention targets for national policy-makers, regulators and energy companies for achieving DR full deployment potential (European Commission, 2013):

- Creating market-based and transparent incentives for Demand Response that reward participation through dynamic prices without unnecessary constraints whilst respecting legal considerations on data security and protection, privacy and intrusion.
- Opening up the market to exploit the potential of Demand Response.
- Bringing the technology into the market through the roll-out of smart metering with the appropriate functionalities.

According to current literature, DR may be seen as a flexibility resource creating value for the entire system including energy markets and may offer services such as real-time congestion management, balancing of the electricity system and ancillary services. Thus, it improves transmission and distribution grid management and system economic efficiency therefore blackouts resultant costs and investment costs in transport capacity and backup generation

plants are postponed or avoided (Jiang et al., 2015; Dabur et al., 2012). According to Qdr (2006) resource-efficiency due to an alignment between production and customers' electricity prices is the most important benefit of Demand Response. The resource-efficiency resultant from DR may be classified in different benefit group categories. Møller Andersen et al. (2006) divide these groups into three categories: market efficiency; system reliability and volatility of prices and quantities. While Qdr (2006) divides the benefits groups into four categories: Market-wide financial benefits; Market performance benefits; Reliability benefits and Participant financial benefits. Considering both approaches, despite different categories classification, there are similarities in what they englobe. Market efficiency or market performance benefits categories are both relative to DR value in mitigating market power, improving resource utilization, and according to the first approach with the expression of consumer preferences (Greening, 2010). The participation of consumers both individually and through third party services such as aggregators, increases market competition and reduces suppliers' ability to increase prices on markets.

System reliability benefits, concerns on security of supply and operational stability of the system and grids, thus Demand Response improves the balance between generation and supply, reducing constraints and network losses allowing a better management of outages and voltage. Moreover, increasing system efficiency as result of DR value, reduces or postpone the need for backup capacity by shifting consumption from peak hours.

Market-wide financial benefits are focused on DR value concerning wholesale market prices volatility. Demand Response avoids the need to use fuel-expensive power plants and reduce wholesale market prices eventually reducing consumers' electricity bill. Electricity reduction bills and financial incentives resultant from consumers' participation in DR programs is focused by Qdr (2006) in a participant financial benefit group.

Residential and commercial consumers or larger entities such as industries may benefit from DR financial incentives when being flexible and adjusting their electricity consumption in response to control signals. There is a wide range of benefits resulting from the implementation of Demand Response in energy markets. According to Aalami et al. (2010), it allows to optimize the use of generation reducing the call from expensive generating units, to increase the short-term capacity, to reduce the price volatility in the spot market and the price of electricity for all

electricity consumers, to reduce the need for new costly transmission and distribution infrastructure enforcements, to reduce market power, power interruptions and preventing black-outs risks, and to increase power system reliability, efficiency, security and stability (Greening, 2010). Moreover, it enables to increase the amount of zero-carbon wind and solar power that can be integrated into energy markets, contributing for the decarbonization of energy markets. Demand Response participation in energy markets holds the potential to be a win-win solution both for the end-consumers, regardless if they are industrial, commercial or households, and for the different power systems operators particularly due to an increase both on elasticity and economic efficiency of wholesale market operation. For a Demand Response market integration boost and to benefit all market participants, both efficiency and controlled loads should be maximized (Strbac, 2008). Most of the DR benefits are included in market (financial and performance) benefits, system benefits and consumer benefits. DR benefits may englobe another category associated to society-wide benefits. These category benefits are associated to the value created by DR, concerning environment and GHG emission reduction. For renewable generation, such as wind and solar, DR acts as cost effective GHG free balancing resource. A study concerning DR potentials in EU estimated that by 2020 DR would represent a 100 TWh annual energy savings resulting in a 30 million tons of CO₂ reduction (Torriti et al., 2010).

The use of DR as a form of standing reserve increases system stability by reducing the need for spinning reserves and increasing renewable generation penetration in the grid what may assume an important relevance in periods where there is a mismatch between demand and renewable generation production. Fossil-fuel power plants are permanently burning fossil resources to cover energy supply needs during peak periods. Through fewer fossil-generating units scheduling to operate, fossil fuel burn decreases and the amount of GHG emissions from electricity production associated to fuel burn also decreases. Moreover, in countries dependent on fossil resources importations for electricity production, security of supply may increase, thus a more efficient managing of the system allows fossil fuel power plants to operate fewer times. In summary, DR creates additional value for society thus balancing the system results in fossil fuel consumption reduction that leads to CO₂ emission reduction.

Possibly the most significant promise associated to DR is related to the elasticity increase of consumers resulting in an increased efficiency of wholesale market operations. Still, the future demand for flexibility remains as the main uncertain factor associated to DR. So far, the lack

of understanding of DR economics, is a key factor behind DR marginal implementation. Moreover, and despite the numerous possible advantages of DR, there are still barriers to DR to be considered as effective resource to contribute for system operation. The major DR barriers identified in the literature can be divided into three different groups: Regulatory changes, power market reform, and technology advancements. Market rules and enhancement in DR enabling technologies are important to make DR a viable and efficient resource.

In Nordic electricity market, the development of smart meters is vital for Demand Response deployment, considering that depends on technology and equipment enabling data and calculation processing towards defining the most economic viable solutions. DR smart meters should have specific functionalities, such as: hourly measuring in order to allow consumer response to hourly spot prices variations, real-time Demand Response and real-time consumption data and to enable load changes as deliveries of system services (Nordic Council of Ministers, 2014). Traditional meters are only able to measure the total power usage without record options, thus, they do not have an interface and the ability to communicate with utilities, end-users or appliances. The slow introduction of DR technology enabling to meet DR and smart grid requirements constitutes a barrier for DR expansion. In Finland, one of the most advanced European countries regarding Demand Response implementation, by 2017, around 1800 MW from existing residential heating loads could already be controlled through smart metering infrastructure (Valtonen, et al., 2017). Directive 2006/32/EC concerning Energy End-Use Efficiency and Energy Services was adopted in December 2005 and referred that “*real-time demand management technologies such as advanced metering systems*” should be adopted by member States and these should “*ensure that end-users are provided with competitively priced individual metering and informative billing that shows their actual energy consumption*” (EU, 2006). Furthermore, these words are reinforced on Directive 2009/72/EC that states: “*Member States shall ensure the implementation of intelligent metering systems that shall assist the active participation of consumers in the electricity supply market.*”. Article number 2, refers, that by 2020, at least 80% of consumers shall be equipped with intelligent metering if economic assessment is considered to be positive and it is expected that almost 72% of European consumers will have a smart meter for electricity (EU, 2009). Directive concerning Energy Performance of Buildings Directive, Directive 2010/31/EU, does not directly approach Demand Response but Article 8 refers that: “*Member States shall encourage the introduction of intelligent metering systems whenever a building is constructed or undergoes major renovation,*

(...) encourage, where appropriate, the installation of active control systems such as automation, control and monitoring systems that aim to save energy” (EU, 2010). The aim of such policies is to help consumers to change behaviors and reduce their energy consumption through informed actions based on transparent access to their data. Directive 2009/72/EC clearly refers that “Consumers should also have the right to be properly informed about their energy consumption. Prepayments should reflect the likely consumption of electricity and different payment systems should be non-discriminatory. Information on energy costs provided to consumers frequently enough will create incentives for energy savings because it will give customers direct feedback on the effects of investment in energy efficiency and change of behaviour.” (EU, 2009). Moreover, Directive 2012/27/EU supports these words “Directives 2009/72/EC and 2009/73/EC require Member States to ensure the implementation of intelligent metering systems to assist the active participation of consumers in the electricity and gas supply markets. As regards electricity, where the roll-out of smart meters is found to be cost-effective, at least 80% of consumers must be equipped with intelligent metering systems by 2020.” (EU, 2012).

Smart meters’ investment costs and their economic sustainability, may represent a barrier for DR deployment. According to Zhou and Brown (2017) smart meter deployment on Europe is based on cost-benefit analysis (CBA) outcomes, which differ significantly between countries that are already implementing smart metering technology and countries where there is no legal framework for wide-scale smart meter deployment (Figure 2.7) due to different local conditions, meter functionalities, and CBA methodologies used. In Finland, Italy and Sweden smart meters’ implementation have started and already accounts for 23% of the 2020 EU target. In Austria, Denmark, Spain, Estonia, Finland, France, Greece, Ireland, Italy, Luxembourg, Malta, Netherlands, Poland, Romania, Sweden and the United Kingdom smart meters’ economic analysis had positive results and large-scale deployment of these meters will move forward. Per opposition, in Germany, Belgium, Slovakia, Latvia, Lithuania, Portugal and the Czech Republic smart meters’ economic analysis had negative or inconclusive results. Germany, Slovakia and Latvia concluded that smart meters’ deployment was viable for some customers. In Bulgaria, Cyprus, Slovenia and Hungary, economic analysis was not performed.

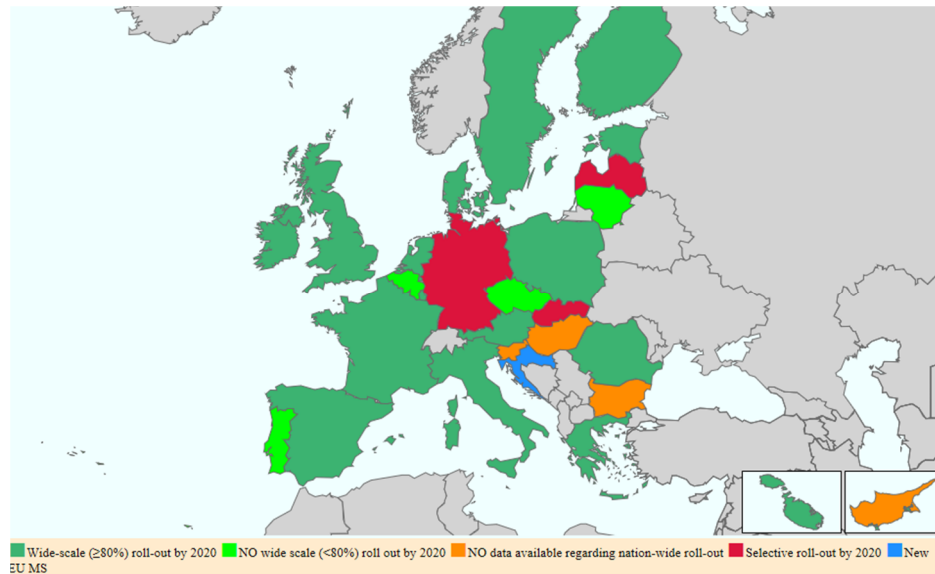


Figure 2.7 – Comparative assessment of the electricity and gas smart metering roll-out.

Source: JRC and DG ENER (2019)

In Great Britain (GB) the industrial and commercial sectors are the most active in DR participation, thus they have access to metering requirements. Even so 71% of companies from industrial, commercial and public sectors do not participate in DR due to concerns in business economic performance and difficulties in understanding products and channels for participation (Bray et al., 2018). Small consumers DR participation is limited due to metering technology barriers. However, considering the low participation DR levels of large consumers, the questions that emerge from what is failing are plural: are load control “*intentional*” programs being incorrectly designed? Is “*automatic*” load control being a missed opportunity? Some authors defend that this last option could be more attractive for consumers, even when financial incentives are more attractive in end-user active load control. Thus, future DR participation require new business development models in order to fulfill client’s needs and requirements. Despite energy markets follow a non-suitable design between wholesale and retail sectors, limited communication metering, culture and behaviors from energy consumers is possibly the greater barrier or at least the most uncertain features concerning DR. According to Greening (2010), organizational, institutional, and cultural reasons are the greater barriers to DR implementation. Figure 2.8 summarizes the challenges of the operating system that lead to DR deployment with its benefits and barriers.

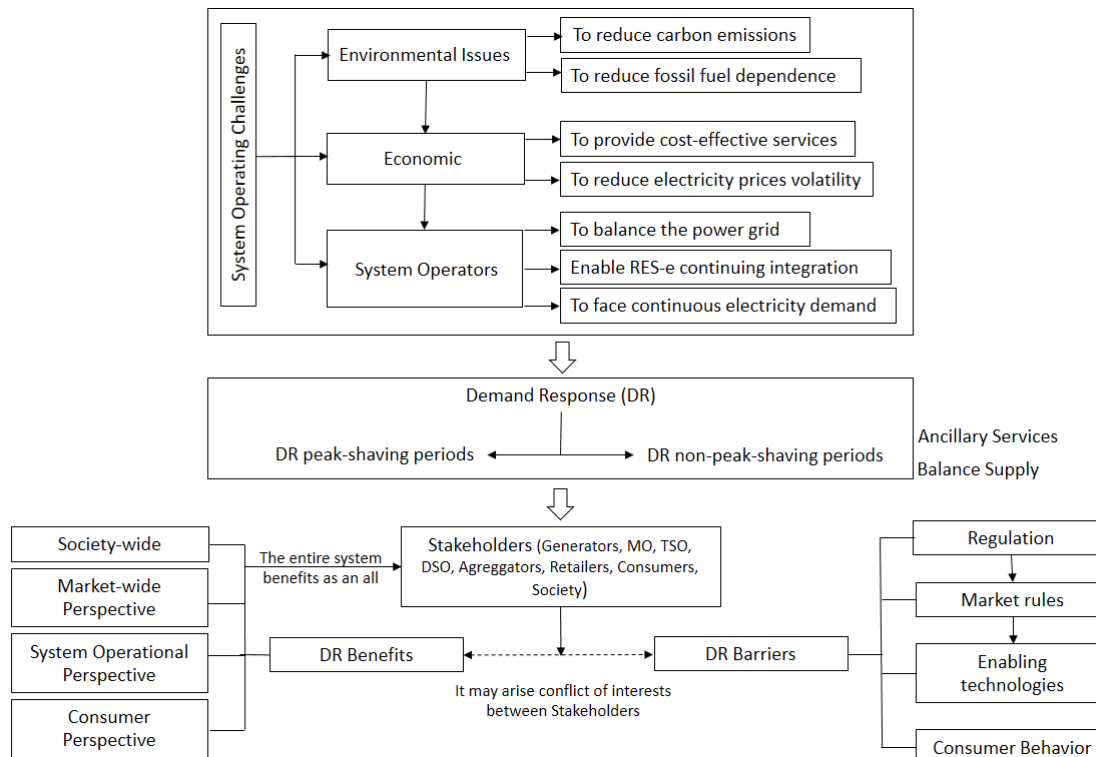


Figure 2.8 – Summary of the main factors driving to DR benefits and barriers. Source: From the author

Consumers' participation and access to energy markets still remain a barrier in most of the member states. The relevant role and responsibilities of the different actors are not clarified and flexibility is being sell directly through the retailer. The main barrier for demand aggregators to participate in energy markets are associated with regulation absence: neither the method to engage consumers nor the viable access to the market is set in regulation framework, thus aggregating demand is not yet a priority in most countries. To fulfill Electricity Directive, Article 17.3a set all states should be enabled to have access to the market in non-discriminatory basis. When roles and responsibilities are not clear and information to consumers is not done in a transparent manner, free DR market competition may be compromised and DR participation cannot reach its full potential. Barbero et al. (2018) state that in Germany aggregators need to sign five contracts per consumer, in France 90% of aggregator profit is handled back to retailers and in Nordic countries, possible conflicts of interest may arise, thus aggregators are also retailers.

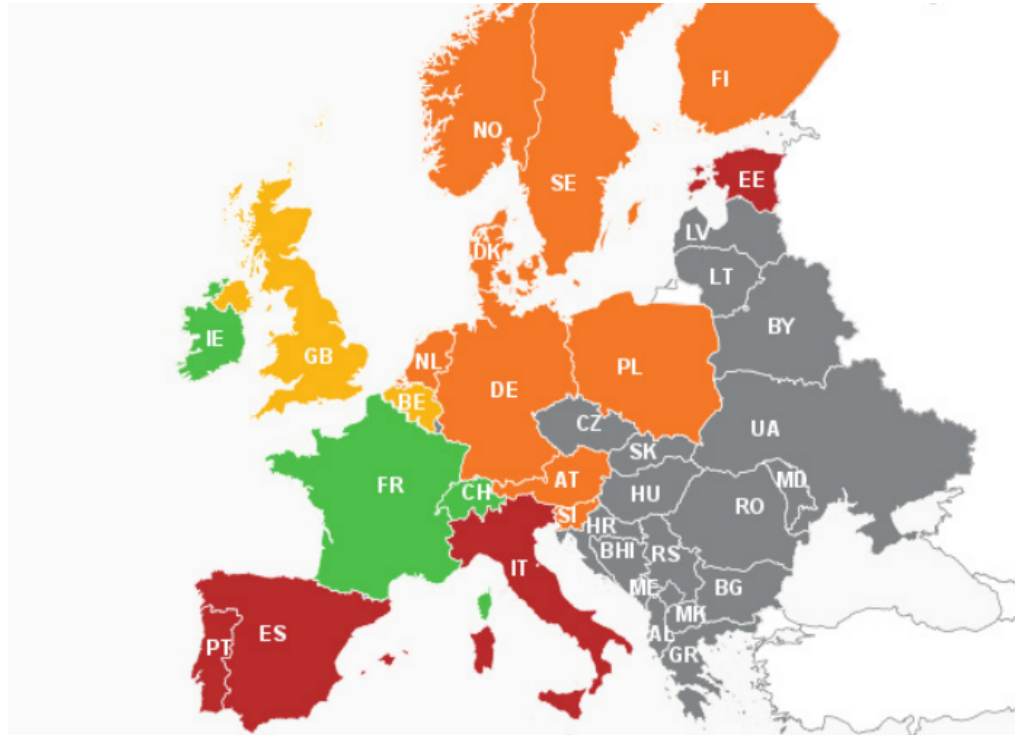


Figure 2.9 – Service providers access to markets in Europe. Source: SEDC (2017)

In Figure 2.9 countries in green colour already have detailed frameworks for independent Demand Response aggregators, such as France and Switzerland. Countries in orange such as Belgium and Germany are in the midst of establishing their own respective frameworks that will establish clear rules between the aggregator and retailer/BRP. Countries in red represented countries such as Spain and Portugal have no frameworks for independent Demand Response aggregators established.

Despite market access details (associated to ancillary services, balancing market and capacity market), technology (associated to network, smart meters and smart appliances) and regulation (aggregation and benefits) barriers, a study performed by Bray et al. (2018) on the Policy and Regulatory Barriers to Local Energy Markets identified as barriers to DR deployment the limited awareness of DSR and the cyber security concerns (Bray et al., 2018).

Moreover, DR characteristics implicate the interaction among different parties that may originate conflict of interests among the different actors such as TSO, DSO, aggregators and final consumers with different purposes and objectives (Annala et al. 2018; Paterakis et al., 2017). Transmission System Operators (TSO) decisions affect Distribution System Operators

(DSO) and on the opposite, DSO decisions affect TSO thus transmission and distribution grids are interconnected. Cost minimization and reliability maximization are a possible example of conflict of interest between TSO's and DSO's. Moreover, retailers' objectives may conflict with DSO's promoting controlling loads based on wholesale market prices, which may increase local networks congestions. The control of loads by aggregators may create imbalances between retailers' purchases and sales, since if the issue is not addressed in the market rules and if there is lack of clarity on their roles and responsibilities, free-riding may occur increasing costs for customers (Labatut et al., 2015). Table 2.6 resumes the benefits and barriers to DR, concerning all the stakeholders.

Table 2.6 – Benefits and barriers to DR, concerning all the stakeholders. Source: From the author

		Stakeholders								References
		Society	MO	Generators	TSO	DSO	Retailers	Consumer	Aggregators	
<i>Benefits</i>	Carbon emissions mitigation	x		x						Dabur et al. (2012), Strbac (2008).
	Mitigate fossil fuel dependence	x								Paterakis et al. (2017), Dabur et al. (2012)
	Security of supply	x			x	x		x		Møller Andersen et al. (2006), Dabur et al. (2012)
	Decrease fuel costs			x						Paterakis et al. (2017).
	Reduce the need for backup power			x						Jiang et al. (2015), Parvania et al. (2012)
	Improve balance between generation and supply				x					Strbac (2008)
	Maintain system security				x					Vallés et al. (2016).
	Help to manage short-term or reduce constraints in networks					x				Vallés et al. (2016), Rahiman et al. (2014), Strbac (2008).
	Reduce network losses					x				Vallés et al. (2016).
	Increase the amount of distributed generation in the distribution network infrastructure					x				Strbac (2008)
	Postpone or avoid network investments					x				Vallés et al. (2016), Qdr (2006), Dabur et al. (2012), Strbac (2008).
	Manage network congestions				x	x				Vallés et al. (2016), Strbac (2008), Qdr (2006)
	Better manage network faults and outages reduction					x				Vallés et al. (2016), Rahiman et al. (2014), Qdr (2006)
	Better manage of network voltage					x				Paterakis et al. (2017).
	Improving distribution network investment efficiency					x				Vallés et al. (2016).
	Optimize their portfolio and adjust their positions in the market						x			Vallés et al. (2016).
	Reduce electricity prices volatility							x		Paterakis et al. (2017), Rahiman et al. (2014), Møller Andersen et al. (2006)

	Market Functioning	x				Møller Andersen et al. (2006)
	Market Power Mitigation	x	x		x	Paterakis et al. (2017), Møller Andersen et al. (2006), Qdr (2006)
	Bill savings and financial incentives				x	Paterakis et al. (2017), Rahiman et al. (2014), Dabur et al. (2012), Qdr (2006)
	Lower wholesale market prices				x	Qdr (2006)
	Consumer-oriented products development				x	Rahiman et al. (2014), Møller Andersen et al. (2006)
	Job creation due to innovation and new technology	x				Dabur et al. (2012)
Barriers	Hampering use of DR incentives		x	x		Annala et al. (2018)
	Smart metering (SM) and information and communication technologies (ICT) minimum functional requirements development necessity			x	x	Greening (2010)
	Increase the complexity of the system operation		x	x		Strbac (2008)
	Retail price regulation hampering use of DR incentives and uncertain benefits				x	Vallés et al. (2016).
	Data privacy protection concerns and cyber security				x	Annala et al. (2018) Bray et al. (2018), Vallés et al. (2016).
	Stakeholders lack of interest				x	Annala et al. (2018) Bray et al. (2018), Dabur et al. (2012)
	Difficulties in changing consumption patterns				x	Annala et al. (2018)

Discomfort during curtailing periods					x		Annala et al. (2018)
Inappropriate market structure and lack of incentives		x	x	x	x	x	Vallés et al. (2016).
Difficulties in understanding complex tariffs or mechanisms for DR					x		Vallés et al. (2016), Annala et al. (2018)
Market rules preventing participation of aggregated loads in wholesale, balancing and capacity markets						x	Annala et al. (2018)
Lack of standardized processes between balance responsible parties and aggregator						x	Annala et al. (2018)
Metering investments					x		Zhu et al. (2011)
Lack of communication between consumers and utilities				x	x	x	Dabur et al. (2012)
Lack of funds for investigation	x						Dabur et al. (2012)
Government regulation lag	x						Dabur et al. (2012)

2.6. DEMAND RESPONSE AND ELECTRICITY MARKETS

2.6.1. THE IMPACT OF VARIABLE RENEWABLE ENERGY SOURCES ON ELECTRICITY MARKETS AND PRICES

Since the beginning of the industrial revolution (18th century), energy demand and supply densities have been growing considerably (Grubler et al., 2012). Besides the controversial of the causal relationships between energy consumption and economic growth (Chen et al., 2012), it is widely documented that the continuous energy consumption is mainly driven by a continuous electricity demand (The World Bank, 2018; BP, June 2018; Enerdata, 2018; IEA, 2020). The IEA scenarios for 2050 reveal a future continuous demand for energy (IEA, 2018). Moreover, most of the worldwide generated electricity is provided by fuel or coal fired power plants and combined cycle gas turbines power plants (Figueiredo, 2017).

Since the 1970s electrical systems operation are essentially based on the management of centralized generation capacity to supply end-consumers, mostly fossil fuel dependent, which is now being discussed at Clean Energy Package (Lavoine, 2018). The fossil fuel dependence of economy has arisen environmental issues and concerns (Paraschiv et al., 2014). According to estimations, if by 2050 the greenhouse gas emissions (GHG) are not reduced by 50% the worst impacts regarding climate changes will be impossible to avoid (Haney et al., 2010). The Paris Agreement reached an historic consensus to limit the global temperature rise below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5°C (Rogelj et al., 2016). In order to reach this goal, power generation from variable renewable energy sources (VRE), particularly wind and solar technologies, is expected to have a major importance in the future design of power systems and progressively supplant power generation from conventional power plants using coal, gas, lignite, or nuclear energy (Peng and Poudineh, 2017; Hu et al., 2018). The deployment of alternative energy technologies promoted by environmental issues and supported by environmental policies, the increasing electrification of energy services, the energy security concerns and the service-oriented economy based on energy access, lead to an ongoing transition in power systems that will require a shift towards decentralized energy systems, and a new approach at production, distribution. Final user's flexibility may bring economy-wide benefits for the entire energy sector (Peng and Poudineh, 2017).

According to most scenarios, a continuous increase of the contribution of VRE to global electricity supply is expected: International Renewable Energy Agency (IRENA) estimates that the renewable energy share in the total global final energy mix would represent 21% by 2030 (IRENA, 2017). International Energy Agency (IEA) projections estimate that the contribution of VRE to global electricity supply has to increase to 25% in 2040 (IEA, 2015) and European Union (EU) estimates that by 2050 the share of VRE in gross electricity generation will represent 36% (Rintamäki et al., 2017; Valtonen et al., 2017). The experienced and predictable progress towards renewable energy sources investment into the electric power system presents some unsolved challenges, due to the variability, intermittency, locational dependence and unequaled production with demand needs and may have the potential to jeopardize system stability and power quality (Stötzer et al., 2015; Chao, 2011; Ponds et al., 2018). The sharply growing outputs of intermittent renewable sources and of distributed energy resources (DERs) emerging on the supply-side of the grid has emerged difficulties regarding the intermittency and bi-directionality of the grid and undertake changes and new challenges to the electricity markets (Rintamäki et al., 2017; Valtonen et al., 2017). DERs include renewable energy technologies, electric vehicles and other energy resources, namely, Demand Response (DR) programs, batteries, micro grids and small generators (Gürtler and Paulsen, 2018). The integration and interaction of these resources into the existing grid with non-VRE resources and with energy markets creates a challenge for power systems worldwide since is difficult for networks operators to monitor and control voltage (Ponds et al., 2018).

The large penetration levels of renewable energy resources, which being produced at zero or nearly-zero marginal costs are prioritized over other sources, displace out of the electricity spot market traditional fossil fuel power plants with higher marginal costs and imposes system operators to secure larger reserves of dispatchable capacity (Ponds et al., 2018). Therefore, due to production decline the costs associated to thermal plants generation will tend to decrease clearing wholesale energy prices. However, production costs may increase during the hours that renewable energy resources are out of the energy market (Peng and Poudineh, 2017). In a competitive electricity market, the impact of the short-term renewable energy resources is larger in thermal-dominated systems and tend to lower the wholesale price (Cludius et al. 2014). The ranking effect of available energy sources based on their marginal costs of production is called the merit order effect (MOE) (Figueiredo, 2017). The MOE of the fluctuating VRE tends to have higher influence on electricity prices than changes on the residual demand, despite a study

performed by Gürtler and Paulsen (2018), concluded that the price effects from demand changes depend on the price levels of different fuel types. However, fluctuating outputs from generation has been better integrated along the years.

The demand changes lead to a modification of the generation power system marginal price and decreasing wholesale prices Peng and Poudineh (2017), thus variable renewable energy (VRE) technologies with zero marginal costs tends to decrease electricity prices (Cludius et al., 2014). Several simulation and regression analyses have studied the effect of renewables on the prices: Würzburg et al. (2013), Pereira and Saraiva (2013), Cutler et al. (2011), Cruz et al. (2011) and Mauritzen (2010). Electricity spot markets are in fact day-ahead markets, thus the auction occurs in the before and the delivery on price dampening effect of renewable energy sources (RES) takes place during the following day, meaning that the price is set based on forecasts that may be affected by errors with impact on spot markets prices (Paraschiv et al., 2014). The literature about how RES-E generation has an impact on spot prices and price volatility remains non-conclusive (Figueiredo, 2017). A study performed by Dillig et al. (2016), based on historic market data to quantify the effect of renewables on prices, concluded that renewable energies reduced the market prices during the last years and brought savings of nearly 30 billion euros for the German power consumers. To analyze the impact of privileged renewable electricity generation on spot market prices in the years 2001 and 2004–2006 Sensfuß et al. (2008), through a calibrated PowerACE model simulated electricity market prices and demonstrated that renewable electricity generation has a considerable impact on market prices. These studies were referent to Germany, a pioneer regarding renewable energy resources, where renewables account for 29% of the gross electricity generation (Paraschiv et al., 2014). A study that aimed to quantify individual contributions of Germany and Sweden electricity markets on day-ahead prices from 2008 to 2015 using the fundamental electricity market model EMMA developed by Welisch et al. (2016) concluded that the largest factor depressing prices was the expansion of renewable energy, despite Germany's nuclear phase-out had an upward effect on prices. Moreover, fuel and CO₂ prices were also important price drivers in Germany, while in Sweden it was demand for electricity (Hirth, 2018). Fuel and CO₂ prices were important price drivers in Germany, while in Sweden it was electricity demand. This difference is explained by the nature of the hydro-dominate Nordic electricity system. In both countries, however, the single largest factor depressing prices was the expansion of renewable energy. Another study performed by Kyritsis et al. (2017), which aimed to investigate the effects of intermittent solar

and wind power generation on electricity price formation in Germany, study the relationship between day-ahead electricity prices and solar and wind power generation and total electricity load for all hours, peak hours, and off-peak hours, using data over the period from 2010 to 2015. The study concludes that both solar and wind power generation induce a merit order effect, despite have different effects on the volatility of electricity prices.

While solar power generation reduces the volatility of electricity prices as it reduces the probability of electricity price spikes, the wind power volatility increases electricity prices volatility, by introducing electricity price spikes. Hildmann et al. (2015) conducted an empirical analysis performed on the EPEX German-Austrian price zone based on data provided by the European Energy Exchange (EEX) and on high-resolution time-series data of the German power system, for the full years 2011–2013. It was concluded that reducing the (volume) dominance of RES feed-in in the EPEX spot by means of mandatory spot pools will significantly reduce the spot price volatility due to RES feed-in, and the spot settlement of RES with marginal cost is possible. Negative spot prices disappear and, on most days, at least some of the RES volume is settled. Within the context of the distribution of costs and benefits of Germany's Renewable Energy Sources Act (EEG), a study performed by Cludius et al. (2014) that aimed to discuss results on merit order effects based on model the electricity spot (day-ahead) price as dependent on the feed-in of wind and photovoltaics (PV) and total load as an indicator for total demand for the individual years 2008–2012, as well as for the three years 2010–2012, concluded that Electricity generation by wind and PV has reduced spot market prices considerably by 6€/MWh in 2010 rising to 10€/MWh in 2012. The results were used to build a near-term forecasting tool for merit order effects, projected to reach 14-16 €/MWh in 2016. Also, Rintamäki et al. (2017), concluded that wind and solar power production have statistically and economically significant effects on day-ahead price volatility in Denmark and Germany. In the short run, Danish daily price volatility is lower when there is more wind power production. By contrast, wind power increases the daily price volatility in Germany. A study performed by Verhaeghe et al. (2016), presents an assessment of the impact of renewable generation on the electricity markets and is based on a set of assumptions that do not completely represent current Energy Only Market functioning. It has concluded that large-scale deployment of renewable energy sources, mainly onshore and offshore wind and photovoltaic, is having a pronounced impact on the energy market, both regarding generation mix and price formation. The econometric analysis demonstrates that both wind and solar generation (in

Germany) have a negative effect on French prices. In France, increasing solar and wind generation by 1GW, would cause a decrease on the average price, respectively, by 0.67 and 0.45 Euros. In Germany, wind and solar generation also decreases prices. Renewable electricity generation may also lead to changes in the export and import of load flows of electricity (Winkler et al., 2016). The study developed by Winkler et al. (2016) concludes that interconnections contribute to the convergence of French and German prices. Cross-border exchanges, through more interconnections, decrease price volatility in both countries, although the reduction of volatility is more pronounced in France than Germany. Also, Kalantzis and Milonas, (2010) concluded that electricity spot prices converge over time particularly during periods of high demand (peak hours compared to off-peak hours, winter and summer compared to spring and autumn) and price convergence is stronger in interconnected markets of neighboring countries. However, a study that assess the state of spot price convergence between several European electricity day-ahead markets from 2002 to 2004 performed by da Silva and Soares (2008) indicates that although day-head prices seem to be more convergent within each one of the European markets, they are still far behind the aimed integrated level.

An assessment of both the merit-order effect and the market values of electricity generated from variable renewable energy sources, namely wind and solar photovoltaics, considering the historical price development in several European countries was performed by Hirth (2018). Through a multivariate regression analysis and ex-post calculations, all the analyzed countries demonstrate a consistent, negative impact of renewable electricity on electricity spot market prices and a decreasing market value of renewable energy source, possibly due to increasing renewable load participation. The market values of renewables decreased with their increasing share in total electricity demand.

Regarding the Italian market Gianfreda et al. (2016) have investigated the effect of RES generation on the Italian spot and regulation prices. Results indicate that conventional production units may bid on all market sessions, but, the presence of RES in spot market sessions has significantly relocated conventional supply on markets. However, conventional production may obtain high premia for their flexible production that may inject energy in the system with a few minutes, which might partially compensate the profit foregone in day-ahead market sessions. Empirical evidence of the merit-order effect in the Italian market was found and 1 GWh from solar and wind (hourly average) reduces prices by 2,3 €/MW and 4,2 €/MWh.

Another study that aimed to assess in what extent the penetration of solar and wind electricity (RES) sources has lowered day-ahead wholesale electricity prices, through an analysis on a year to year basis Clò et al. (2015), demonstrated that the impact of RES on prices and the net monetary benefits decrease over time, in correspondence with the increasing degree of penetration of solar and wind sources. In Texas, a study performed by Woo et al. (2011) concluded that the increases in wind generation tend to reduce the level of electricity spot prices but also tend to enlarge the spot-price variance. The study was performed through an estimated model that enables a direct prediction of the effect of an increase in wind generation on spot electricity price level and variance. To analyze the reduction in the wholesale price of electricity as a result of more RES-E generation from wind generation being fed into the grid in the Spanish market De Miera et al. (2008) conducted a study through the identification of the direct effect through the use of historical data to analyze the market in three consecutive days with similar levels of electricity demand to isolate the impact of wind generation from the other factors. The conclusions indicate that an absolute negative correlation exists between wind electricity promotion and the wholesale market price, i.e., the increase in the costs of RES-E support may be offset by the short/medium-term reduction in the wholesale price, leading to a reduction of retail electricity prices. To assess the integration of high penetration of RES-E on the electricity market, the spot electricity market price behavior and the cost allocation mechanism of interconnections through implicit auctioning, a statistical modelling Vector Autoregressive (VAR) and Vector Error Correction Models (VECM), were considered by Figueiredo (2017). Additionally, non-parametric models were applied to capture the level of price convergence. Results of this study indicate a good integration between the Portuguese and Spanish spot electricity markets. Moreover, the high-level of RES-E generation, has proven to have a decreasing effect on spot electricity prices.

Another study performed by Pacheco (2010) to investigate the dynamic relationship between prices of wholesale electricity market in Spain and prices of the main fuel references to generate electricity, concluded that Spanish wholesale electricity spots prices were correlated, as in Portugal and France. Wholesale electricity spots were also correlated with fuel prices, which confirm that electricity prices are directly impacted by fuel prices.

The estimated models demonstrate a good integration level between the Portuguese and Spanish spot electricity markets which was not the case between the Spanish and French spot electricity

markets. Low marginal cost generation technologies are proven to have a decreasing effect on spot electricity prices. Also, Ribeiro (2014), concluded that wind power generation outputs, decrease electricity prices. Also, both nuclear and hydroelectric power have a major influence on prices. The volatility of electricity prices in MIBEL was found to be influenced by meteorological variables, namely, wind speed.

A study conducted in Great Britain by Green et al. (2011), to analyse how the mix of generating capacity would change if large amounts of intermittent renewables are built and what this means for operating patterns and the distribution of prices over time, concluded despite the changes to the industry's capacity mix, there will be a substantial amount of capacity which will only run for relatively short periods, and will require high prices during those periods to recover its fixed costs from an energy-only market. Year-to-year variations in wind speeds will have some impact on electricity prices and generators' profits, but these are smaller than those that have resulted from variations in fuel prices over the last ten years.

The integration of renewable resources instigated deep changes in the organization of the energy sector. Electricity demand may vary significantly during the day, season and year. Since the demand side for electricity has been traditionally considered inelastic, this causes considerable changes on the supply side thus generation should be dispatched in all time periods to fully supply the demand needs (Paterakis et al., 2017). In periods where electricity demand is at peak level, installed generation capacity must be able to meet maximum (peak) demand and high cost-generating units must be used to fulfill the demand (Walawalkar et al., 2008; Strbac, 2008). The difficult balance between generation and demand in the power systems triggered by an increasing VRE penetration, can be mitigated due to the production of the conventional power plants generation, hydro-pump storage, increasing transmission grid capacity and increasing cross-border interconnections, which may provide backup capacity and the flexibility to absorb the steep ramps in the net load (Figueiredo, 2017; Peng and Poudineh, 2017; Stötzer et al., 2015). To provide security of supply generation must have about 20% capacity margin, thus Demand Response through flexible load control opens up significant scope in order to reduce the need for generation capacity and increase the efficiency of generation investment (Strbac, 2008).

The VRE impact on prices volatility is important to be understood, since in future power grids the flexibility to shift loads away from the high peak (usually from 8 am to 8 pm) to low off-peak and respond to price signals is crucial for demand-side participation. Demand Response (DR) mechanisms may improve power systems flexibility and reliability, through enabling consumers to directly or indirectly participate into electricity markets as a resource that will reduce peak demand reducing the need for expensive power plants and provide balancing and reserve power levels (Chen, 2018; Feuerriegel and Neumann, 2016; Shariatzadeh et al., 2015). The implementation and optimization of large-scale DR resources could become central in achieving this goal (Haney et al., 2010). Consumers participation in the electricity market might be achieved through demand side management programs (DSM), developed to improve the efficiency, reliability and environmental impact of power systems (Shariatzadeh et al., 2015). However, within a wholesale prices energy market there are still some technical and institutional barriers that prevent dynamic pricing correlating with demand (Chen, 2018).

2.6.2. DEMAND RESPONSE EFFECT ON MARKETS PRICES AND PEAK LOAD

Wholesale energy markets include both futures markets but also intra-day and spot markets and are made up of several different time-differentiated markets, that are, to some extent, coupled into the three-time frames namely short-term, very short-term and long-term energy markets (Braithwait and Eakin, 2002; Bertoldi et al. 2016; IRENA, 2017). Short-term energy markets are usually seen as a reference in most power systems, and include both day-ahead (DA) and intra-day (ID) markets, where energy is bought and sold minutes prior to the time of consumption. After “*gate closure*” of wholesale markets the balance between real demand and supply is done through balancing markets and ancillary services (Bertoldi et al., 2016). In these markets both design and pricing may depend from each other thus load resources can be allocated to more than one market according with their flexibility (Braithwait and Eakin, 2002).

The interaction between buyers and sellers in a market, may be described through the existence of an auction. Retailer, usually buyer entities use traditional load forecasting tools in ordered to predict demand behavior and to present buying bids in the pool market, per other side, generation generally selling entities present its selling bids. The buying and selling bids are communicated to the market system operator for the day-ahead. The selling bids are organized by market operator from lowest price to highest price in an ascending order for each period.

The buying bids are organized by market operator from highest price to lowest price in a descending order for each timeframe. They are analyzed as aggregated supply curve (upward) and demand curve (downward). This market model is typically for the next 24 or 48 hours, representing an energy retail market for the short-term. Market equilibrium is achieved with the interaction between demand and supply curves, and the market clearing price corresponds to the crossing point between the two curves and corresponds to the value where the marginal benefit of the demand equals the supply marginal revenue (Figure 2.10). It may be said that the market price and quantity are in equilibrium during a certain period if both buyers and sellers are satisfied with the market outcome. Market is continuously recalculating the equilibrium point thus costumers may change the quantity demanded for each price or “*the demand schedule*” for each period (hour, day, week, month or year).

Since the beginning of electricity markets deployment, electricity has been seen by users as a commodity with few motivations for consumers with flat tariff prices to change their demand profiles. Electricity markets were established based on the premise that short run price elasticity of the demand for electricity is small due to its importance, convenience and low cost (Kirschen, 2003; Paterakis et al., 2017). Price elasticity may be defined as the sensitivity of quantity to changes in price (Brunekreeft, 2004). Only when existing a transfer from flat tariffs to time varying prices exposition, consumers will consider taking short run actions to maximize the value they get from the electrical energy with benefits both for consumer and social welfare (Kirschen, 2003; Pinson and Madsen, 2014).

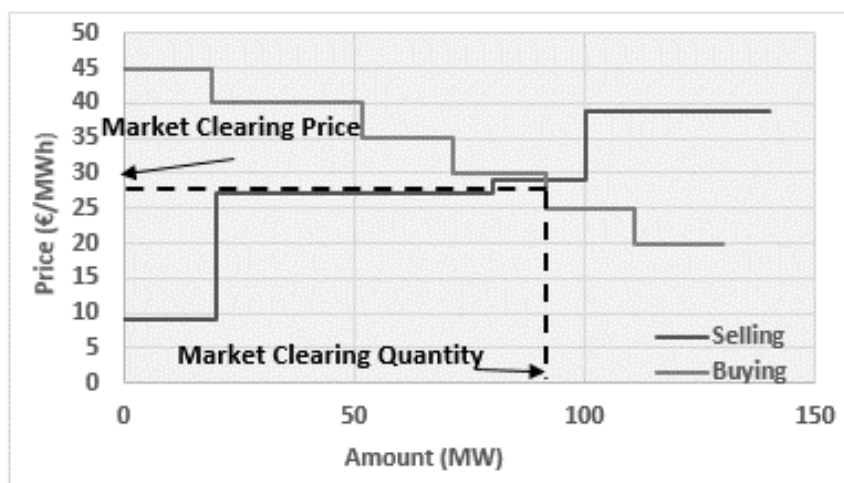


Figure 2.10 – Market clearing price in a double-sided market. Source: From the author

The optimal operation of electricity markets is challenging considering the low elasticity of the demand, particularly in short term periods, which has consequences such as large price spikes and the exercise of market power by generating companies (Kirschen, 2003; Yang and Chen, 2009). Wang and Chen (2012) discussed market-oriented reform in the Chinese electricity industry and the effects caused by the five major state-owned power generator companies that aimed to bid at the lowest price in order to win without profit being guaranteed. This environment caused private competing companies to move away from investing and participating in the market resulting in a deadweight loss associated with a monopoly consistent with Harberger's Triangle model (Wang and Chen, 2012). As a result of such market-design, Zhang et al. (2017) identified as major constraints to DSM in China the insufficient and improper market-based DSM mechanism, grid companies' low motivation for DSM due to their traditional business model, the underdeveloped energy service industry, and electricity end-user's low incentive for DSM (Zhang et al., 2017).

The asymmetry of the market and the absence of demand bidding means that only generation entities present its bids on an asymmetric pool and demand side is being fit to pay any price to be supplied (Figure 2.11). On a single-sided market with passive, inelastic demand, market clearing prices tend to increase when compared with a double-sided market or market where both demand and supply participate (European Commission, 2013).

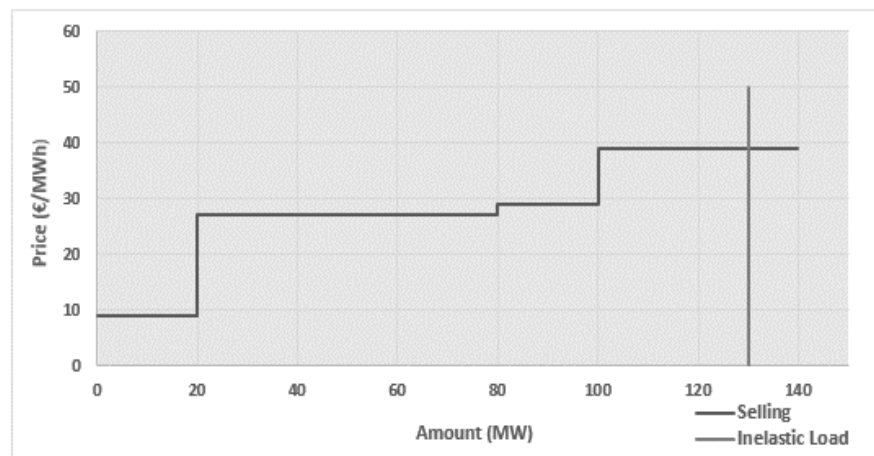


Figure 2.11 – Market clearing price in a one-sided market. Source: From the author

By bidding higher prices suppliers may move the selling curve upwards and raise the market clearing prices in order to obtain larger profits. By encouraging Demand Response, market equilibrium is adjusted to demand curve and prices would not increase so rapidly. Rather than being fixed at a specific load level, if demand side curtail or shift load consumption in periods of high prices, responding to dynamic prices from system operator, their load reductions will allow the market to clear at lower prices (Figure 2.12).

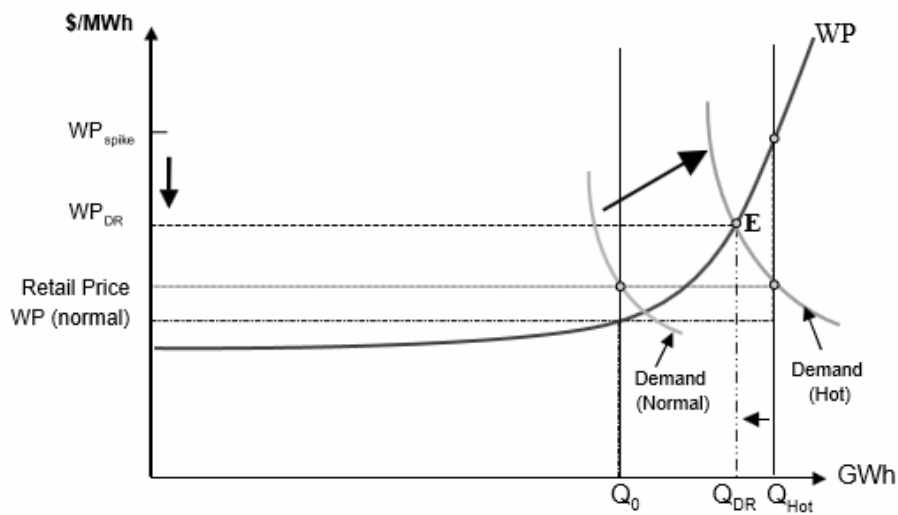


Figure 2.12 – The effect of Demand Response on wholesale market price. Source: Braithwait and Eakin (2002)

Demand Response load shifting management technique do not actually decrease the amount of energy consumed, but merely shift it to when it is more convenient from the grid operation perspective thus it can reduce both peak loads, as well as marginal costs at peak time (Feuerriegel and Neumann, 2016). The beneficial effect from Demand Response action on wholesale market spot price reduction is illustrated in Figure 2.13. Due to its varying nature spot prices, it provides a holistic approach to Demand Response, reflecting the cost of electricity supply at a period, offering opportunities for customers, particularly for storage-type ones, to save in electricity costs through rescheduling their electricity consumption (Daryanian et al., 1989). A study performed by Honkapuro et al. (2015) discovered that from retailer's point of view the economic profitability of the DSM is significantly higher, if resources are utilized in reserve or balancing power markets, instead of day-ahead spot-markets.

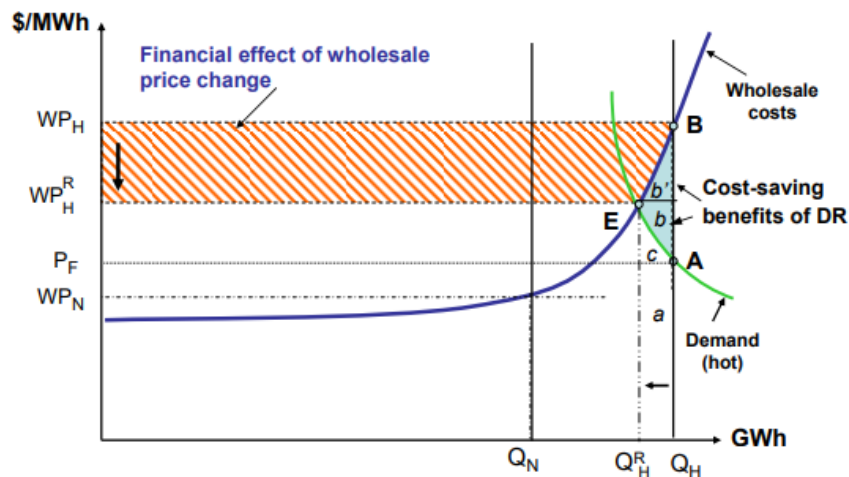


Figure 2.13 – The benefits of Demand Response on wholesale market prices. Source: Braithwait et al. (2006)

Market economics focuses on both optimization and equilibrium, macroeconomics enquires if indicators such as inflation and cost of capital are in equilibrium, and microeconomics addresses the optimizing behavior of consumers and producers and questions if the market quantities and prices are economically efficient (Brunekreeft, 2004). Demand-price elasticity concept has originated from the microeconomic theory and reflects the relative change in the demand with respect to the relative change in the price, in other words, it suggests that consumers will increase their demand up to the point where the marginal benefit they derive from the electricity is equal to the price they have to pay (Mohajeryami et al., 2017). Mohajeryami et al. (2017) proposed an algorithm to study the impact of DR on price volatility through a demand-price elasticity-based model that was used to simulate the customer reaction for a real time pricing. The purpose of this study was to investigate the positive effects of employing Demand Response programs on the spot market price. The results obtained were a total demand reduced by 2.23% and the total cost of electricity for the analyzed period was reduced by 26.23%, which indicates a considerable shift of demand from expensive peak time to less-expensive off-peak period of time due to customer's exposure to the real time pricing (Mohajeryami et al., 2017). Aalami et al. (2010) also proposed a load economic model based on the price elasticity of demand that considers both incentives and penalties of DR programs effects. Through Multi Attribute Decision Making (MADM) techniques the portfolio of DR programs was prioritized according to ISO, utility, costumer and regulator viewpoints. From ISO perspective, Time-of-Use (TOU) program is the most suitable program with a peak reduction of 7.6% and a 0.3%

energy consumption reduction. From the utility perspective, a combination of TOU and Critical Peak Pricing (CPP) programs was the most suitable solution with a 7.4% peak reduction but with an increase both in the energy consumption and customers total cost when comparing with the base case. From customer point of view, Emergency Demand Response Program (EDRP) represented the most advantage solution with a 2.6% energy consumption reduction and the highest customer's benefit value being achieved. From regulator point of view, DLC program is the most suitable, as the results demonstrate an improvement in the load profile characteristics. In this study the maximum peak reduction from all programs corresponded to a 7.6% peak reduction with a TOU program and to a 2.6% maximum energy reduction with an EDRP (Aalami et al., 2010). The same authors have previously developed a model based on the load elasticity concept that was implemented on the peak load of the Iranian power grid combining both TOU and EDRP programs, simultaneously (Aalami et al., 2008). Through its application, considering a 150 Rials/kWh incentive, the numerical simulation results demonstrate cuts on the peak load and transfers the demand to the valley period. Load shape could be changed thus loads are transferred from expensive periods to less expensive periods, if ISO policy applies Demand Response programs (Aalami et al., 2008). Yu et al. (2011) in their study also concluded price responsive behaviors were associated to the interaction between utilities and electricity prices.

Asadinejad and Tomsovic (2017) model based upon demand price elasticity considers a Demand Response combination of both TOU and IBDR programs, since it aims to explore both reward and punishment in DR tariffs. A case study using data from the WECC 240 bus reduced model was used to design optimum peak and off-peak customer tariffs and the load change using both self-elasticity and cross-elasticity. Results demonstrate that the proposed DR programs reduce price variation with LMP reductions, exceeding 15\$/MW in peak season of consumption, as well as demand peak power. The all chain from generation to consumer's benefits from cost reductions. This study quantifies that customers could save up to 10% and LSES could have up to 50% more revenue using the proposed DR scheme (Asadinejad and Tomsovic, 2017). In most cases, demand-price elasticity models demonstrate that DR programs through load shifting or load scheduling may reduce peak load and energy consumption when comparing with DR programs absence. Also, Feuerriegel and Neumann (2016) study results demonstrates that load shifting provides relative savings of 2.83% compared to a scenario without load shifting and total annual financial savings for both households and service sector

may achieve €3.110 million. This study was based on multi-scenarios formulation as optimization problems and comparison based on historic German data from 2011, to quantify the economic benefits. In the first scenario (Scenario A), load shifting model is based on a linear optimization problem that minimize the retailer's accumulated expenditures with the purpose of using load shifting to optimize electricity procurement. In this model, the retailer merely shifts load from peak to off-peak hours in order to purchase electricity at lower prices. In the second scenario (Scenario B), a linear optimization problem was developed in order to assess DR potential at the exchange for reserve energy. The third scenario (Scenario C) quantify the economic benefits using DR to avoid balancing energy (Feuerriegel and Neumann, 2016).

Literature about the analysis of impacts of DR programs on spot prices is sparse and to some point the existing literature is not conclusive about DR programs effect on price volatility. Su and Kirschen (2009) developed a complex bid model to allow price-sensitive consumers to bid in day-ahead clearing market. When analyzing the impact of the complex bid model on demand shifting on the price-responsive bidders, on the price-taking bidders and on the generators, results demonstrate that a reduction in the load generally reduces the market clearing price in the period that occurs, but the load recovery causes price increases at other periods (Su and Kirschen, 2009). Daryanian et al. (1989) study results indicate that higher amplitudes of the price variation would result in higher saving rates, for the considered case study savings are equal to the avoided cost of using electricity at higher-priced hours minus the additional cost of using electricity at the substituted lower-priced hours. The results were achieved applying a non-simplex algorithm for finding the optimal electricity usage pattern in a real case study for an industrial costumer with storage, concerning both the response to spot pricing of electricity and the economic feasibility (Daryanian et al., 1989).

Using a different methodology, Märkle-Huß et al. (2018) simulated the ex post impact of load shifting on electricity spot prices and load, using data from the EEX electricity market in 2014. The results of this study found that load shifting flattens the demand curve and removes peaks, resulting in an average reduction of spot and peak price but with an increase of electricity prices volatility. Moreover, results demonstrate that if a 25% of the available potential for load shifting was adopted, nationwide electricity expenses could be reduced approximately 6% (Märkle-Huß et al., 2018). In the Netherlands the system benefits for long-term DR perspective may achieve 2.4 to 6.3 billion EUR up to 2050 (Klaassen et al., 2017). Also, a study that simulated the impact

of Real Time Pricing (RTP) in the Nordic Power markets concluded that with RTP participation savings could reach €97 million, and peak demand prices diminishes as the share of the RTP customer's increases or demand becomes more price elastic (Savolainen and Svento, 2012).

A study considering Austrian electricity market data, developed based on supplier's perspective, concluded that at residential level cost savings may be achieved through load shifting of residential loads (Prüggler, 2013). Another case-study performed in Spain for a typical summer day concluded that electricity costs may reduce between 8% and 22% (Lujano-Rojas et al., 2012). Another study performed in Spain by Conchado et al. (2016) studied the economic and environmental benefits of a DR program for the generation, distribution network and demand components of an electricity system and found that the benefits are quite low compared to the costs, mostly for the generation system (Conchado et al., 2016).

2.6.3. THE IMPACT OF DEMAND RESPONSE ON SOCIAL WELFARE

To be reliable, electric power systems need to operate in a perfect equilibrium between the supply and the demand side that in real time is constantly fluctuating (Aryandoust and Lilliestam, 2017). In order to supply the demand at, or almost, its peak level, generation is expected to meet maximum peak periods through the use of higher cost generating units (Walawalkar et al., 2008). Moreover, the introduction of large amounts of renewable generation with variable output that is often mismatched with demand peak hours, e.g. wind power peak is more likely to occur in off-peak hours, requires high ramping capability that should be met by dispatchable energy resources in order to avoid disturbances in transmission and distribution assets (Jiang et al., 2015; Parvania et al., 2012).

In a competitive electricity market, real electricity prices may experience wide fluctuations and are set according with market clearing price under a price auction. All the electricity supply entities (generators) are paid at this price, and a reduction in marginal costs of production may be triggered through a minor reduction in demand consumption (Walawalkar et al., 2008). Moreover, economic benefits from load reductions would also extend to load-reducing and non-load-reducing customers (Jiang et al., 2015).

With the unbundling of the electric sector, the system will be considered as an efficient one if the fluctuations on the demand side remain insignificant (Albadi and El-Saadany, 2007). Through demand encouragement to adapt consumption according with market signals, the need for expensive generating units would be reduced and the integration of variable outputs from renewable sources would be potentiate (Jiang et al., 2015). Still, demand participation in DSM programs remains minimal, as well as the short-run price elasticity of demand (Mansur, 2008). Low demand-response participation levels may potentially result in social welfare losses in deregulated markets. Through the introduction of administered DR programs in concert with energy spot markets, the negative outputs from low demand-response participation could be minimized (Walawalkar et al., 2008). According to Walawalkar et al. (2008) social welfare is a measure of the benefits accruing to participants in the market for a good or service, which can be decomposed in producer and consumer surplus' components. While the first component represents the difference between costs of generators and market clearing price, the second component represents the difference between how much consumers are willing to pay for a certain good or service and the effective price they pay for it, or the market clearing price. Considering average pricing, the price between peak pricing and low pricing, consumers demand electricity at point A (A') incurring marginal production costs at point B (B'). The market clearance price is set at point C (C') where the supply and demand curves intersect each other. Welfare gain is illustrated in shaded triangles ABC and A'B'C' in Figure 2.14, respectively, for a peak and an off-peak demand curve.

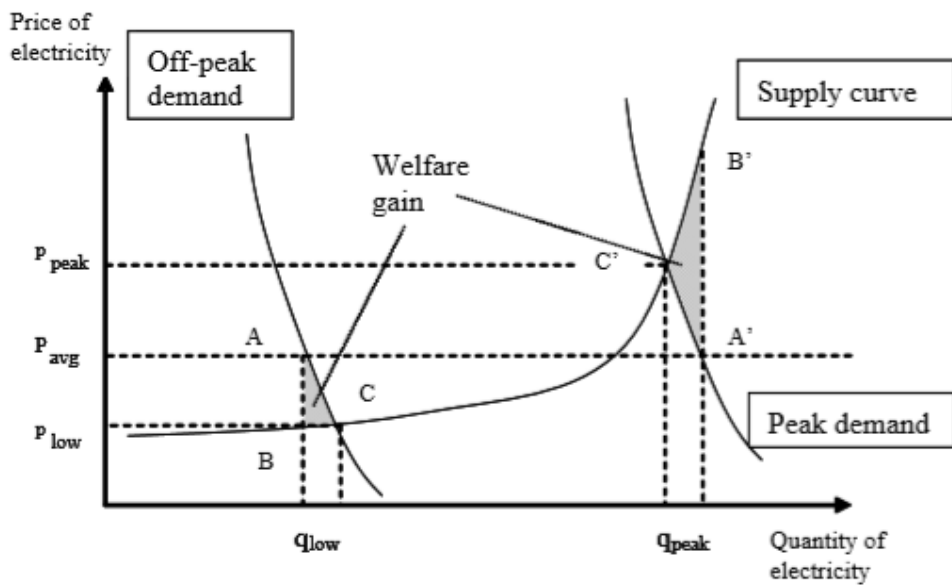


Figure 2.14 – Illustration of welfare gains during off-peak and peak demand. Source: Møller Andersen et al. (2006)

According to Mansur (2008), allocative and production inefficiencies are the two possible causes for welfare losses. Due to short run inelasticity of demand, load allocation is inexistent in wholesale markets, and for such reason welfare effects are associated to an inefficient production. Strategic supply companies may introduce distortions in market equilibrium. Mansur (2008) measured these production distortions in static competitive benchmark analysis to simulate wholesale electricity prices for the PJM. Conclusions of this study indicate that intertemporal constraints result in significant non-convexities in the costs of producing electricity. Welfare loss may occur due to allocative and production inefficiencies but in short run wholesale electricity markets allocative inefficiencies are neglected due to demand inelasticity. When considering short run elasticity of demand due to DR load-responsive participation, allocative causes are no longer neglectable. In PJM both day-ahead and real-time markets allow individual customer or load aggregators to actively participate in the energy market. PJM offer two types of DR programs, an economic DR program and an emergency DR program. In day-ahead market PJM pays the Locational Marginal Price (LMP) to customers if the LMP in a given zone, is above a trigger point set \$75/MWh, but if LMP is less than or equal to trigger point, customer receives the difference between the LMP and the generation and transmission (G&T) components. In such program, DR activity levels was found to be higher when LMP surpass the set trigger point thus little incentive for DR participation is available

below the set trigger point. In PJM's economic DR program, curtailment service is the program with major DR participation. In real-time market PJM pays load curtailment using real-time LMP. These subsidies introduce distortions in the energy market despite the savings for the system. In order to evaluate if these subsidies introduce net deadweight losses or other distortions into the energy market, or instead helps to correcting the market failures caused by inelastic load, studies have simulated demand-side bidding into the PJM market during 2006 to compare the social welfare gains with the subsidies paid to price-responsive load (Walawalkar et al., 2008). Optimal trigger point for incentive was found to be between \$66/MWh and \$77/MWh. Conclusions indicate that social welfare exceeded the distortions introduced by subsidies and PJM's DR market largest economic impact is a transfer of benefits from generators to non-responsive loads consumers. Also, Su and Kirschen (2009) referred in their study that non-responsive loads consumers tend to benefit from DSM free-riding effect. Also, Chao and DePillis (2013) studied the incentive effects of DR load-responsive participation using a static equilibrium model and a dynamic extension of the model. Both equilibrium and dynamic model results suggest that subsidies reduction will tend to increase free-riding effect thus consumer's behaviors will induce both an even higher consumption during peak periods and to excessively reduce demand during a Demand Response event. Moreover, this study concludes that social welfare gains are obtainable if both demand and supply functions are linear and if demand reduction is paid only when the wholesale price is at least twice the fixed retail rate.

Jiang et al. (2015) analytically compared the academic and the industrial welfare approach. The first aims to maximize social welfare considered as the net benefits from electricity consumption and generation based on the utility of dispatchable demand while in industrial welfare approach consumers are considered as "*virtual generators*" and are compensated for their real load curtailment (Jiang et al., 2015). Considering costs minimizing or maximizing social welfare as the most common approach in unit commitment problems, a linear model to maximize daily social welfare through flexible responsive load to price signals was proposed by de La Nieta and Gibescu (2018). This study defines per flexible demand orders, an order with a fixed volume, with duration of 1 hour, with fixed price, minimum acceptance ratio of 1 and the algorithm is the one that selects the flexible hours and the amount of energy to use with the objective of maximizing daily social welfare. Both scenarios with and without DSM were considered in a case study with renewable generation inputs at zero marginal cost. These study results suggest that for suppliers DSM costs may vary according with the chosen strategy, but

if not reduced they will keep the same as the original scenario without DSM. The daily social welfare with flexible demand increases in 73.55€ when compared with the original price.

A 16-year horizon study performed, both from a regional and a national perspective, as well as per voltage level, by Saraiva et al. (2016), with the objective of quantifying the potential economic benefits from the introduction of dynamic tariffs to move peak demand to adjacent hours, has reached different conclusions regarding welfare with DSM benefits. This study considered that according to typical elasticity values, 5% of the energy transactions in day-ahead energy market could move to adjacent hours, $h-1$ and $h+1$. Based on such assumption a Cost Benefit Analysis simulation was performed to identify critical hours to activate dynamic tariffs, to estimate the benefits on the electricity market Social Welfare Function (SWF), on the network losses decrease and on the avoided costs due to postpone network investments and contracting reserves. Results indicate that economic benefits regarding SWF from moving peak demand to adjacent hours would be minimal as well as potential savings associated with contracting secondary reserve and network losses differences. This study also concludes that the possible postponing of network investments may result in more than 98% savings over the 2015-2030 horizon period and a gain of around 7.140 k€ due to dynamic tariffs introduction in the Portuguese Tariff System is expected. Based on this study Pinto and Saraiva (2018), developed an analysis simulating load transfers of 4%, 7%, 10%, 12% and 15% of the peak-demand to the adjacent hours, in order to obtain the Social Welfare Function, electricity prices and traded energy values. Simulation performed for a 10% load shifting demand scenario, considering hour 22 as hour h moving to the adjacent hours, $h-1$ and $h+1$, indicates that both market price and the traded energy reduce during hour h , but increase both in hours $h-1$ and $h+1$, or at 21h and 23h respectively. The total SWF variation for the set of three hours is negative what suggests that, for these particular hours, no advantage would be obtained from the 10% demand transfer. Moreover, the same study performed different case studies for different hours and load shifting demand scenarios and results from the point of SWF were also all negative, suggesting that no advantage should be expected from demand load transfers to the adjacent periods and SWF variations tend to be increasingly negative as the percentage of demand transfer increases.

Besides both studies, in de La Nieta and Gibescu (2018) and in Pinto and Saraiva (2018) prices tend to increase in other hours and reduce during the Demand Response hour, different

conclusions were obtained regarding welfare benefits. The different model approach may explain different results thus while the first study considered complex orders or bids and studied the effect from shifting demand from hour t_x to t_y , the last one considered simple bids and studied the effect from shifting demand from hour h to $h-1$ and $h+1$.

Despite minimizing costs or maximizing social welfare are considered the most common approach, in order to deal with multiple targets in power system scheduling multi-objective optimization models are used. Geng et al. (2017) developed three stochastic scheduling models aiming at maximizing social welfare (SW), minimizing emission (EM) and maximizing renewable production (RE). The model EM results in 36% of the social welfare of model SW, 27% of its emissions, and 43% of its wind spillage, while model RE results in 55% of the social welfare of model SW, 56% of its emissions and 28% of its wind spillage.

The model with lowest emission levels has the lowest demand supplied to reduce emissions and the highest costs among all the models resulting in a decrease 64% of social welfare when compared with maximizing social welfare model. When considering maximizing renewable model, both social welfare and emissions levels results were extreme when compared with other models' values results. Considering this study results it seems incompatible to combine the maximization of social welfare with the minimization of emission levels. Boisvert and Neenan (2003) discuss that there is a gap between the private and public value of DR. Results indicate obstacles for potential welfare gains from DR on electricity markets, both due to customer's unwillingness to adjust electricity consumption and bill savings do not justify the price aggravation associated to the following hours. Moreover, retail customer's adjustment behaviors may result in deadweight losses. Having these obstacles in mind, the author defends that DR load should be treated as a resource and be paid at market prices for curtailments.

2.7. RISK PREMIA DAY-AHEAD PRICES IMPACT VARIABLES

Different energy market design characteristics such as market mechanisms, supply properties and renewables integration set the mote to study and analyse different energy markets. When choosing the energy markets, MIBEL and EEX, particularly Germany bidding area were

chosen. The existence of negative spot prices is possibly the most remarkable difference between Germany and MIBEL bidding zones, reason why the research was focus on these.

According to DR definition, DR aims changes on consumption patterns to induce lower electricity use at times of high market prices and reduce both spikes and instability. Electricity risk premia is considered to be the payment for the risk of spikes in spot prices and instability. In this way the variables that affect one will also affect other. There are some identified variables that are commonly related to MIBEL and EEX risk premia: seasonality and demand unpredictability. Electricity characteristics, namely, the non-storability and the need for real time synchronization with demand within an increasing RES-I stochastic integration, lead to a predictable association of these variables to risk. Despite some of the research performed associate seasonality and demand to risk premia, these two variables seem to be associated with each other. High demand periods occur during specific hours of the day associated with society daily's routine but also during some specific months or times of the year with extreme temperatures, as in winter or summer. It is expected that, during these stages, some short periods of high demand solicitations may occur. Thus, it is expectable and predictable that with future extreme climatic phenomena occurrences, seasonality association to risk premia will continue, and eventually, it might increase in time. The climatic conditions along the year, also modify the composition of supply in the day-ahead market by generation technology with impact both on market clearance prices and risk. According to some of the proclaimed benefits of DR integration in energy markets, it could be seen not only as load peak-shaving mechanism during load-shifting or curtailing processes, but also as a reserve mechanism.

Due to EU environmental regulations and economy decarbonization targets, in these electricity markets renewable generation has been increasing and it is expected to continue in the near future. The increasing participation of RES-I in the market share will increase prices volatility due to its stochastic characteristics (Nicolosi and Fürsch, 2009). RES-I nature, together with changes on supply in the day-ahead market caused by generation technology climatic seasonality, will remain on time and will contribute for market adaptations to accommodate to these new characteristics. By 2050, the renewable energy supplied to EPEX spot is expected to represent 80% of total supply (IRENA, 2015). Despite renewable generation advantages, their continuous integration in energy wholesale markets will continue to increase risk for market-agents if the current market design is not adjusted. Then, the integration of DR in energy

markets may be faced as a positive factor, in order to potentiate and optimize the use of RES-I loads. Moreover, the continuous integration of RES on energy markets is associated with a decrease on the clearing market prices. A study performed on the EEX market in 2018, indicates that in Germany wind and solar power reduces the day ahead spot market price by, respectively, 0.94 Euro/MWh and 0.43 Euro/MWh per GW (Fraunhofer ISE, 2019). Moreover, this supply excess may set at negative prices the market clearing price and remain generation mix inflexibility start-up costs that prevent traditional thermal generators from reducing outputs besides prices go below their marginal costs. Viehmann (2019) study identify associations between negative prices and risk premia. Therefore, these associations could possibly mean that market agents are willing to pay, in order to reduce their exposure to negative electricity prices periods. As previously mentioned, negative prices tend to remain the generation mix inflexible. Such market design features, might have implications for DR future implementation. According to our survey, DR increases their potential to decrease market clearing prices in energy markets dominated by fossil fuels technologies. The inability to stop traditional thermal generators from reducing outputs may preserve these generation technologies in the supply composition of the EEX day-ahead market. Such reality may increase market agent's aversion to risk and keep future associations between negative prices and risk premia. The generation mix by itself, also constitutes a risk factor according to the performed literature. The association between risk premium and generation "*fuels*" such as natural gas, oil and coal was also clear in Cartea and Villaplana (2014) and in Herráiz and Monroy (2009) studies. Apparently, energy markets dominated by non-controllable energy sources, such as RES with high fixed costs and marginal costs that tend for zero, have a lower tendency for DR potentials. This is the case of energy markets dominated by hydropower facilities. Furió and Meneu (2010) research studies found associations between risk premium and hydrological conditions. If on one hand, the continuous integration of RES in the energy markets supply tends to decrease the clearing market prices, on the other hand, tends to increase the uncertainty and the risk. Despite Schwabeneder et al. (2019) refer the tendential absence of potential for DR in markets with larger RES shares, DR will continue to represent an added value for future energy markets deployment. Thus, it introduces flexibility and might transmit confidence signals to markets agents. This flexibility might be particularly useful during system instability periods. System instability and excessive fluctuations may cause several disturbances, such as capacity constraints, outages, transmission bottlenecks, peak demands and, therefore, the potential for market power exercise. Despite no

clear associations were found between market power and risk premia in the analyzed energy markets, studies indicate the presence of market power on some of the analyzed markets (Lagarto et al., 2014). Energy market structures where market power was identified, such as in MIBEL, may suffer from higher day-ahead prices volatility. Ferreira and Sebastião (2017) research found risk premium volatility associated to seasonality. The seasonal spikes in MIBEL spot prices might be associated with the exercise of market power during certain periods, with a relevant hydropower generation contribution on energy market, or with both.

When considering generation in EEX, apparently hydroelectric capacity seems to have more impact on risk premia. Hydroelectric generation in the wholesale market has a significant participation in MIBEL, particularly for the Portuguese generation mix. In MIBEL, during the year of 2018, large hydro represented 10.3% of the total of generation assets by technology in the wholesale market participation, while in Portugal large hydro was the double with 20.6% thus Spain generation are more diversified than Portuguese generation portfolio (OMIE, 2020). Several studies reported in Table 2.7, also establish associations between futures risk premia and spot prices, confirming that these set the costs of electricity in the long run. However, spot prices formation cannot be dissociated from other variables such as seasonality, demand consumptions or with the generation portfolio composition of supply in the day-ahead market. This emerges a continuous endless cycle. Other variables were also found to be related to risk premia such the electrical system tightness, CO₂ prices and characteristics associated with generation and its “*fuels*” in different market designs. System tightness and characteristics related to generation are variables associated with risk premium EEX according to the reported in Table 2.7. The electricity system tightness, is relevant in what refers to neighboring countries energy importation and exportations. Within the implementation of a single European energy market, this variable will assume a future larger importance. Constraints caused by system tightness, might be overcome if DR consumers are called to curtail or shift their load consumption in an emergency period. Today there are still major barriers in what this matter concerns, both regarding the establishment of a harmonized regulation for DR and for a single European energy market. Without clear regulations it is not possible for consumers to actively enroll and participate in their country’s energy wholesale markets neither in neighboring countries wholesale markets. Despite real DR programs for consumers’ participation are already in action in some parts of the world, there is still very few expertise in Europe. Table 2.7 results are a resume of an extended research performed in Sousa and Soares (2020).

Table 2.7 – Results of the survey performed under a risk premium criterion. Source: From the author

Reference	MIBEL	EEX	Main Conclusions
Viehmann (2019)		☑	This study found that energy traders behave rationally like risk-averse agents. A relation between risk premiums and the tightness of the system was demonstrated. Moreover, this study associates negative prices to a left-skewed price distribution and larger negative premiums.
Valitov (2019)		☑	With the aim of analyzing the impact of negative prices on risk premia, using the same methodology used by Viehmann, J. (2011), confirmed the presence of risk premia in the German day-ahead electricity market.
Ferreira and Sebastião (2017)	☑		When studying the relationship between the electricity spot and futures prices, the risk premium was found to be mostly negative. This study also indicates risk premium volatility seasonality.
Ballester et al. (2016)	☑		The relationship between prices, namely futures, spot and over the counter (OTC) forward markets were analyzed. Conclusions found a bidirectional causality from futures and OTC forward prices to spot prices meaning that there is not a price relationship between them.
Cartea and Villaplana (2014)	☑	☑	With the aim of founding a linear dependence between ex-post risk premiums of the electricity markets of Germany, France and Spain, a positive correlation between electricity risk premia in these three countries and risk premia for natural gas futures prices was found.
Viehmann (2011)		☑	In this study have been found participants have risk-averse behavior and willing to pay significant negative risk premia in periods of low demand and positive risk premia during peak hours.
Furió and Meneu (2010)	☑		When analyzing how the risk in spot price formation induces a counteracting premium in the contract prices, the risk premium is found to depend on both the unexpected variations in demand and in the hydroelectric capacity. Moreover, the forward premium turned out to be negatively related to the variance of spot prices.
Pietz (2009)		☑	This study analyzed the futures from an ex post perspective and find evidence for significant positive risk premia at the short-end. Moreover, it was verified the existence of seasonality in the risk premia.
Herráiz and Monroy (2009)	☑		Market efficiency is analyzed for European power markets. The study concludes for the presence of a risk premium in all markets and thus reject the hypothesis of market efficiency. Average risk premia have been positive in power and natural gas but negative in oil and coal markets.

2.8. CONCLUSIONS

Despite the existing barriers, in theory the benefits of DR in wholesale markets would promote a positive effect for all parties. Energy market operation is quite complex and risk may be attributed to a large number of variables. In the future, DR mechanisms integration on markets might be a support risk control tool. But on the other side, future DR full integration on markets might be a chimera. From the economic perspective, some authors refer that DR will suffer economic self-cannibalism (Schwabeneder et al., 2019). Fernandez et al. (2020) work describes the existence of a “*merit-order effect of load-shifting*” thus the main effects of load-shifting on the market are qualitatively similar to renewables effect.

Despite the necessary regulatory framework development, DR implementation need to be viable both from a technical and an economic point of view. This is a complex issue, due to the large number of variables involved in perspectives. To achieve viability, every parties involved should recognize DR value and be rewarded for their flexibility and efforts. In the analyzed electricity markets, energy-traders were found to have risk-aversion, despite the presence of negative prices. As previously referred, these might represent an additional risk-aversion factor, since negative prices are a specific characteristic of EEX. Even though, in MIBEL other variables were found in the performed literature. Some clearly tend to influence positively or negatively the future implementation of DR on the respective wholesale market structures as previously referred.

Some of these variables seem to be associated with each other and it is not possible to clearly state which one is the most prevalent in each market or if these are somehow linked. Moreover, and despite the research was focused on risk premia, the different methodologies and models adopted may help to justify the differences in the association found thus some studies were focused on specific characteristics while others covered a wider range. In any circumstance, it was possible to identify some variables common to these markets. This might indicate that despite the market design, a group of variables might be common to all market designs structures and another group of variables might differ according with the specific market structure characteristics. DR implementation would allow to smooth spikes and extreme fluctuations on spot prices increasing market operation efficiency and energy-trader's

confidence regardless the market design. Moreover, during contingencies, DR may act as a reserve capacity, offering load reductions to solve short-term constraints in the system representing a possible planning resource.

2.9. REFERENCES

- Aalami, H. A., Moghaddam, M. P., & Yousefi, G. R., 2010. Demand response modeling considering interruptible/curtailable loads and capacity market programs. *Applied Energy*, 87(1), 243-250. <https://doi.org/10.1016/j.apenergy.2009.05.041>
- Aalami, H. A., Moghaddam, M. P., & Yousefi, G. R., 2010. Modeling and prioritizing demand response programs in power markets. *Electric Power Systems Research*, 80(4), 426-435. <https://doi.org/10.1016/j.eprsr.2009.10.007>
- Aalami, H., Yousefi, G. R., & Moghadam, M. P., 2008, April. Demand response model considering EDRP and TOU programs. In *2008 IEEE/PES Transmission and Distribution Conference and Exposition* (pp. 1-6). IEEE. <https://doi.org/10.1109/TDC.2008.4517059>
- Aalami, H., Yousefi, G. R., & Moghadam, M. P., 2008, September. A MADM-based support system for DR programs. In *2008 43rd International Universities Power Engineering Conference* (pp. 1-7). IEEE. <https://doi.org/10.1109/UPEC.2008.4651455>
- Abgottspon, H., & Andersson, G., 2012, May. Approach of integrating ancillary services into a medium-term hydro optimization. In *XII SEPOPE: Symposium of Specialists in Electric Operational and Expansion Planning*. Retrieved from: <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.723.5514&rep=rep1&type=pdf> (accessed 2nd January 2020).
- Albadi, M. H., & El-Saadany, E. F., 2007, June. Demand response in electricity markets: An overview. In *2007 IEEE power engineering society general meeting* (pp. 1-5). IEEE. <https://doi.org/10.1109/PES.2007.385728>

Albadi, M. H., & El-Saadany, E. F., 2008. A summary of demand response in electricity markets. *Electric power systems research*, 78(11), 1989-1996. <https://doi.org/10.1016/j.epsr.2008.04.002>

Alberta Electric System Operator (AESO), 2017. Overview of the Alberta Capacity Market. Retrieved from: <https://www.aeso.ca/assets/Uploads/CMD-2.0-Proposals-CONSOLIDATED-Final.pdf> (accessed 2nd January 2020).

Annala, S., Lukkarinen, J., Primmer, E., Honkapuro, S., Ollikka, K., Sunila, K., & Ahonen, T., 2018. Regulation as an enabler of demand response in electricity markets and power systems. *Journal of Cleaner Production*, 195, 1139-1148. <https://doi.org/10.1016/j.jclepro.2018.05.276>

Arias, L. A., Rivas, E., Santamaria, F., & Hernandez, V., 2018. A review and analysis of trends related to demand response. *Energies*, 11(7), 1617. <https://doi.org/10.3390/en11071617>

Aryandoust, A., & Lilliestam, J. (2017). The potential and usefulness of demand response to provide electricity system services. *Applied Energy*, 204, 749-766. <https://doi.org/10.1016/j.apenergy.2017.07.034>

Asadinejad, A., & Tomsovic, K., 2016, September. Impact of Incentive Based Demand Response on large scale renewable integration. In *2016 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT)* (pp. 1-5). IEEE. <https://doi.org/10.1109/ISGT.2016.7781239>

Asadinejad, A., & Tomsovic, K., 2017. Optimal use of incentive and price based demand response to reduce costs and price volatility. *Electric Power Systems Research*, 144, 215-223.

Atkinson, B., Denver A., McMahon, J. E., & Clear R., 2008. Energy-Efficient Lighting Technologies and Their Applications in the Commercial and Residential Sectors, p. 7-19: In Kreith, F., & Goswami, D. Y. (Eds.), *Energy management and conservation handbook*. CRC Press, Taylor & Francis Group, Boca Raton, Florida, USA (2008)

Baitch, A., Chuang, A., Mauri, G., & Schwaegerl, C., 2007, May. International perspectives on demand-side integration. In *Proceedings of CIRED*. <https://doi.org/10.1016/j.epsr.2016.12.012>

- Ballester, J. M., Climent, F., & Furió, D., 2016. Market efficiency and price discovery relationships between spot, futures and forward prices: the case of the Iberian Electricity Market (MIBEL). *Spanish Journal of Finance and Accounting/Revista Española de Financiación y Contabilidad*, 45(2), 135-153. <https://doi.org/10.1080/02102412.2016.1144441>
- Barbero, M., Igualada, L., & Corchero, C., 2018, June. Overview of the regulation on aggregator agents in Europe. In *2018 15th International Conference on the European Energy Market (EEM)* (pp. 1-5). IEEE. <https://doi.org/10.1109/EEM.2018.8470015>
- Bartusch, C., Wallin, F., Odlare, M., Vassileva, I., & Wester, L., 2011. Introducing a demand-based electricity distribution tariff in the residential sector: Demand response and customer perception. *Energy Policy*, 39(9), 5008-5025. <https://doi.org/10.1016/j.enpol.2011.06.013>
- Bertoldi, P., Zancanella, P., & Boza-Kiss, B., 2016. Demand response status in EU Member States. *Europa. eu: Brussels, Belgium*. Retrieved from: <https://core.ac.uk/download/pdf/45616449.pdf> (accessed 22th January 2019).
- Boisvert, R. N., & Neenan, B. F., 2003. Social welfare implications of demand response programs in competitive electricity markets (No. LBNL-52530). Lawrence Berkeley National Lab.(LBNL), Berkeley, CA (United States). Retrieved from: <https://doi.org/10.2172/816220> (accessed 22th January 2019).
- Borenstein, S., Jaske, M., & Rosenfeld, A., 2002. Dynamic pricing, advanced metering, and demand response in electricity markets. Retrieved from: <https://escholarship.org/uc/item/11w8d6m4> (accessed 22th January 2019).
- Boshell, F., & Veloza, O. P., 2008, August. Review of developed demand side management programs including different concepts and their results. In *2008 IEEE/PES Transmission and Distribution Conference and Exposition: Latin America* (pp. 1-7). IEEE. <https://doi.org/10.1109/TDC-LA.2008.4641792>
- BP, June, 2018. BP Statistical Review of World Energy 2018. Retrieved from: <https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review/bp-stats-review-2018-full-report.pdf> (accessed 22th January 2019).

Braithwait, S., & Eakin, K., 2002. The role of demand response in electric power market design. *Edison Electric Institute*, 1-57. Retrieved from: http://assets.fiercemarkets.net/public/smartgridnews/sgrn_2007_12014.pdf (accessed 22th January 2019).

Braithwait, S., Hansen, D. G., & Kirsch, L. D., 2006. Incentives and rate designs for efficiency and demand response. *Lawrence Berkeley National Laboratory. LBNL-60132*. Retrieved from: https://www.smartgrid.gov/files/documents/Incentives_Rate_Design_for_Efficiency_Demand_Response_200612.pdf (accessed 22th January 2019).

Bray, R., Woodman, B., & Connor, P., 2018. Policy and regulatory barriers to local energy markets in Great Britain. *University of Exeter: Exeter, UK*, 1-103. Retrieved from <https://ore.exeter.ac.uk/repository/handle/10871/33607> (accessed 22th January 2019).

Brunekreeft, G., 2004. Market-based investment in electricity transmission networks: controllable flow. *Utilities Policy*, 12(4), 269-281. <https://doi.org/10.1016/j.jup.2004.05.001>

Cartea, A., & Villaplana, P., 2014. An analysis of the main determinants of electricity forward prices and forward risk premia. In *Quantitative Energy Finance* (pp. 215-236). Springer, New York, NY. https://doi.org/10.1007/978-1-4614-7248-3_8

Chakrabarti, B., Bullen, D., Edwards, C., & Callaghan, C., 2012, May. Demand response in the New Zealand Electricity market. In *PES T&D 2012* (pp. 1-7). IEEE. <https://doi.org/10.1109/TDC.2012.6281718>

Chao, H. P., & DePillis, M., 2013. Incentive effects of paying demand response in wholesale electricity markets. *Journal of Regulatory Economics*, 43(3), 265-283. <https://doi.org/10.1007/s11149-012-9208-1>

Chao, H. P., 2011. Efficient pricing and investment in electricity markets with intermittent resources. *Energy Policy*, 39(7), 3945-3953. <https://doi.org/10.1016/j.enpol.2011.01.010>

Chen, C., 2018. Demand response: An enabling technology to achieve energy efficiency in a smart grid. In *Application of Smart Grid Technologies* (pp. 143-171). Academic Press. <https://doi.org/10.1016/B978-0-12-803128-5.00004-0>

- Chen, P. Y., Chen, S. T., & Chen, C. C., 2012. Energy consumption and economic growth—New evidence from meta analysis. *Energy policy*, 44, 245-255. <https://doi.org/10.1016/j.enpol.2012.01.048>
- Clò, S., Cataldi, A., & Zoppoli, P., 2015. The merit-order effect in the Italian power market: The impact of solar and wind generation on national wholesale electricity prices. *Energy Policy*, 77, 79-88. <https://doi.org/10.1016/j.enpol.2014.11.038>
- Cludius, J., Hermann, H., Matthes, F. C., & Graichen, V., 2014. The merit order effect of wind and photovoltaic electricity generation in Germany 2008–2016: Estimation and distributional implications. *Energy economics*, 44, 302-313. <https://doi.org/10.1016/j.eneco.2014.04.020>
- Conchado, A., Linares, P., Lago, O., & Santamaría, A., 2016. An estimation of the economic and environmental benefits of a demand-response electricity program for Spain. *Sustainable Production and Consumption*, 8, 108-119. <https://doi.org/10.1016/j.spc.2016.09.004>
- Cruz, A., Muñoz, A., Zamora, J. L., & Espínola, R., 2011. The effect of wind generation and weekday on Spanish electricity spot price forecasting. *Electric Power Systems Research*, 81(10), 1924-1935. <https://doi.org/10.1016/j.epsr.2011.06.002>
- Cutler, N. J., Boerema, N. D., MacGill, I. F., & Outhred, H. R., 2011. High penetration wind generation impacts on spot prices in the Australian national electricity market. *Energy Policy*, 39(10), 5939-5949. <https://doi.org/10.1016/j.enpol.2011.06.053>
- da Silva, P. P., & Soares, I., 2008. EU spot prices and industry structure: assessing electricity market integration. *International Journal of Energy Sector Management*. <https://doi.org/10.1108/17506220810892919>
- Dabur, P., Singh, G., & Yadav, N. K., 2012. Electricity demand side management: Various concept and prospects. *International Journal of Recent Technology and Engineering (IJRTE)*, 1(1), 1-6. Retrieved from: <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.686.6816&rep=rep1&type=pdf> (accessed 2nd January 2020).

Daryanian, B., Bohn, R. E., & Tabors, R. D., 1989. Optimal demand-side response to electricity spot prices for storage-type customers. *IEEE transactions on Power Systems*, 4(3), 897-903. <https://doi.org/10.1109/59.32577>

Datchanamoorthy, S., Kumar, S., Ozturk, Y., & Lee, G., 2011, October. Optimal time-of-use pricing for residential load control. In *2011 IEEE International Conference on Smart Grid Communications (SmartGridComm)* (pp. 375-380). IEEE. <https://doi.org/10.1109/SmartGridComm.2011.6102350>

de La Nieta, A. A. S., & Gibescu, M., 2018, June. Maximal daily social welfare through demand side management in the day-ahead electricity market. In *2018 15th International Conference on the European Energy Market (EEM)* (pp. 1-5). IEEE. <https://doi.org/10.1109/EEM.2018.8469920>

De Miera, G. S., del Río González, P., & Vizcaíno, I., 2008. Analysing the impact of renewable electricity support schemes on power prices: The case of wind electricity in Spain. *Energy Policy*, 36(9), 3345-3359. <https://doi.org/10.1016/j.enpol.2008.04.022>

Dillig, M., Jung, M., & Karl, J., 2016. The impact of renewables on electricity prices in Germany—An estimation based on historic spot prices in the years 2011–2013. *Renewable and Sustainable Energy Reviews*, 57, 7-15. <https://doi.org/10.1016/j.rser.2015.12.003>

Eid, C., Koliou, E., Valles, M., Reneses, J., & Hakvoort, R., 2016. Time-based pricing and electricity demand response: Existing barriers and next steps. *Utilities Policy*, 40, 15-25. <https://doi.org/10.1016/j.jup.2016.04.001>

Enerdata, 2018. Global Energy Statistical Yearbook 2018. Retrieved from: <https://yearbook.enerdata.net/electricity/electricity-domestic-consumption-data.html> (accessed 2nd January 2020).

ERSE, 2019. Entidade Reguladora dos Serviços Energéticos. Aprovação das Regras do Projeto-Piloto de participação do consumo no mercado de reserva de regulação. Diário da República n.º 10/2019, Série II de 2019-01-15: 1920 – 1922.

Eto, J., 1996. The past, present, and future of US utility demand-side management programs. Retrieved from: <https://emp.lbl.gov/sites/all/files/39931.pdf> (accessed 2nd January 2020).

EU, 2006. Directive 2006/32/EC of the European Parliament and of the Council of 5 April 2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC.

EU, 2009. Directive 2009/72/ec of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in electricity and repealing directive 2003/54/ec. Off. J. Eur. Union L 211 (2009): 55-93.

EU, 2010. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings. OJ L 153, 18.6.2010, p. 13–35

EU, 2012. Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32. OJ L 315, 14.11.2012, p. 1–56

EU, 2016. Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on common rules for the internal market in electricity (recast). COM (2016) 864 final/2 - 2016/0380 (COD)

EU, 2016b. Clean Energy for All Europeans. COM (2016), 860.

EU, 2019. Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU. *OJ L 158*, 14.6.2019, p. 125–199

European Commission, 2012. Energy roadmap 2050. Retrieved from: https://ec.europa.eu/energy/sites/ener/files/documents/2012_energy_roadmap_2050_en_0.pdf (accessed 2nd January 2020).

European Commission, 2013. Incorporating demand side flexibility, in particular demand response, in electricity markets. Commission Staff Working Document, SWD (2013) 442 final, november 2013. Retrieved from:

https://ec.europa.eu/energy/sitemissings/ener/files/documents/com_2013_public_intervention_swd07_en.pdf (accessed 2nd January 2020).

Faria, P., & Vale, Z., 2011. Demand response in electrical energy supply: An optimal real time pricing approach. *Energy*, 36(8), 5374-5384. <https://doi.org/10.1016/j.energy.2011.06.049>

Farmad, H. S., & Biglar, S., 2012. Integration of demand side management, distributed generation, renewable energy sources and energy storages. <https://doi.org/10.1049/cp.2012.0784>

Fernandez, J. M. R., Payan, M. B., & Santos, J. M. R., 2020. The Merit-Order Effect of Load-Shifting: An Estimate for the Spanish Market. *Environmental and Climate Technologies*, 24(1), 43-57. <https://doi.org/10.2478/rtuct-2020-0003>

Ferreira, M., & Sebastião, H., 2017. The Iberian electricity market: Price dynamics and risk premium in an illiquid market. Available at SSRN 2962283. <https://dx.doi.org/10.2139/ssrn.2962283>

Feuerriegel, S., & Neumann, D., 2016. Integration scenarios of Demand Response into electricity markets: Load shifting, financial savings and policy implications. *Energy Policy*, 96, 231-240. <https://doi.org/10.1016/j.enpol.2016.05.050>

Figueiredo, N. M. D. S. C., 2017. *Electricity market integration and spot price convergence in a context of high penetration of renewables* (Doctoral dissertation, Universidade de Coimbra). Retrieved from: <http://hdl.handle.net/10316/32025> (accessed 2nd January 2020).

Foley, A. M., Gallachóir, B. Ó., Hur, J., Baldick, R., & McKeogh, E. J., 2010. A strategic review of electricity systems models. *Energy*, 35(12), 4522-4530. <https://doi.org/10.1016/j.energy.2010.03.057>

Fraunhofer ISE, 2019. Net Public Electricity Generation in Germany in 2018. Retrieved from: https://www.ise.fraunhofer.de/content/dam/ise/en/documents/News/Stromerzeugung_2018_2_en.pdf (accessed 2nd January 2020).

Furió, D., & Meneu, V., 2010. Expectations and forward risk premium in the Spanish

deregulated power market. *Energy Policy*, 38(2), 784-793.
<https://doi.org/10.1016/j.enpol.2009.10.023>

Gellings C., Parmenter K. E., 2008. Demand-Side Management p. 13-5: In Kreith, F., & Goswami, D. Y. (Eds.), *Energy management and conservation handbook*. CRC Press, Taylor & Francis Group, Boca Raton, Florida, USA (2008)

Gellings, C. W., 1985. The concept of demand-side management for electric utilities. *Proceedings of the IEEE*, 73(10), 1468-1470.
<https://doi.org/10.1109/PROC.1985.13318>

Gellings, C. W., 2009. *The smart grid: enabling energy efficiency and demand response*. The Fairmont Press, Inc.

Geng, Z., Conejo, A. J., Chen, Q., Xia, Q., & Kang, C., 2017. Electricity production scheduling under uncertainty: Max social welfare vs. min emission vs. max renewable production. *Applied Energy*, 193, 540-549. <https://doi.org/10.1016/j.apenergy.2017.02.051>

Gianfreda, A., Parisio, L., & Pelagatti, M., 2016. The impact of RES in the Italian day-ahead and balancing markets. *The Energy Journal*, 37(Bollino-Madlener Special Issue).
<https://doi.org/10.5547/01956574.37.SI2.agia>

Gómez, M., Cámara, M. Á., Jiménez, E., & Martínez-Cámara, E., 2010, March. A new energetic scenario with renewable energy. In *Proceedings of the International Conference on Renewable Energies and Power Quality (ICREPQ 2010)*, Granada, Spain (pp. 23-25).
<https://doi.org/10.24084/repqj08.670>

Green, R., Vasilakos, N., & Kensington, S., 2011. The long-term impact of wind power on electricity prices and generating capacity. *University of Birmingham Economics Discussion Paper*, 11-09. <https://dx.doi.org/10.2139/ssrn.1851311>

Greening, L. A., 2010. Demand response resources: Who is responsible for implementation in a deregulated market?. *Energy*, 35(4), 1518-1525.
<https://doi.org/10.1016/j.energy.2009.12.013>

Grubler, A., Johansson, T. B., Muncada, L., Nakicenovic, N., Pachauri, S., Riahi, K., ... & Strupeit, L., 2012. Energy primer.

Gugler, K., Rammerstorfer, M., & Schmitt, S., 2013. Ownership unbundling and investment in electricity markets—A cross country study. *Energy Economics*, 40, 702-713. <https://doi.org/10.1016/j.eneco.2013.08.022>

Gürtler, M., & Paulsen, T., 2018. The effect of wind and solar power forecasts on day-ahead and intraday electricity prices in Germany. *Energy Economics*, 75, 150-162. <https://doi.org/10.1016/j.eneco.2018.07.006>

Haney, A. B., Jamasb, T., Platchkov, L. M., & Pollitt, M. G., 2010. Demand-side management strategies and the residential sector: lessons from international experience. *The future of electricity demand: Customers, citizens and loads*, 337-378

Herráiz, Á. C., & Monroy, C. R., 2009. Analysis of the efficiency of the Iberian power futures market. *Energy Policy*, 37(9), 3566-3579. <https://doi.org/10.1016/j.enpol.2009.04.019>

Herter, K., 2007. Residential implementation of critical-peak pricing of electricity. *Energy policy*, 35(4), 2121-2130. <https://doi.org/10.1016/j.enpol.2006.06.019>

Hildmann, M., Ulbig, A., & Andersson, G., 2015. Empirical analysis of the merit-order effect and the missing money problem in power markets with high RES shares. *IEEE Transactions on Power Systems*, 30(3), 1560-1570. <https://doi.org/10.1109/TPWRS.2015.2412376>

Hirth, L., 2018. What caused the drop in European electricity prices? A factor decomposition analysis. *The Energy Journal*, 39(1). <https://doi.org/10.5547/01956574.39.1.lhir>

Honkapuro, S., Valtonen, P., Tuunanen, J., Partanen, J., & Järventausta, P., 2015, May. Demand side management in open electricity markets from retailer viewpoint. In *2015 12th International Conference on the European Energy Market (EEM)* (pp. 1-5). IEEE. <https://doi.org/10.1109/EEM.2015.7216652>

Hu, J., Harmsen, R., Crijns-Graus, W., Worrell, E., & van den Broek, M., 2018. Identifying barriers to large-scale integration of variable renewable electricity into the electricity market:

A literature review of market design. *Renewable and Sustainable Energy Reviews*, 81, 2181-2195. <https://doi.org/10.1016/j.rser.2017.06.028>

IEA Staff, 2003. IEA Staff, Organization for Economic Cooperation & Development, & SourceOECD (Online service). (2003). *The power to choose: Demand response in liberalised electricity markets*. Organization for Economic. Retrieved from: https://www.oecd-ilibrary.org/energy/the-power-to-choose_9789264105041-en (accessed 2nd January 2020).

IEA, 2015. World energy outlook 2015. Paris: International Energy Agency (IEA). 2015. Retrieved from: <https://www.iea.org/reports/world-energy-outlook-2015> (accessed 2nd January 2020).

IEA, 2018. Annual Energy Outlook 2018 with projections to 2050. February 2018. Retrieved from: <https://www.eia.gov/outlooks/aeo/pdf/AEO2018.pdf> (accessed 2nd January 2020).

IEA, 2020. Key world energy statistics 2020. Paris: International Energy Agency (IEA). 2020. Retrieved from: <https://www.iea.org/reports/key-world-energy-statistics-2020/final-consumption#abstract> (accessed 2nd January 2020).

IRENA, 2015. Renewable Energy Prospects: Germany, REmap 2030 analysis. International Renewable Energy Agency (IRENA), Abu Dhabi, www.irena.org/remap Retrieved from: <https://www.irena.org/publications/2015/Nov/Renewable-Energy-Prospects-Germany> (accessed 2nd January 2020).

IRENA, 2017 May. Adapting market design to high shares of variable renewable energy. International Renewable Energy Agency, Abu Dhabi. Retrieved from: <https://www.irena.org/publications/2017/May/Adapting-Market-Design-to-High-Shares-of-Variable-Renewable-Energy> (accessed 2nd January 2020).

IRENA, 2017. International Renewable Energy Agency. Rethinking energy 2017: Accelerating the global energy transformation. International Renewable Energy Agency. Retrieved from: <https://www.irena.org/publications/2017/Jan/REthinking-Energy-2017-Accelerating-the-global-energy-transformation> (accessed 2nd January 2020).

Jamasb, T., & Pollitt, M. G., 2011. *The future of electricity demand: customers, citizens and loads* (Vol. 69). Cambridge University Press.

Jiang, B., Farid, A. M., & Youcef-Toumi, K., 2015. Demand side management in a day-ahead wholesale market: A comparison of industrial & social welfare approaches. *Applied Energy*, 156, 642-654. <https://doi.org/10.1016/j.apenergy.2015.07.014>

JRC and DG ENER, 2019. Retrieved from: <https://ses.jrc.ec.europa.eu/smart-metering-deployment-european-union> (accessed 2nd January 2020).

Kalantzis, F., & Milonas, N. T., 2010, June. Market integration and price dispersion in the European electricity market. In *2010 7th International Conference on the European Energy Market* (pp. 1-6). IEEE. <https://doi.org/10.1109/EEM.2010.5558751>

Kirschen, D. S., 2003. Demand-side view of electricity markets. *IEEE Transactions on power systems*, 18(2), 520-527. <https://doi.org/10.1109/TPWRS.2003.810692>

Klaassen, E. A. M., Van Gerwen, R. J. F., Frunt, J., & Slootweg, J. G., 2017. A methodology to assess demand response benefits from a system perspective: A Dutch case study. *Utilities Policy*, 44, 25-37. <https://doi.org/10.1016/j.jup.2016.11.001>

Kostková, K., Omelina, L., Kyčina, P., & Jamrich, P., 2013. An introduction to load management. *Electric Power Systems Research*, 95, 184-191. <https://doi.org/10.1016/j.epsr.2012.09.006>

Kreith F., 2008. Introduction to Energy Management and Conservation, p. 1-1: In Kreith, F., & Goswami, D. Y. (Eds.), *Energy management and conservation handbook*. CRC Press, Taylor & Francis Group, Boca Raton, Florida, USA (2008)

Kyritsis, E., Andersson, J., & Serletis, A., 2017. Electricity prices, large-scale renewable integration, and policy implications. *Energy Policy*, 101, 550-560. <https://doi.org/10.1016/j.enpol.2016.11.014>

Labatut, M., Mandatova, P., & Renaud, C., 2015. Designing fair and equitable market rules for demand response aggregation. *EURELECTRIC, Tech. Rep.* Retrieved from:

https://cdn.eurelectric.org/media/1923/0310_missing_links_paper_final_ml-2015-030-0155-01-e-h-D4D245B0.pdf (accessed 2nd January 2020).

Lagarto, J., Sousa, J. A., Martins, Á., & Ferrão, P., 2014. Market power analysis in the Iberian electricity market using a conjectural variations model. *Energy*, 76, 292-305. <https://doi.org/10.1016/j.energy.2014.08.014>

Lampropoulos, I., Kling, W. L., Ribeiro, P. F., & van den Berg, J., 2013. History of demand side management and classification of demand response control schemes, IEEE Power & Energy Society General Meeting. <https://doi.org/10.1109/PESMG.2013.6672715>

Lavoine, O., 2018. Thoughts on an electricity system and grid paradigm shift in response to the EU energy transition and the clean energy package. Retrieved from: <https://op.europa.eu/pt/publication-detail/-/publication/8f342510-e702-11e8-b690-01aa75ed71a1> (accessed 2nd January 2020).

Lujano-Rojas, J. M., Monteiro, C., Dufo-Lopez, R., & Bernal-Agustín, J. L., 2012. Optimum residential load management strategy for real time pricing (RTP) demand response programs. *Energy policy*, 45, 671-679. <https://doi.org/10.1016/j.enpol.2012.03.019>

Mansur, E. T., 2008. Measuring welfare in restructured electricity markets. *The Review of Economics and Statistics*, 90(2), 369-386. <https://doi.org/10.1162/rest.90.2.369>

Märkle-Huß, J., Feuerriegel, S., & Neumann, D., 2018. Large-scale demand response and its implications for spot prices, load and policies: Insights from the German-Austrian electricity market. *Applied Energy*, 210, 1290-1298. <https://doi.org/10.1016/j.apenergy.2017.08.039>

Mathieu, J. L., Haring, T., & Andersson, G., 2012, December. Harnessing residential loads for demand response: Engineering and economic considerations. In *Interdisciplinary Workshop on Smart Grid Design and Implementation*. Retrieved from: <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.700.9317&rep=rep1&type=pdf> (accessed 2nd January 2020).

Mauritzen, J., 2010. What happens when it's windy in Denmark? An empirical analysis of wind power on price volatility in the Nordic electricity market. *An Empirical Analysis of Wind Power*

on Price Volatility in the Nordic Electricity Market (December 28, 2010). NHH Dept. of Finance & Management Science Discussion Paper, (2010/18). <https://dx.doi.org/10.2139/ssrn.1754931>

Moghaddam, M. P., Abdollahi, A., & Rashidinejad, M., 2011. Flexible demand response programs modeling in competitive electricity markets. *Applied Energy*, 88(9), 3257-3269. <https://doi.org/10.1016/j.apenergy.2011.02.039>

Mohajeryami, S., Doostan, M., Moghadasi, S., & Schwarz, P., 2017. Towards the Interactive Effects of Demand Response Participation on Electricity Spot Market Price. *International Journal of Emerging Electric Power Systems*, 18(1). <https://doi.org/10.1515/ijeeps-2016-0158>

Mohajeryami, S., Moghaddam, I. N., Doostan, M., Vatani, B., & Schwarz, P., 2016. A novel economic model for price-based demand response. *Electric Power Systems Research*, 135, 1-9. <https://doi.org/10.1016/j.epsr.2016.03.026>

Møller Andersen, F., Grenaa Jensen, S., Larsen, H. V., Meibom, P., Ravn, H., Skytte, K., & Tøgeby, M., 2006. *Analyses of demand response in Denmark* (No. RISO-R--1565 (EN)). Risoe National Lab.. Retrieved from: https://inis.iaea.org/search/search.aspx?orig_q=RN:38013867 (accessed 2nd January 2020).

Newbery, D., Pollitt, M. G., Ritz, R. A., & Strielkowski, W., 2018. Market design for a high-renewables European electricity system. *Renewable and Sustainable Energy Reviews*, 91, 695-707. <https://doi.org/10.1016/j.rser.2018.04.025>

Nicolosi, M., & Fürsch, M., 2009. The impact of an increasing share of RES-E on the conventional power market—the example of Germany. *Zeitschrift für Energiewirtschaft*, 33(3), 246-254. <https://doi.org/10.1007/s12398-009-0030-0>

Nillesen, P., & Pollitt, M., 2019. Ownership Unbundling of Electricity Distribution Networks. Retrieved from: <https://www.repository.cam.ac.uk/bitstream/handle/1810/229501/0836%26EPRG0820.pdf?sequence=2> (accessed 2nd January 2020).

Nordic Council of Ministers, 2014. Demand response in the Nordic electricity market: Input to strategy on demand flexibility, THEMA Consulting, Nordic Council of Ministers, Copenhagen. Retrieved from: <https://www.nordicenergy.org/wp-content/uploads/2014/10/Demand-response-in-the-Nordic-electricity-market.pdf> (accessed 2nd January 2020).

OMIE, 2020. Informe Annual 2019. Retrieved from: <https://www.omie.es/es/publicaciones/informe-anual> (accessed 27th May 2020).

Oren, S. S., & Smith, S. A., 1992. Design and management of curtailable electricity service to reduce annual peaks. *Operations Research*, 40(2), 213-228. <https://doi.org/10.1287/opre.40.2.213>

Ottesen, S. Ø., Tomasgard, A., & Fleten, S. E., 2018. Multi market bidding strategies for demand side flexibility aggregators in electricity markets. *Energy*, 149, 120-134. <https://doi.org/10.1016/j.energy.2018.01.187>

Pacheco, R. F. F. M., 2010. *Econometric study of the spanish electricity spot market and primary energy markets using VAR/VECM methodology: (cointegration and nonstationary time series)* (Doctoral dissertation). Retrieved from: <http://hdl.handle.net/10071/4237> (accessed 2nd January 2020).

Paiho, S., Saastamoinen, H., Hakkarainen, E., Similä, L., Pasonen, R., Ikäheimo, J., ... & Horsmanheimo, S., 2018. Increasing flexibility of Finnish energy systems—A review of potential technologies and means. *Sustainable cities and society*, 43, 509-523. <https://doi.org/10.1016/j.scs.2018.09.015>

Paraschiv, F., Erni, D., & Pietsch, R., 2014. The impact of renewable energies on EEX day-ahead electricity prices. *Energy Policy*, 73, 196-210. <https://doi.org/10.1016/j.enpol.2014.05.004>

Parvania, M., Fotuhi-Firuzabad, M., & Shahidehpour, M., 2012, July. Demand response participation in wholesale energy markets. In *2012 IEEE Power and Energy Society General Meeting* (pp. 1-4). IEEE. <https://doi.org/10.1109/PESGM.2012.6344591>

Paterakis, N. G., Erdinç, O., & Catalão, J. P., 2017. An overview of Demand Response: Key elements and international experience. *Renewable and Sustainable Energy Reviews*, 69, 871-891. <https://doi.org/10.1016/j.rser.2016.11.167>

Peng, D., & Poudineh, R., 2017. Electricity market design for a decarbonised future: An integrated approach. <https://doi.org/10.26889/9781784670948>

Pereira, A. J., & Saraiva, J. T., 2013. Long term impact of wind power generation in the Iberian day-ahead electricity market price. *Energy*, 55, 1159-1171. <https://doi.org/10.1016/j.energy.2013.04.018>

Pietz, M., 2009, December. Risk premia in the German electricity futures market. In *2009 3rd International Conference on Energy and Environment (ICEE)* (pp. 160-170). IEEE <https://doi.org/10.1109/ICEENVIRON.2009.5398651>

Pinson, P., & Madsen, H., 2014. Benefits and challenges of electrical demand response: A critical review. *Renewable and Sustainable Energy Reviews*, 39, 686-699. <https://doi.org/10.1016/j.rser.2014.07.098>

Pinto, P. T., & Saraiva, J. T., 2018, June. Evaluation of the Impact of Shifting Demand from Peak to Adjacent Hours in the Social Welfare Function of the Iberian Electricity Market, MIBEL. In *2018 15th International Conference on the European Energy Market (EEM)* (pp. 1-5). IEEE. <https://doi.org/10.1109/EEM.2018.8469803>

Ponds, K. T., Arefi, A., Sayigh, A., & Ledwich, G., 2018. Aggregator of demand response for renewable integration and customer engagement: Strengths, weaknesses, opportunities, and threats. *Energies*, 11(9), 2391. <https://doi.org/10.3390/en11092391>

Prügler, N., 2013. Economic potential of demand response at household level—Are Central-European market conditions sufficient?. *Energy Policy*, 60, 487-498. <https://doi.org/10.1016/j.enpol.2013.04.044>

Qdr, Q. J. U. D. E., 2006. Benefits of demand response in electricity markets and recommendations for achieving them. *US Dept. Energy, Washington, DC, USA, Tech. Rep.*

Retrieved from: <https://eetd.lbl.gov/sites/all/files/publications/report-lbnl-1252d.pdf> (accessed 2nd January 2020).

Rahiman, F. A., Zeineldin, H. H., Khadkikar, V., Kennedy, S. W., & Pandi, V. R., 2014. Demand Response Mismatch (DRM): Concept, impact analysis, and solution. *IEEE Transactions on Smart Grid*, 5(4), 1734-1743. <https://doi.org/10.1109/TSG.2014.2309995>

REN, 2020. Projeto-Piloto de participação do consumo no mercado de reserva de regulação Relatório ao abrigo da Diretiva n.º 4/2019, de 15 de janeiro. Retrieved from: <https://www.erse.pt/media/sloIn1rn/anexo-ii-ren-relat%C3%B3rio-diretiva-n-%C2%BA-4-de-2019-v2.pdf> (accessed 10th December 2020).

Ribeiro, J. G. A., 2014. Previsão de preços de eletricidade para o mercado MIBEL. Retrieved from: <https://repositorio-aberto.up.pt/bitstream/10216/75709/2/31953.pdf> (accessed 2nd January 2020).

Rintamäki, T., Siddiqui, A. S., & Salo, A., 2017. Does renewable energy generation decrease the volatility of electricity prices? An analysis of Denmark and Germany. *Energy Economics*, 62, 270-282. <https://doi.org/10.1016/j.eneco.2016.12.019>

Rogelj, J., Den Elzen, M., Höhne, N., Fransen, T., Fekete, H., Winkler, H., ... & Meinshausen, M., 2016. Paris Agreement climate proposals need a boost to keep warming well below 2 C. *Nature*, 534(7609), 631-639. <https://doi.org/10.1038/nature18307>

Sæle, H., & Grande, O. S., 2011. Demand response from household customers: experiences from a pilot study in Norway. *IEEE Transactions on Smart Grid*, 2(1), 102-109. <https://doi.org/10.1109/TSG.2010.2104165>

Saraiva, J. T., Fidalgo, J. N., Pinto, R. B., Soares, R., Afonso, J. S., & Pires, G., 2016, June. Implementation of dynamic tariffs in the Portuguese electricity system-preliminary results of a Cost-Benefit Analysis. In *2016 13th International Conference on the European Energy Market (EEM)* (pp. 1-5). IEEE. <https://doi.org/10.1109/EEM.2016.7521329>
<https://doi.org/10.1109/EEM.2016.7521329>

Savolainen, M. K., & Svento, R., 2012. Real-time pricing in the nordic power markets. *Energy economics*, 34(4), 1131-1142. <https://doi.org/10.1016/j.eneco.2011.10.006>

Schwabeneder, D., Fleischhacker, A., Lettner, G., & Auer, H., 2019. Assessing the impact of load-shifting restrictions on profitability of load flexibilities. *Applied Energy*, 255, 113860. <https://doi.org/10.1016/j.apenergy.2019.113860>

SEDC, 2014. Mapping demand response in Europe today. Tracking Compliance with Article, 15. Retrieved from: https://www.smart.eu/wp-content/uploads/2014/04/SEDC-Mapping_DR_In_Europe-2014-04112.pdf (accessed 2nd January 2020).

SEDC, 2017. Explicit demand response in europe-mapping the markets 2017. SEDC: Brussels, Belgium. Retrieved from: <https://www.smart.eu/wp-content/uploads/2017/04/SEDC-Explicit-Demand-Response-in-Europe-Mapping-the-Markets-2017.pdf> (accessed 2nd January 2020).

Sensfuß, F., Ragwitz, M., & Genoese, M., 2008. The merit-order effect: A detailed analysis of the price effect of renewable electricity generation on spot market prices in Germany. *Energy policy*, 36(8), 3086-3094. <https://doi.org/10.1016/j.enpol.2008.03.035>

Shariatzadeh, F., Mandal, P., & Srivastava, A. K., 2015. Demand response for sustainable energy systems: A review, application and implementation strategy. *Renewable and Sustainable Energy Reviews*, 45, 343-350. <https://doi.org/10.1016/j.rser.2015.01.062>

Shen, B., Ghatikar, G., Lei, Z., Li, J., Wikler, G., & Martin, P., 2014. The role of regulatory reforms, market changes, and technology development to make demand response a viable resource in meeting energy challenges. *Applied Energy*, 130, 814-823. <https://doi.org/10.1016/j.apenergy.2013.12.069>

Siano, P., 2014. Demand response and smart grids—A survey. *Renewable and sustainable energy reviews*, 30, 461-478. <https://doi.org/10.1016/j.rser.2013.10.022>

Sirin, S. M., & Gonul, M. S., 2016. Behavioral aspects of regulation: A discussion on switching and demand response in Turkish electricity market. *Energy Policy*, 97, 591-602. <https://doi.org/10.1016/j.enpol.2016.08.005>

Smith C. B., Capehart B. L. & Wesley M. R. Jr., 2008. Industrial Energy Efficiency and Energy Management, p. 10-47: In Kreith, F., & Goswami, D. Y. (Eds.), Energy management and conservation handbook. CRC Press, Taylor & Francis Group, Boca Raton, Florida, USA (2008)

Sousa, J., & Soares, I., 2020. Demand response, market design and risk: A literature review. *Utilities Policy*, 66, 101083. <https://doi.org/10.1016/j.jup.2020.101083>

Spees, K., & Lave, L. B., 2007. Demand response and electricity market efficiency. *The Electricity Journal*, 20(3), 69-85. <https://doi.org/10.1016/j.tej.2007.01.006>

Steen, D., Le, T., & Bertling, L., 2012. Price-Based demand-side management for reducing peak demand in electrical distribution systems—with examples from Gothenburg. In *NORDAC 2012*. Retrieved from: http://publications.lib.chalmers.se/records/fulltext/163330/local_163330.pdf (accessed 2nd January 2020).

Stötzer, M., Hauer, I., Richter, M., & Styczynski, Z. A., 2015. Potential of demand side integration to maximize use of renewable energy sources in Germany. *Applied Energy*, 146, 344-352. <https://doi.org/10.1016/j.apenergy.2015.02.015>

Strbac, G., 2008. Demand side management: Benefits and challenges. *Energy policy*, 36(12), 4419-4426. <https://doi.org/10.1016/j.enpol.2008.09.030>

Su, C. L., & Kirschen, D., 2009. Quantifying the effect of demand response on electricity markets. *IEEE Transactions on Power Systems*, 24(3), 1199-1207. <https://doi.org/10.1109/TPWRS.2009.2023259>

Su, C. L., & Supervisor Kirschen (Professor), 2007. *Optimal demand-side participation in day-ahead electricity markets* (Doctoral dissertation, University of Manchester). Retrieved from: <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.712.5363&rep=rep1&type=pdf> (accessed 2nd January 2020).

The World Bank, 2018. Electric power consumption (kWh per capita). Retrieved from: <https://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC> (accessed 2nd January 2020).

Torriti, J., Hassan, M. G., & Leach, M., 2010. Demand response experience in Europe: Policies, programmes and implementation. *Energy*, 35(4), 1575-1583. <https://doi.org/10.1016/j.energy.2009.05.021>

Valdes, J., González, A. B. P., Camargo, L. R., Fenández, M. V., Macia, Y. M., & Dorner, W., 2019. Industry, flexibility, and demand response: Applying German energy transition lessons in Chile. *Energy Research & Social Science*, 54, 12-25. <https://doi.org/10.1016/j.erss.2019.03.003>

Valitov, N., 2019. Risk premia in the German day-ahead electricity market revisited: The impact of negative prices. *Energy Economics*, 82, 70-77. <https://doi.org/10.1016/j.eneco.2018.01.020>

Vallés, M., Reneses, J., Cossent, R., & Frías, P., 2016. Regulatory and market barriers to the realization of demand response in electricity distribution networks: A European perspective. *Electric Power Systems Research*, 140, 689-698. <https://doi.org/10.1016/j.epsr.2016.04.026>

Valtonen, P., Mendes, G., & Honkapuro, S., 2017, December. Demand response for increased grid flexibility: The case of Finland. In *2017 IEEE Innovative Smart Grid Technologies-Asia (ISGT-Asia)* (pp. 1-6). IEEE. <https://doi.org/10.1109/ISGT-Asia.2017.8378444>

VanderKley, T. S., Negash, A. I., & Kirschen, D. S., 2014, July. Analysis of dynamic retail electricity rates and domestic demand response programs. In *2014 IEEE Conference on Technologies for Sustainability (SusTech)* (pp. 172-177). IEEE. <https://doi.org/10.1109/SusTech.2014.7046239>

Verhaeghe, C., Roques F., & Li Y., 2016, September. Assessment of the impact of renewable generation on Central-Western Europe electricity markets. Report for Conseil Consultatif du Gaz et de l'Electricité.

Viehmann, J., 2011. Risk premiums in the German day-ahead Electricity Market. *Energy policy*, 39(1), 386-394. <https://doi.org/10.1016/j.enpol.2010.10.016>

Viehmann, J., 2019. *Essays on Market Design and Strategic Behaviour in Short-term Power*

Markets (Doctoral dissertation, Universitäts-und Stadtbibliothek Köln). Retrieved from: <http://nbn-resolving.de/urn:nbn:de:hbz:38-94528> (accessed 2nd January 2020).

Walawalkar, R., Blumsack, S., Apt, J., & Fernands, S., 2008, July. Analyzing PJM's economic demand response program. In *2008 IEEE Power and Energy Society General Meeting- Conversion and Delivery of Electrical Energy in the 21st Century* (pp. 1-9). IEEE. <https://doi.org/10.1109/PES.2008.4596905>

Walawalkar, R., Blumsack, S., Apt, J., & Fernands, S., 2008. An economic welfare analysis of demand response in the PJM electricity market. *Energy Policy*, 36(10), 3692-3702. <https://doi.org/10.1016/j.enpol.2008.06.036>

Walawalkar, R., Fernands, S., Thakur, N., & Chevva, K. R., 2010. Evolution and current status of demand response (DR) in electricity markets: Insights from PJM and NYISO. *Energy*, 35(4), 1553-1560. <https://doi.org/10.1016/j.energy.2009.09.017>

Wang, Q., & Chen, X., 2012. China's electricity market-oriented reform: from an absolute to a relative monopoly. *Energy Policy*, 51, 143-148. <https://doi.org/10.1016/j.enpol.2012.08.039>

Welisch, M., Ortner, A., & Resch, G., 2016. Assessment of RES technology market values and the merit-order effect—an econometric multi-country analysis. *Energy & Environment*, 27(1), 105-121. <https://doi.org/10.1177%2F0958305X16638574>

Winkler, J., Gaio, A., Pfluger, B., & Ragwitz, M., 2016. Impact of renewables on electricity markets—Do support schemes matter?. *Energy Policy*, 93, 157-167. <https://doi.org/10.1016/j.enpol.2016.02.049>

Woo, C. K., Horowitz, I., Moore, J., & Pacheco, A., 2011. The impact of wind generation on the electricity spot-market price level and variance: The Texas experience. *Energy Policy*, 39(7), 3939-3944. <https://doi.org/10.1016/j.enpol.2011.03.084>

Würzburg, K., Labandeira, X., & Linares, P., 2013. Renewable generation and electricity prices: Taking stock and new evidence for Germany and Austria. *Energy Economics*, 40, S159-S171. <https://doi.org/10.1016/j.eneco.2013.09.011>

Yang, D., & Chen, Y., 2009, July. Demand response and market performance in power economics. In *2009 IEEE Power & Energy Society General Meeting* (pp. 1-6). IEEE. <https://doi.org/10.1109/PES.2009.5275733>

Yang, W., Yu, R., & Nambiar, M., 2013. Quantifying the benefits to consumers for demand response with a statistical elasticity model. *IET Generation, Transmission & Distribution*, 8(3), 503-515. <https://doi.org/10.1049/iet-gtd.2013.0155>

Yousefi, A., Aalami, H., Shayesteh, E., & Moghaddam, M. P., 2008, April. Enhancement of spinning reserve capacity by means of optimal utilization of EDRP Program. In *Proceeding of the Fourth IASTED International Conference, Power and Energy Systems*. Retrieved from: https://www.researchgate.net/profile/H_Aalami/publication/276269935_Enhancement_of_spinning_reserve_capacity_by_means_of_optimal_utilization_of_EDRP_Program/links/558bca2e08ae31beb1005fac/Enhancement-of-spinning-reserve-capacity-by-means-of-optimal-utilization-of-EDRP-Program.pdf (accessed 2nd January 2020).

Yu, R., Yang, W., & Rahardja, S., 2011, October. Optimal real-time price based on a statistical demand elasticity model of electricity. In *2011 IEEE First International Workshop on Smart Grid Modeling and Simulation (SGMS)* (pp. 90-95). IEEE. <https://doi.org/10.1109/SGMS.2011.6089205>

Yu, R., Yang, W., & Rahardja, S., 2012. A statistical demand-price model with its application in optimal real-time price. *IEEE Transactions on Smart Grid*, 3(4), 1734-1742. <https://doi.org/10.1109/TSG.2012.2217400>

Zhang, S., Jiao, Y., & Chen, W., 2017. Demand-side management (DSM) in the context of China's on-going power sector reform. *Energy Policy*, 100, 1-8. <https://doi.org/10.1016/j.enpol.2016.09.057>

Zhou, S., & Brown, M. A., 2017. Smart meter deployment in Europe: A comparative case study on the impacts of national policy schemes. *Journal of Cleaner Production*, 144, 22-32. <https://doi.org/10.1016/j.jclepro.2016.12.031>

Zhu, N., Bai, X., & Meng, J., 2011, March. Benefits analysis of all parties participating in demand response. In *2011 Asia-Pacific Power and Energy Engineering Conference* (pp. 1-4).

IEEE. <https://doi.org/10.1109/APPEEC.2011.5748396>

3

THE POTENTIAL TO PERFORM DEMAND RESPONSE IN MIBEL AND EEX

3.1. INTRODUCTION

Price-sensitive consumers who are willing to adapt their consumptions habits to balance the system may provide high energy mix value contributing to reduce the market wholesale price. Moreover, flexibility value, services to the network (such as curtailing or diminishing load consumption during peak periods to avoid congestion) and capacity value (ensure system and supply adequacy by demand peak reduction rather than in investing in new peak plants) can be offered by electricity end-users. These may offer their flexibility value to grid operators, retailers and aggregators that can value this flexibility in markets. Demand Response can offer high added value in energy markets. According to Stötzer et al. (2015), from the market point of view, demand side integration may provide increased capacity, flexibility and pricing capability particularly in a growing renewable generation reality. According to Wang et al. (2015), the wholesale electricity market comprises three market places according to different time scales:

1. Day-ahead market (DAM): for the settlement in a given hour of operation for the following day.
2. Intraday market for the settlement hour-ahead before operation.
3. Real time market or Balancing market for the system balance during the operational hour

Some authors like Joskow (2019), refer that day-ahead wholesale energy market traditional mechanisms need to be redesigned to accommodate consumer active participation. Reducing bid sizes, delivery periods and the time-lag between market transactions and delivery dates in electricity markets are some of the policy implications pointed by Feuerriegel and Neumann (2016). This may originate more complex and challenging market operations thus the demand is price dependent. In practice the ISO forecasts the demand 24 hours in advance and communicates it to generators, but an accurate and precise forecast of demand is very difficult to preview. After being ordered, both the generation and selling bids, the optimization problem is run and the market clearing price is set for all the market participants for the next 24 hours. If consumers are price-reactive a mismatch between the ISO forecast demand and the real demand may lead to a new price. Su and Kirschen (2009) study proposes a day-ahead centralized complex-bid market-clearing mechanism that allows consumers to submit complex bids. This study considers the load shifting behavior of consumers who do submit price-sensitive bids assuming that the total energy consumption of a price-responsive consumer over one price cycle is independent of the shape of the price profile during that cycle. Results indicate that market-clearing prices tend to reduce with an increasing level of demand shifting, improving the economic efficiency of the day-ahead market. Savings in the system operating cost is transferred to the demand-side with increasing level of demand shifting and the last authors argue that this bidding mechanism is useful in managing the risk particularly if the day-ahead prices are volatile (Su and Kirschen, 2009). Despite several research studies argue about the market benefits of price-sensitive consumers bidding strategies, the participation of demand side bids on electricity markets is still minor (Hajati et al., 2011). Moreover, some performed studies recognize limitations and the real bid effect on consumer's behavior is still not perfectly studied (Steriotis et al., 2018).

Despite the absence of guarantees concerning consumer behavior, per principle, consumers exposed to volatility in prices will have a more conscious demand profile than electricity consumers who pay a flat tariff without being aware of prices spikes during the day. In Crampes and Léautier (2015) research, an ex post efficiency and welfare are expected, only if markets were perfect, thus in reality, asymmetries caused by consumers holding information on their value for electricity, reduces welfare. According to Yu et al. (2020) power price and load demand are considered to be the parameters that most affect elasticity. In Table 3.1, are

summarized some of the market design factors that may affect market elasticity and consumer behavior.

Table 3.1 – Summary of market design factors that may affect market elasticity and consumer behavior. Source: Kirschen et al. (2000)

Compulsory Pool		Optional	
Optional Compulsory Pool	versus	Consumers are completely exposed to the pool price.	Consumers may celebrate bilateral contracts with producers that shield them from the pool price instability.
One-Sided Market		Two-Sided Market	
One-Sided Market	versus	Consumers cannot bid in the market in any form and are considered as inflexible load to be satisfied at any moment.	Consumers may bid for their demand either directly or through aggregators. In a double-sided market they have the opportunity to indicate the value they willing to pay for the load.
Yes		No	
Capacity Payments		Generators are paid for making generation capacity available, irrespective of the amount of electrical energy that this generation capacity actually produces	Generators are not paid for making generation capacity available.
Yes		No	
Geographically-differentiated Pricing		Electricity prices will reflect network constraints instigating geographical differences in prices.	A uniform price used for the entire system.
Simple Bids		Complex Bids	
Simple or Complex Bids		Involve only a single quantity and a price. The generator assume the risk	Reflect the various elements of the cost of running a generating unit. the generator does not assume the risk associated with

	associated with the start-up and no-load costs of its unit	the start-up and no-load costs of its unit and passes it into the pool
	Yes	No
Price Capping	The price of electricity is capped at an officially determined Value of Lost Load (VOLL)	The price of electricity is not limited by Value of Lost Load (VOLL)
	Firm Bids and Offers	Non-firm Bids and Offers
Firmness of Bids and Offers	Bidders required to meet the physical commitment to generate or purchase electricity and are exposed to financial risks if they do not deliver or take delivery of the quantity they bid.	
	Ex post	Real time Ex ante
Ex ante vs Ex post vs Real time price determined to the delivery	From an economist's perspective, fixing prices ex post is deeply unsatisfactory. It also precludes any reaction from the consumers, as they will not know the price until it is too late to adjust consumption Adjusting prices in real time or very close to real time could lead to a true interaction between supply and demand in the setting of the price. Setting the price in advance gives consumers time to adjust their activities and their demand profile.	

Consumers' response to electricity prices is affected to a number of factors that influence their behavior. According to Kirschen et al. (2000), the market structure is a factor to have in consideration. Centralized or pool-based markets operation differs significantly from decentralized markets operation. In the first, elasticity must be considered centrally, thus both electricity prices and generation scheduling are affected, while in a flexible market - where each customer can negotiate its own prices and generators schedule their own production - elasticity would be factored in automatically instead being centrally addressed.

3.2. MODELLING REVIEW

Despite DR is not a new topic of interest, its concept was initially introduced during the 1970s, despite it has attracted more attention in recent years due to the increasing of variable and unpredictable renewable generation and a significant number of model assessments has been developed to address different DR perspectives. Electricity market itself, technical aspects of the electricity system and the impact of DR in end-consumer are the most frequent DR research focus. Such a wide range of DR topics of interests, bring very different model approaches, thus models feature to answer very specific questions. According to Bossmann and Eser (2016) the heterogeneity in approaching DR models may be inappropriate to provide a holistic approach towards DR. Moreover, Bergaentzle et al. (2014) study suggests that different DSM models should be deployed depending on the specific generation mix in any given country. Beside the natural benefits from cross-borders infrastructures, DSM improves the flexibility and reliability of the energy system, absorbing some shock on generation mix.

An extensive analysis of DR models is described by Bossmann and Eser (2016), which classifies DR models in four main groups: pricing schemes, electricity systems/markets, specific end-uses and control-strategies. Pricing schemes research studies are focused on dynamic pricing schemes and other DR programs, assessing the functioning of these in the context of the overall electricity system or market, abstracting from the other three groups perspectives. Methodologically, these models typically assume a top-down perspective and apply simulation or optimization approaches, using a variety of mathematical methods. Electricity systems/markets research studies are focused on investigate the implementation of DR programs in the context of electricity systems and markets, abstracting from specific pricing schemes and end-uses. Methodologically, these models assume the same approach as the previous ones. Some DR models may, however, cover more than one group, thereby, are neither purely economic nor technical analysis (Table 3.2).

Table 3.2 – LR models methodological summary. Source: An adaptation of Bossmann and Eser (2016)

	1. Pricing Schemes	2. Electricity systems/markets	3. Specific end-uses	4. Control-strategies
1. Pricing schemes		Assessment of pricing schemes with respect to electricity markets (1,2)	Assessment of pricing schemes with respect to electricity markets (1,3)	Assessment of control-strategies on the basis of specific price signals (1,4)
2. Electricity systems/markets			Assessment of electricity systems/markets performance with respect to specific end-uses. (2,3)	
3. Specific end-uses				Assessment of control strategies for specific DR uses (3,4)
4. Control-strategies				

Research on the potential of demand side management and demand side integration, is mainly divided into system-oriented services and market-oriented services. According to Stötzer et al. (2015) system-oriented services concerns with the use of demand side measures to balance system operation with uncertain renewable generation while market-oriented services concerns about demand side measures to optimize the use of renewable energy resources (Kwon and Østergaard, 2014). Other studies classify DR potentials in different categories such as Theoretical, Technical, Economic and Achievable, as have been addressed by Dranka and Ferreira (2019). The flexibility on the supply side is regarded as an important condition as more intermittent renewable energy resources are integrated on energy markets. In power systems, traditionally, fossil generation was the provider for flexibility. Flexibility potential was based on different technologies: base load (inflexible but cheap), load following (can adapt to daily/weekly variations of load but are more expensive units) and peak units (flexible but the most expensive). Gas turbines and internal combustion engines are the most flexible unit, while CCGT and steam turbines are subject to more constraints (Papaeftymiou et al., 2014). With the continuing integration of RES-I in energy markets, traditional thermal power plants assume a

particular relevance in balancing markets. Flexibility can be assessed in three different timescales: short-term, mid-term and long-term flexibility. The first refers to balancing markets, the second to day-ahead and daily markets and the last refers to planning phase (Ahmadihangar et al., 2020). Flexibility resources may be divided to three categories: Supply, Demand and Storage. Figure 3.1 represents the characteristics of the three flexibility resources in different time frames. DR resources tend to be more flexible in short-term and mid-term than in long-term flexibility.

Several studies aimed to assess the potential and financial value of flexible demand. A study performed for the 2031 scenario year by Merrick et al. (2017) estimates a \$3 per year for the average energy arbitrage value per ERCOT customer of optimal load shifting technologies. This study was performed considering a competitive electricity market, where consumers exhibit optimal load shifting behavior to maximize utility and producers/suppliers profit under supply capacity constraints, in order to assess the optimum electricity load shifting value. A study performed by Gils (2014), identify substantial DR potentials in all consumer sectors. These authors add up to a minimum load reduction of 61 GW and a minimum load increase of 68 GW, available in every hour of the year. Söder et al. (2018) study compares flexibility potentials and how they were estimated in seven Northern European countries. Results estimate a total flexibility of 12–23 GW in a system with a total peak load of 77 GW.

Zarnikau and Hallett (2008) assessed the aggregated industrial Demand Response to price change, based on a market-based analysis. This study results indicate that the responsiveness of industrial loads is very small to wholesale electricity price levels and that there are factors contributing to the low responsiveness, including types of Demand Response service, and short notice period for price change. According to Vlot et al. (2013) the technical and economic feasibility of the introduction of automated Demand Response from domestic smart appliances in a European classical load shifting of washing appliances creates sufficient value in the day-ahead market to justify investments in smart energy control services. Sezgen et al. (2007) estimated the value of Demand Response technologies such as load curtailment, load shifting and short-term fuel substitution, through financial engineering methodologies, finding that Demand Response can reduce electricity price fluctuations as well as the average electricity price.

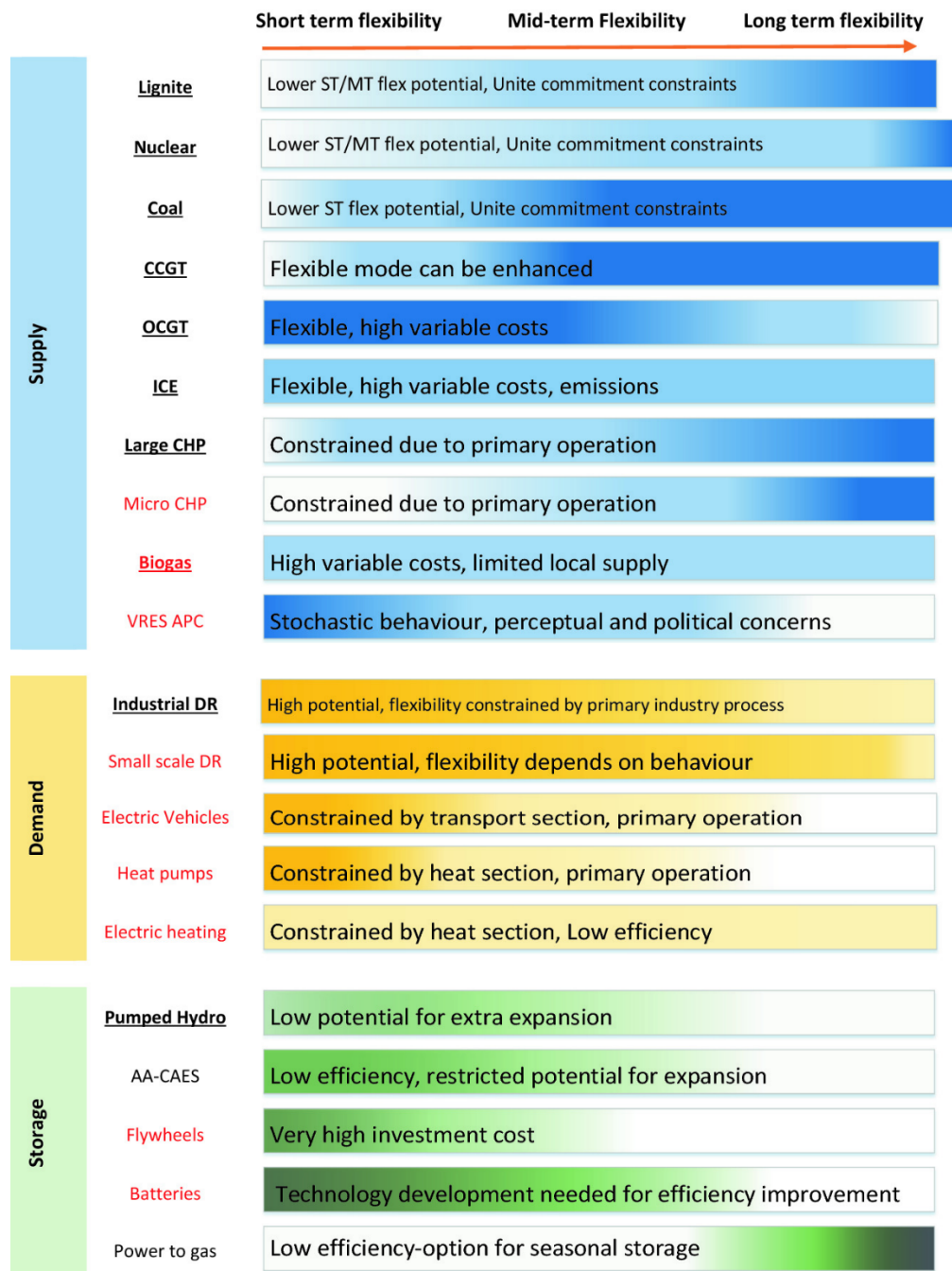


Figure 3.1 – Characteristics of flexibility resources in different time frames. Source: Ahmadiyahangar et al. (2020)

Vallés et al. (2016) study aims to present a quantitative analysis of the potential economic benefits AD could bring to distribution grid investments in the long term when different options for the implementation of AD are considered. The study is supported by a case study of Spain,

which is built using realistic exemplary distribution networks. Anjo et al. (2018) assessed the impact of Demand Response in the long-term, using a model of the Portuguese electricity system and applying the modeling tool OSeMOSYS. The theoretical potential of DR is computed to understand better the impact on the overall system planning, by analyzing three scenarios: a business as usual scenario, a carbon-free system scenario in 2050, and a scenario without heavy carbon emission restrictions. Feuerriegel and Neumann (2016) studied three scenarios for Germany: a Scenario A analyzes potential financial savings from utilizing DR in order to optimize electricity procurement, a Scenario B trades Demand Response potential at the exchange for reserve energy, and a Scenario C using Demand Response to avoid balancing energy. Results found annual financial savings up to €3.110 M for both households and the service sector. Katz et al. (2015) study used a long-term electricity market equilibrium model in order to evaluate the levels of market impact for household customers. The model has three levels: in the first level is a price-taker approach, the second level acknowledges the price impact of the optimal response or short-run equilibrium approach, and the third level integrates fixed costs as well and may be referred to as the long-term equilibrium approach. Results indicate that reduction in peak prices has an impact on the revenue of peak suppliers, and these will not earn a sufficient return to pay for the fixed costs. The model results expect capacity to be reduced, which will increase prices. Supply costs to customers in a long run equilibrium with all customers reacting to spot prices, at the given elasticity, results in a change in consumer surplus of 7.55% – significantly lower than what could be expected if only looking at a short-term equilibrium.

Schwabeneder et al. (2019) assessed the economic potential of load shifting in various European day-ahead spot markets, namely, for Germany, France, Romania, Spain and Sweden, during the years, 2016, 2017, and 2018. Both, economic and environmental indicators, were evaluated to determine the impact of load-shift optimization. Results indicate significantly different results per country. In countries with a significant capacity of hydro storage, like Sweden and Spain, the possible benefits of Demand Response were lower than half of the benefits in other countries.

3.3. MODEL DESCRIPTION

3.3.1. POTENTIAL FOR LOAD SHIFTING

There is an extensive range of literature referring to demand flexibility approaching both economic and environmental benefits (Aalami et al., 2010; Torriti et al., 2010; Peng and Poudineh, 2017). Generally, demand-side flexibility is obtained through Demand Response programs that can be designed with different purposes, as previously described in Introduction section 2.3.

Parvania et al. (2012) assess two types of energy market DR programs. In the first program type, the objective is to minimize the sum of the cost of the energy provided by generating units and the cost of load reduction, while in the second program type the goal is to maximize the social welfare through a double-sided energy market. Yu et al. (2020) developed a dynamic economic model for responsive loads based on the “*flexible demand elasticity*” and “*the customer benefit function*” concepts as a combination of EDRP and TOU programs. Considering the flexible demand elasticity and benefit function, a Multi Attribute Decision Making (MADM) method was employed to improve the characteristics of load profile. Moreover, entropy methods and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) were employed in order to provide the decision maker the most suitable program. Numerical analysis was performed based on IEEE ten-unit test system, and results found load peak reductions and increased distances between the valley and peak loads, differing on the scenario. In DR programs, consumers are motivated to move their consumption from peak hours to off-peak hours, thus the rates which customers pay for electricity consumption varies with time such that the rate of electricity in peak hours is higher than that of other hours.

Arteconi et al. (2016) study results clearly show that increasing the number of participating consumers increases the flexibility of the system and, therefore, reduces the overall operational costs. On the other hand, the benefit per individual participant decreases in the presence of more ADR-adherent consumers since a reduced effort from each consumer is needed. Total cost saving ranges at most between about 400 € and 200 € per participant per year for a 5% and 100% ADR penetration rate respectively. The increasing penetration of flexible loads in the market would increase elasticity, originating a decreasing tendency in spot prices setting. According to Sezgen et al. (2007), load curtailment involves reducing electricity usage during a

given time period without causing demand to increase during another period while load shifting requires consumers to shift procedures to another period typically from on-peak to off-peak hours. Figure 3.2 demonstrate the effect of demand flexibility on loads.

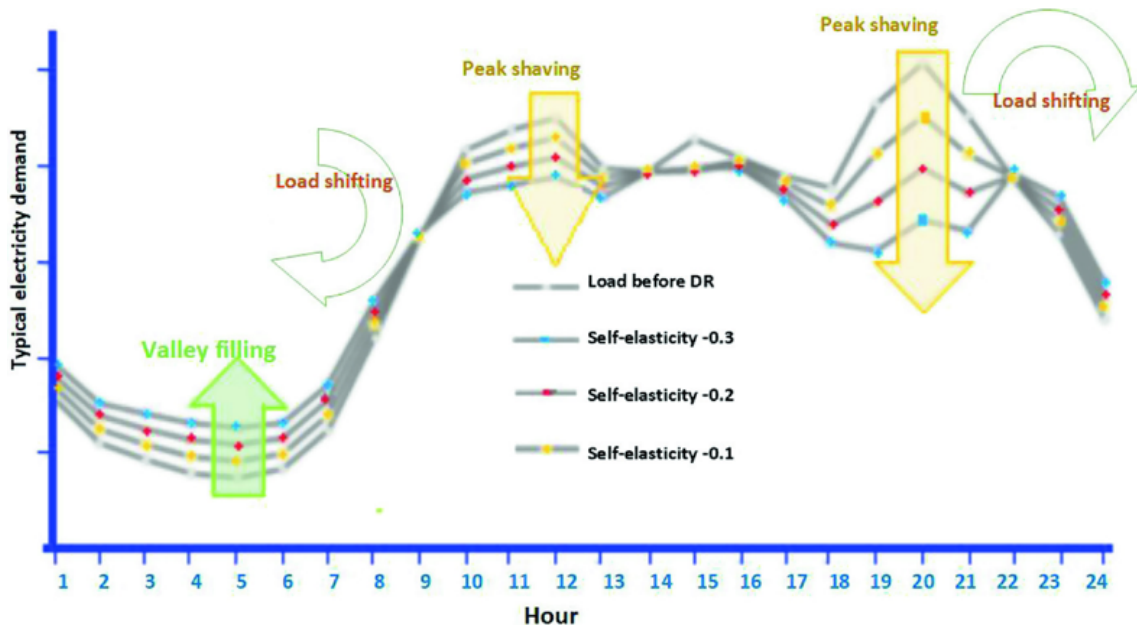


Figure 3.2 – The effect of demand flexibility on load. Source: Cruz et al. (2018)

A number of research work performed demonstrate that load shifting and load reduction or curtailing reduces system peak load, bringing together economic and environmental benefits. According to Fernandez et al. (2020): “*Load-shifting plans are expected to yield a reduction of the cost of the traded energy for the customers, since the cost-saving due to the energy eschewed at peak hours would be greater than the extra cost due to the increased demand at off-peak hours.*”. Fernandez et al. (2020) work aim to quantify and compare the main effects on the Spanish/Iberian market and found the main effects of load-shifting on the market are qualitatively similar to that of renewables, describing the existence a “*merit-order effect of load-shifting*”.

Märkle-Huß et al. (2018) describe load shifting as moving electricity consumption to a different time in order to minimize electricity generation costs, and this study demonstrates load shifting potential for Germany with load peaks flattening. A reduction in peak loads, system operation cost and in price spikes was demonstrated by Duan et al. (2019) in a Demand Response model where the aggregator can submit demand shifting bids into the day-ahead market. This author

foundings demonstrate that demand shifting was able to contribute for peak shaving with few impacts on consumers. Also, Spees and Lave (2008) study concluded that a small demand shifting amount could represent system cost savings in the market operator perspective. Stötzer et al. (2015) determined an 8GW load shifting potential in the German residential and commercial sectors by 2030. Another study performed in Spain by Conchado et al. (2016) studied the economic and environmental benefits of a DR program in Spanish households and concluded that DR full deployment could reduce the energy demand of the system by 1.3% and peak demand by 1.9%.

When focusing on wholesale electricity markets, namely on the assessment impacts of DR mechanisms such as load shifting in electricity wholesale prices, there is few expertise about the potential effects on these markets. DR activities may not decrease the amount of energy consumed but merely shift it to other periods. The shifting process may reduce peak load and marginal costs at peak time, causing price volatility reduction due to displacement of demand curve from peak demand to off-peak demand (Aghaei and Alizadeh, 2013). This author consider that DR has several benefits, such as: economic, pricing, risk management and reliability, market efficiency impacts, lower cost electric system and service, customer services, and environmental benefits. Notwithstanding economic benefits can be classified among the most important ones. Despite all the potential DR benefits De Ridder et al. (2009) consider that DR may increase electricity retailers' profits and Conchado and Linares, (2012) refers that the assessment of DR benefits can be approached from a range of possible methods, such as those based on avoided costs, resource planning, welfare analysis, value of system reliability, transmission planning and forward capacity auctions. These authors also refer that DR benefits will depend on the purpose, design and performance of the DR program implemented, as well as on other factors such as the structure of the market/system and the enabling technologies in place.

According to the performed literature, power price and load demand are considered to be the parameters that most affect elasticity. For this reason, in order to trigger load shifting DR potentials both in MIBEL and EEX energy markets, these variables were considered.

To achieve realistic results, the performed research study modeled the electricity price based on the real data from MIBEL spot market and EEX in a continuous period from 2015 till 2020.

With respect to its temporal perspective, a DR model may either assume an ex-ante or an ex-post point of view (Bossmann and Eser, 2016). In accordance with most of the system performance studies performed, this study assumes an ex-post temporal perspective and use an hourly temporal resolution.

Feuerriegel and Neumann (2016) refers that DR does not serve as market product itself, but as a mechanism for load shifting to reduce both peak loads, as well as marginal costs at peak time. Despite DR is frequently studied in the context of load shifting, it does not decrease the amount of energy consumed, and can be used by retailers to reduce procurement costs, to match electricity demand and supply, as well as to reduce electricity procurement during peak times. The same authors refer that DR could be used to enhance electricity retailers' profits. In order to be profitable from a market perspective, price spread is considered to be a key factor (Schwabeneder et al., 2019). The introduction of flexible loads, through load curtailing or load shifting processes, will require consumers to reduce or shift load to another period, typically from peak to off-peak periods, increasing market elasticity and decreasing spot prices. Deane et al. (2015) study examines the impact of DR simulations for the reference scenarios of 10% and 15% of each member State peak demand. From an EU wide perspective, the introduction of DR in 2030 reduces total system generations costs (i.e. variable cost of generation and start-up costs of generators) by €2.0bn or approximately €0.5/MWh. For the year 2050 the impact is slightly bigger at a total reduction in system costs of €2.8bn or approximately €0.6/MWh.

The research performed demonstrate that further studies are still necessary in order to better understand the load shifting effects in the spot market prices. It was an aim of this investigation to study in what form the shifting of loads would affect the spot market prices in the studied markets. Moreover, it aimed to assess how shifting procedures to another period of the day would impact on on-peak and off-peak hours.

To examine the impact of DR, economic potential simulations were undertaken for the reference scenarios of 5% and 15%. The reference information for the scenarios is provided by the hourly merit order generation and demand curves for 2015 to 2020, retrieved from the historical data. In this research study it was considered two load shifting reference scenarios in a continuous temporal period of 24 hours from 1st January 2015 till 30th June 2020 for three different countries electricity markets, namely, Portugal, Spain and Germany. A single year

analysis for one energy market correspond to 8760 hourly clearing prices and traded energy that include hundreds of production and demand bids taking part in each hour of market. (Fernandez et al., 2020).

To evaluate the impact of performing load shifting from one hour to any of the 23 hours left, implies the analysis of 552 new simulated hourly clearing prices for a day period. Within a year this implies the analysis of 201.480 simulated hourly clearing prices, which in a continuous period from 2015 till 2020, correspond to 1.208.880 simulated hourly clearing prices for one market and within a specific considered scenario. The total simulations performed, for the three analyzed markets and two scenarios implies a total analysis of 6.653.808 simulated hourly clearing prices.

3.3.2. ELECTRICITY PRICE AND VOLUME

To obtain realistic results, the market scenarios considered in this work were developed with real data from the Iberian energy market and from the combined German and Austrian market. Both the real spot prices and forecasted load volumes were considered in order to consider DR as a planning tool.

3.3.3. MODEL ASSUMPTIONS AND LIMITATIONS

With respect to the model perspective, distinguished by Bossmann and Eser (2016) this model assumes a top-down perspective. Metz et al. (2007) defines top-down models as “*models applying macroeconomic theory, econometric and optimization techniques to aggregate economic variables. Using historical data on consumption, prices, incomes, and factor costs, top-down models assess final demand for goods and services, and supply from main sectors, such as the energy sector, transportation, agriculture, and industry*”. Likewise, Metz et al. (2007) defines bottom-up models as “*models represent reality by aggregating characteristics of specific activities and processes, considering technological, engineering and cost details*”.

With the aim of studying the price variation per unit of load during a load reduction process, a curtailing or load shifting process it is necessary to know a function of that price. It is possible to establish a price function per unit of load, P , dependent from N variables, i.e. forecasted load, production sources, etc.

$$P \equiv P(x_0, x_1, \dots, x_N) \quad (3.1)$$

A possible simplification would be to identify the variables x_i as elements of the group ξ :

$$\xi \equiv (x_0, x_1, \dots, x_N) \quad (3.2)$$

As a first supposition, it is assumed that $P(\xi)$ is of class C^∞ and analytic. Therefore, it can be written as a Taylor Series:

$$P(\xi) = P(\xi_0) + \frac{dP}{d\xi}(\xi - \xi_0) + \frac{1}{2!} \frac{d^2P}{d\xi^2}(\xi - \xi_0)^2 + \dots \quad (3.3)$$

Besides there are no guaranties that such a function has an analytic behavior, but when studying small variations from the group ξ it is possible to approximate the variation from $P(\xi)$ for the first term of Taylor Series (linearization).

$$\delta P = P(\xi) - P(\xi_0); \quad (3.4)$$

$$\delta \xi = \xi - \xi_0; \quad (3.5)$$

$$\delta P \approx \frac{dP}{d\xi} \delta \xi \quad (3.6)$$

During the studied process – load shifting – the price variations occur due to load variations in relation to the forecasted load. In this way, the variation δP occurs exclusively per variation of one variable: x_0 . Identifying x_0 as the forecasted load: $x_0 \equiv Q$; Then it is possible to write:

$$\delta P = \frac{dP}{dQ} \delta Q \quad (3.7)$$

During the calculation of the price variation δP_i it is necessary to know how to calculate the quantities of $\frac{dP}{dQ}$ and δQ .

The quantity corresponding to $\frac{dP}{dQ}$ can be directly known from the publish data in MIBEL and EPEX spot. For example, during the day, to each hour there is the forecasted load Q and the corresponding spot price P . The quotient between these two quantities will be same to the

mentioned quantity. Indeed, there is a language abuse thus the quantity it is written considering P and Q differentials.

Meanwhile, this quotient $\frac{dP}{dQ}$ can be seen as a derivative and, for that reason, the slope of a function in a certain point, time in this case and in each hour the slope is given by the quotient mentioned. δQ is an imposed value, which in this research may correspond to 5% or 15% according to the load shifting scenario. Supposing a 5% load withdraw from the foreseen forecasted load, then $\delta Q = -0.05Q$, per other side when increasing 5% the foreseen forecasted load, then $\delta Q = +0.05Q$.

During a load shifting process, it is possible to diminish a certain percentage of load, transferring it into another hour. As an example, when considering the load shifting between hour 1 and hour 2, both hour prices should be affected. The new prices from hour 1 and hour 2, can be known according to the formulation:

$$P'_i = P_i + \delta P_i \quad (3.8)$$

here, P_i is the known spot price and δP_i are the previously calculated variations.

Supposing that we want to reduce the load production from hour 1 by a quantity ε and transfer that production to hour 2; this implies that $\delta Q_2 = -\delta Q_1$. Spot prices and forecasted loads for each hour are acknowledged values: P_1, Q_1, P_2, Q_2 .

$$\delta P_1 = \left(\frac{dP}{dQ}\right)_1 \delta Q_1 = \frac{P_1}{Q_1} (-\varepsilon) Q_1 = -\varepsilon P_1 \quad (3.9)$$

$$\delta P_2 = \left(\frac{dP}{dQ}\right)_2 \delta Q_2 = \frac{P_2}{Q_2} (+\varepsilon) Q_1 = +\varepsilon \frac{Q_1}{Q_2} P_2 \quad (3.10)$$

$$P'_1 = P_1 + \delta P_1 = (1-\varepsilon) P_1 \quad (3.11)$$

$$P'_2 = P_2 + \delta P_2 = \left(1 + \varepsilon \frac{Q_1}{Q_2}\right) P_2 \quad (3.12)$$

Where, P'_1 represents the new price for hour 1, P_1 the spot price foreseen for hour 1, $\left(\frac{dP}{dQ}\right)_1$ represents the variation quotient of price per load (€/Mwh/Mwh) in hour 1, ε represents the

clipping percentage; it is negative thus the load is being retrieved from hour 1 to hour 2, Q_1 represents the forecasted load for hour 1. P'_2 represents the new price for hour 2, P_2 the spot price foreseen for hour 2, $\left(\frac{dP}{dQ}\right)_2$ represents the variation quotient of price per load (€/Mwh/Mwh) in hour 2, ε represents the clipping percentage; it is positive thus the load is being added from hour 1 to hour 2, Q_2 represents the forecasted load for hour 2. The figure below Figure 3.3, schematically represents the mathematical model exposed above.

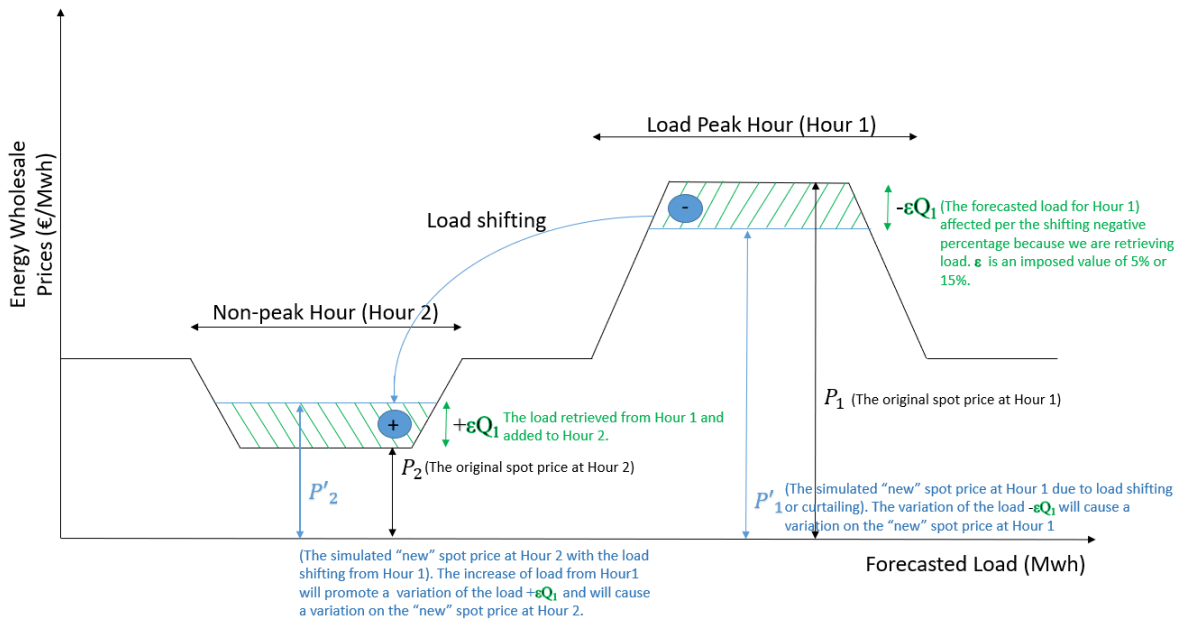


Figure 3.3 – Mathematical model schematic representation. Source: From the author

In the end, the price spikes variation that will be translated into a profitable or a non-profitable scenario considering Demand Response flexibility, can be given by:

$$\text{"Net Income"} = \delta P_1 + \delta P_2 = \varepsilon \left(\frac{Q_1}{Q_2} P_2 - P_1 \right) \quad (3.13)$$

When the price variation is higher than zero, it means that economically is not viable to perform Demand Response and the final consumer could pay an even higher price but per other side if the price variation is lower than zero, then it is economically compensating to perform Demand Response.

If "Net Income" > 0 the final price will be higher.

If “Net Income” < 0 the final price will be lower.

In this study, the mathematical model was tested using real market data both from MIBEL and EPEX Spot using historical data retrieved from the ENTSO-E (2020), (European Network of Transmission System Operators for Electricity) Transparency Platform for the mentioned temporal analysis. The day-ahead spot market prices and demand values correspond to historic wholesale market day-ahead auctions results for a continuous analysis for Portugal, Spain and Germany, and were considered in order to achieve more realistic results. The prices for the common Germany-Austria-Luxembourg market area were used until September 2018. Then, due to the market split after October 2018, the prices were from the new Germany-Luxembourg area. The study conducted an ex-post analysis based on real historical data.

However, the impacts on utilities are often beyond the focus of the models. The present DR model represent a simplified economic analysis model focused on market prices. The model does not integrate DR measures into a major modelling environment with alternative flexibility options, such as storage expansion, grid reinforcement, RES curtailment or installation of flexible generation capacities in order to determine the cost-optimal price. Also, practical demand-response implementation details, such as market access requirements, was beyond the scope of this study.

This study aims to assess the influence on market prices when a high penetration of flexible demand caused by load shifting. The possible effect of additional load on power plants with higher marginal cost on generation portfolio was considered static. If an amount of load is shifted to an hour with lower prices, power plants with higher marginal cost might have to be activated and prices could raise during that hour, but this is not certain as that power plants with higher marginal cost might not need to be activated.

3.4. RESULTS AND DISCUSSION

The economic impact analysis of load-shift on different markets spot prices is presented in this section.

In principle, it is expected that an increasing number of load participants on energy market would increase the flexibility of the system and, therefore, a reduction of the overall costs was expected. However, the overall results of this study, indicates that an increasing penetration of flexible loads does not necessary correspond to a general decrease on wholesale energy market prices. In all the energy markets studied, in nearly half of the simulated hours, instead of decreasing wholesale energy market prices, flexible loads would have the opposite effect. The load flexibility impact on prices was found to be different for every country and energy market analyzed.

The daily 552 simulated hours associated to positive and negative DR potential were converted into percentages. The values presented in Table 3.3, 3.4 and 3.5 represent the monthly aggregated DR economic potential, in percentage, respectively, for Portugal, Spain and Germany considering 15% and 5% scenarios.

Table 3.3 – Monthly aggregated results for Portugal DR potential for 15% and 5% scenarios.

2020					
15% Scenario			5% Scenario		
	% DR Positive	% DR Negative		% DR Positive	% DR Negative
January	49.39808322	50.60191678	January	49.49742871	50.50257129
February	49.3878061	50.6121939	February	49.19415292	50.80584708
March	49.6953006	50.3046994	March	49.46677605	50.53322395
April	52.10144928	47.89855072	April	52.17391304	47.82608696
May	51.90509584	48.09490416	May	51.95184666	48.04815334
June	51.90936556	48.09063444	June	52.00483092	47.99516908
July	-	-	July	-	-
August	-	-	August	-	-
September	-	-	September	-	-
October	-	-	October	-	-
November	-	-	November	-	-
December	-	-	December	-	-
Total	50.73400526	49.26599474	Total	50.71700293	49.28299707
2019					
15% Scenario			5% Scenario		
	% DR Positive	% DR Negative		% DR Positive	% DR Negative
January	49.33964469	50.66035531	January	49.50911641	50.49088359
February	49.70885093	50.29114907	February	49.70238095	50.29761905
March	50.62697762	49.37302238	March	51.00785187	48.99214813
April	51.9263285	48.0736715	April	52.14975845	47.85024155
May	52.6940159	47.3059841	May	52.84595605	47.15404395
June	53.02536232	46.97463768	June	53.15217391	46.84782609
July	51.72393642	48.27606358	July	52.0687237	47.9312763
August	52.37844787	47.62155213	August	52.53623188	47.46376812
September	50.35024155	49.64975845	September	50.47705314	49.52294686
October	49.53249182	50.46750818	October	49.52080411	50.47919589
November	47.46980676	52.53019324	November	47.43961353	52.56038647

December	48.02477793	51.97522207	December	47.942964	52.057036
Total	50.57239592	49.42760408	Total	50.70295978	49.29704022
2018					
15% Scenario			5% Scenario		
	% DR Positive	% DR Negative		% DR Positive	% DR Negative
January	50.60776064	49.39223936	January	50.82982702	49.17017298
February	50.23938923	49.76061077	February	50.46583851	49.53416149
March	50.67385445	49.32614555	March	50.61525841	49.38474159
April	52.33695652	47.66304348	April	52.37318841	47.62681159
May	51.98106592	48.01893408	May	52.42519869	47.57480131
June	51.52777778	48.47222222	June	51.90821256	48.09178744
July	51.01098644	48.98901356	July	51.34992987	48.65007013
August	50.69541842	49.30458158	August	50.91164095	49.08835905
September	49.81280193	50.18719807	September	49.83091787	50.16908213
October	49.1058906	50.8941094	October	48.91304348	51.08695652
November	49.13647343	50.86352657	November	49.11835749	50.88164251
December	49.8655914	50.1344086	December	50.19284712	49.80715288
Total	50.58431049	49.41568951	Total	50.7461501	49.2538499
2017					
15% Scenario			5% Scenario		
	% DR Positive	% DR Negative		% DR Positive	% DR Negative
January	48.41047218	51.58952782	January	48.35787751	51.64212249
February	48.48602484	51.51397516	February	48.31780538	51.68219462
March	49.81835228	50.18164772	March	49.48435486	50.51564514
April	52.35507246	47.64492754	April	52.36714976	47.63285024
May	52.61220196	47.38779804	May	52.7057036	47.2942964
June	51.89613527	48.10386473	June	52.43357488	47.56642512
July	52.74661057	47.25338943	July	53.0972417	46.9027583
August	52.37260402	47.62739598	August	52.71154745	47.28845255
September	52.48188406	47.51811594	September	52.64492754	47.35507246
October	49.24614306	50.75385694	October	49.27536232	50.72463768
November	48.5326087	51.4673913	November	48.39371981	51.60628019
December	48.67928939	51.32071061	December	48.62669472	51.37330528
Total	50.646862	49.353138	Total	50.71288859	49.28711141
2016					
15% Scenario			5% Scenario		
	% DR Positive	% DR Negative		% DR Positive	% DR Negative
January	48.35787751	51.64212249	January	48.13581113	51.86418887
February	48.4007996	51.5992004	February	48.20714643	51.79285357
March	49.29684753	50.70315247	March	49.25583031	50.74416969
April	52.01690821	47.98309179	April	52.03502415	47.96497585
May	51.53108929	48.46891071	May	51.56030856	48.43969144
June	51.95048309	48.04951691	June	52.13768116	47.86231884
July	52.06287985	47.93712015	July	52.4485741	47.5514259
August	52.53623188	47.46376812	August	52.68817204	47.31182796
September	51.25	48.75	September	52.13768116	47.86231884
October	50.07597008	49.92402992	October	50.28634876	49.71365124
November	48.26086957	51.73913043	November	48.04347826	51.95652174
December	49.02992052	50.97007948	December	49.00654511	50.99345489
Total	50.40349331	49.59650669	Total	50.50151991	49.49848009
2015					
15% Scenario			5% Scenario		
	% DR Positive	% DR Negative		% DR Positive	% DR Negative
January	48.28190743	51.71809257	January	48.07152875	51.92847125

February	48.05900621	51.94099379	February	48.02018634	51.97981366
March	49.5546701	50.4453299	March	49.47263565	50.52736435
April	52.40942029	47.59057971	April	52.40942029	47.59057971
May	52.72323516	47.27676484	May	52.80504909	47.19495091
June	52.62077295	47.37922705	June	52.76570048	47.23429952
July	52.22066386	47.77933614	July	52.51870033	47.48129967
August	52.62388967	47.37611033	August	52.64726508	47.35273492
September	52.37381309	47.62618691	September	50.64009662	49.35990338
October	49.53833567	50.46166433	October	49.29873773	50.70126227
November	48.26086957	51.73913043	November	48.12801932	51.87198068
December	49.05329593	50.94670407	December	48.84291725	51.15708275
Total	50.65162633	49.34837367	Total	50.4790651	49.5209349

Table 3.4 – Monthly aggregated results for Spain DR potential for 15% and 5% scenarios.

2020				
15% Scenario			5% Scenario	
	% DR Positive	% DR Negative		
January	48.60916316	51.39083684	January	48.457223
February	49.32533733	50.67466267	February	49.12543728
March	49.53123169	50.46876831	March	49.26168991
April	51.50966184	48.49033816	April	51.51570048
May	51.77068724	48.22931276	May	51.78237494
June	51.82971014	48.17028986	June	51.89009662
July	-	-	July	-
August	-	-	August	-
September	-	-	September	-
October	-	-	October	-
November	-	-	November	-
December	-	-	December	-
Total	50.42821008	49.57178992	Total	50.33758888
2019				
15% Scenario			5% Scenario	
	% DR Positive	% DR Negative		
January	48.80785414	51.19214586	January	48.87213651
February	49.56004141	50.43995859	February	49.64415114
March	50.92581741	49.07418259	March	51.26567444
April	52.11956522	47.88043478	April	52.1557971
May	52.5829827	47.4170173	May	52.61220196
June	52.86231884	47.13768116	June	52.98913043
July	51.77653109	48.22346891	July	52.13300608
August	52.23819542	47.76180458	August	52.43104254
September	50.36835749	49.63164251	September	50.40458937
October	49.46820944	50.53179056	October	49.25783076
November	46.92028986	53.07971014	November	46.90217391
December	47.54558205	52.45441795	December	47.45208041
Total	50.43686766	49.56313234	Total	50.5158017
2018				
15% Scenario			5% Scenario	
	% DR Positive	% DR Negative		
January	50.3915381	49.6084619	January	50.54347826
February	50.42054865	49.57945135	February	50.51112836
March	49.91210594	50.08789406	March	49.80077347
April	52.14975845	47.85024155	April	52.1678744

May	52.06287985	47.93712015	May	52.29079009	47.70920991
June	51.68478261	48.31521739	June	52.13164251	47.86835749
July	51.37914914	48.62085086	July	51.72393642	48.27606358
August	51.11617578	48.88382422	August	51.37330528	48.62669472
September	50.01207729	49.98792271	September	49.98188406	50.01811594
October	49.03576438	50.96423562	October	48.98316971	51.01683029
November	48.43599034	51.56400966	November	48.42995169	51.57004831
December	49.68443198	50.31556802	December	49.7428705	50.2571295
Total	50.52424119	49.47575881	Total	50.64090471	49.35909529
2017					
15% Scenario			5% Scenario		
	% DR Positive	% DR Negative		% DR Positive	% DR Negative
January	47.99555867	52.00444133	January	48.00140252	51.99859748
February	47.88431677	52.11568323	February	47.47670807	52.52329193
March	49.53123169	50.46876831	March	49.16207664	50.83792336
April	52.01086957	47.98913043	April	52.01086957	47.98913043
May	52.61220196	47.38779804	May	52.61220196	47.38779804
June	52.24033816	47.75966184	June	52.73550725	47.26449275
July	52.80504909	47.19495091	July	53.16736793	46.83263207
August	52.59467041	47.40532959	August	52.75245442	47.24754558
September	52.45169082	47.54830918	September	52.54227053	47.45772947
October	49.10004675	50.89995325	October	49.14095372	50.85904628
November	48.32125604	51.67874396	November	48.23671498	51.76328502
December	47.75596073	52.24403927	December	47.62155213	52.37844787
Total	50.45424308	49.54575692	Total	50.46963273	49.53036727
2016					
15% Scenario			5% Scenario		
	% DR Positive	% DR Negative		% DR Positive	% DR Negative
January	48.00724638	51.99275362	January	47.7968677	52.2031323
February	48.23838081	51.76161919	February	48.2133933	51.7866067
March	49.51365288	50.48634712	March	49.45505684	50.54494316
April	51.95048309	48.04951691	April	51.95048309	48.04951691
May	51.81743806	48.18256194	May	51.87587658	48.12412342
June	52.57850242	47.42149758	June	52.66304348	47.33695652
July	52.1914446	47.8085554	July	52.51870033	47.48129967
August	52.58882655	47.41117345	August	52.68232819	47.31767181
September	51.17753623	48.82246377	September	51.07487923	48.92512077
October	50.23375409	49.76624591	October	50.44997662	49.55002338
November	48.12801932	51.87198068	November	47.96497585	52.03502415
December	48.63838242	51.36161758	December	48.52734923	51.47265077
Total	50.4282475	49.5717525	Total	50.43814918	49.56185082
2015					
15% Scenario			5% Scenario		
	% DR Positive	% DR Negative		% DR Positive	% DR Negative
January	47.87868163	52.12131837	January	47.63908368	52.36091632
February	47.87784679	52.12215321	February	47.82608696	52.17391304
March	49.47263565	50.52736435	March	49.36130318	50.63869682
April	52.17995169	47.82004831	April	52.17995169	47.82004831
May	52.71154745	47.28845255	May	52.78167368	47.21832632
June	52.87439614	47.12560386	June	52.81400966	47.18599034
July	52.37844787	47.62155213	July	52.69985975	47.30014025
August	52.74076671	47.25923329	August	52.73492286	47.26507714
September	52.39130435	47.60869565	September	52.39130435	47.60869565
October	49.29289388	50.70710612	October	49.02992052	50.97007948

November	48.06763285	51.93236715	November	47.8442029	52.1557971
December	48.68513324	51.31486676	December	48.29359514	51.70640486
Total	50.55899203	49.44100797	Total	50.4790651	49.5209349

Table 3.5 – Monthly aggregated results for Germany DR potential for 15% and 5% scenarios.

2020					
15% Scenario			5% Scenario		
	% DR Positive	% DR Negative		% DR Positive	% DR Negative
January	47.14820009	52.85179991	January	47.06054231	52.93945769
February	46.77036482	53.22963518	February	46.75162419	53.24837581
March	46.51939529	53.48060471	March	46.34946678	53.65053322
April	47.22826087	52.77173913	April	46.78743961	53.21256039
May	49.28705002	50.71294998	May	49.1058906	50.8941094
June	48.27294686	51.72705314	June	48.14009662	51.85990338
July	-	-	July	-	-
August	-	-	August	-	-
September	-	-	September	-	-
October	-	-	October	-	-
November	-	-	November	-	-
December	-	-	December	-	-
Total	47.54426497	52.45573503	Total	47.3719851	52.6280149
2019					
15% Scenario			5% Scenario		
	% DR Positive	% DR Negative		% DR Positive	% DR Negative
January	47.66245909	52.33754091	January	47.57480131	52.42519869
February	46.75854037	53.24145963	February	46.73913043	53.26086957
March	46.44908004	53.55091996	March	46.44908004	53.55091996
April	47.3852657	52.6147343	April	47.17995169	52.82004831
May	49.32211314	50.67788686	May	49.13510986	50.86489014
June	48.01932367	51.98067633	June	47.63285024	52.36714976
July	48.12996727	51.87003273	July	47.95465171	52.04534829
August	48.03646564	51.96353436	August	48.04815334	51.95184666
September	46.8236715	53.1763285	September	46.65458937	53.34541063
October	46.21902758	53.78097242	October	46.20733988	53.79266012
November	47.37318841	52.62681159	November	47.34299517	52.65700483
December	47.17741935	52.82258065	December	47.14820009	52.85179991
Total	47.45276368	52.54723632	Total	47.34553253	52.65446747
2018					
15% Scenario			5% Scenario		
	% DR Positive	% DR Negative		% DR Positive	% DR Negative
January	47.41117345	52.58882655	January	47.31767181	52.68232819
February	46.6873706	53.3126294	February	46.6873706	53.3126294
March	46.79479667	53.20520333	March	46.73620063	53.26379937
April	48.33333333	51.66666667	April	47.7173913	52.2826087
May	48.10659187	51.89340813	May	47.75596073	52.24403927
June	48.24879227	51.75120773	June	48.08574879	51.91425121
July	48.31697055	51.68302945	July	48.03646564	51.96353436
August	48.25268817	51.74731183	August	47.90205704	52.09794296
September	46.56880734	53.43119266	September	46.28134557	53.71865443
October	46.45752556	53.54247444	October	46.4516508	53.5483492
November	47.74154589	52.25845411	November	47.73550725	52.26449275
December	47.63908368	52.36091632	December	47.5514259	52.4485741
Total	47.55337238	52.44662762	Total	47.36096334	52.63903666

2017					
15% Scenario			5% Scenario		
	% DR Positive	% DR Negative		% DR Positive	% DR Negative
January	46.94950912	53.05049088	January	46.94950912	53.05049088
February	46.81030021	53.18969979	February	46.86853002	53.13146998
March	46.55455291	53.44544709	March	46.49595687	53.50404313
April	49.0821256	50.9178744	April	48.67753623	51.32246377
May	48.61500701	51.38499299	May	48.15918654	51.84081346
June	48.58091787	51.41908213	June	48.34541063	51.65458937
July	48.07152875	51.92847125	July	47.85530622	52.14469378
August	48.03062179	51.96937821	August	47.77349229	52.22650771
September	46.60024155	53.39975845	September	46.53985507	53.46014493
October	46.65147265	53.34852735	October	46.35343619	53.64656381
November	47.31280193	52.68719807	November	47.20410628	52.79589372
December	47.66830295	52.33169705	December	47.61570827	52.38429173
Total	47.5803489	52.4196511	Total	47.40460895	52.59539105
2016					
15% Scenario			5% Scenario		
	% DR Positive	% DR Negative		% DR Positive	% DR Negative
January	46.86769518	53.13230482	January	46.86769518	53.13230482
February	46.47051474	53.52948526	February	46.47051474	53.52948526
March	46.50767608	53.49232392	March	46.45493965	53.54506035
April	49.58333333	50.41666667	April	49.29951691	50.70048309
May	48.89551192	51.10448808	May	48.51566152	51.48433848
June	47.40942029	52.59057971	June	47.14371981	52.85628019
July	48.39878448	51.60121552	July	47.96049556	52.03950444
August	48.19424965	51.80575035	August	47.96049556	52.03950444
September	46.49154589	53.50845411	September	46.34661836	53.65338164
October	46.50537634	53.49462366	October	46.42356241	53.57643759
November	47.54830918	52.45169082	November	47.53019324	52.46980676
December	48.01309023	51.98690977	December	47.35857878	52.64142122
Total	47.57804996	52.42195004	Total	47.36367867	52.63632133
2015					
15% Scenario			5% Scenario		
	% DR Positive	% DR Negative		% DR Positive	% DR Negative
January	46.94816054	53.05183946	January	46.94119287	53.05880713
February	46.71325052	53.28674948	February	46.71325052	53.28674948
March	46.15609985	53.84390015	March	46.09750381	53.90249619
April	49.15458937	50.84541063	April	49.15458937	50.84541063
May	49.41561477	50.58438523	May	49.36886396	50.63113604
June	48.33937198	51.66062802	June	48.18236715	51.81763285
July	48.25268817	51.74731183	July	48.25268817	51.74731183
August	49.40392707	50.59607293	August	49.40392707	50.59607293
September	48.32125604	51.67874396	September	48.32125604	51.67874396
October	48.49812997	51.50187003	October	48.49812997	51.50187003
November	47.06521739	52.93478261	November	47.06521739	52.93478261
December	47.18326321	52.81673679	December	47.01379149	52.98620851
Total	47.97608142	52.02391858	Total	47.93883447	52.06116553

Results for Portugal tend to be more favorable for DR. *Per* opposition, Germany tends to be a less favorable market for implementing DR. According to the results found, MIBEL would experience a more positive impact on prices resultant from load flexibility than EEX.

For Portugal and Spain, when considering the 15% scenario, generically there is a positive potential for flexible loads in more than 50% of the hours. This means that in most of the hours it would be economically viable to perform DR. When considering the 5% scenario, the potential for DR suffers a slightly decrease. In any circumstance, the 5% scenario aggregated value is very similar to the 15% scenario. Germany energy market was found to be the market where load flexibility represents fewer impact on prices. In both the reference scenarios, 5% and 15%, the economic potential was lower when compared with Portugal and Spain. When analyzing the 15% scenario, there is a negative potential predominance for DR, meaning that in most of the hours it would not be economically viable to perform DR. When considering the 5% scenario, the potential for DR suffers a decrease in parallel with the results found for all the other energy markets. In any circumstance, the aggregated results found in this energy markets are very similar to the 15% scenario results.

Despite the positive or negative tendency associated to each market and scenario, there is an equilibrium in all markets and even between load-shifting reference scenarios. The aggregated results demonstrate the number of hours in which is possible to perform viably DR is very similar to the number of hours in which is not variable to perform DR, thus load flexibility tend to increase prices instead of reducing them. The market characteristics could possibly be the reason for the obtained differences among these markets.

When analyzing the DR potential along the years for each energy market, there is no tendency pattern for the potential levels, with exception of Germany. In this energy market there is a notorious decrease in DR potentiality along the years. The continuous decrease on DR potential coincides with the decrease in share of fossil energy technologies, particularly what concerns hard coal, and the increase share of non-fossil energy technologies, particularly wind generation.

Two reference load shifting scenarios (5% and 15%) were considered, in order to assess the impacts of smaller and larger load shifting on prices. The research results demonstrate that for all the three analyzed countries the 5% scenario corresponded to a slightly diminution on the economic potential for performing DR. If on one hand, it was expected that the 5% scenario, would correspond to lower DR potentiality, on the other hand, it was expected a larger difference in what regards DR potentials results for both scenarios. The small difference

between the 5% scenario and the 15% scenario reveals that the larger is the load shifting amount percentage, the difficult is to implement DR on energy markets thus the impact on energy prices would not be expressive. From the technical point of view, it is more viable to shift smaller amounts of load than larger amounts. The results demonstrate that with a small amount of load shifting it is possible to obtain nearly the same economic potential to perform DR. If it is less viable to perform large load-shifting processes it is more viable and possible to perform small load-shifting processes. As so, these results could indicate that lower flexibility levels would produce a similar price variation and in a certain way this could facilitate DR implementation on energy markets. Anjo et al. (2018) results also demonstrate that with just 50% of the potential of DR implemented, 95% of the cost benefits could be reached (compared with 100% implementation).

According to this study, there are mainly four causes that tend to conditionate DR potentials. These are associated with the energy market generation portfolio that tend to affect DR potentials in the three markets, with the internal concurrency market rules, with the load-shifting period and period of the year and with the global amount of load. In markets where market power exists this tend to influence the DR potentials, namely, decreasing the potential thus in the hours with peak consumption the price volatility is lower, which may indicate that there is lower concurrency level among the generation companies. *Per* contrary, in off-peak hours the price volatility is higher and the potential for performing DR increases. In summary, the results indicate that despite the load shifting procedures decrease the load consumption, for both scenarios, there are some hour groups namely during peak-hours where the spot prices do not keep up with the load decrease tendency and prices do not decrease significantly, meaning that in peak-hours there is less volatility and consequently less potential for Demand Response mechanisms. Lagarto et al. (2014) performed a study that comprised seven generating firms and 130 power plants of Portugal and Spain, in which a model was a market representation where power plants, fuels, CO₂ and the DA electricity market were provided as input data. This study results are in line to this study conclusions, as so during off-peak hours (hour 1 to hour 8) companies tend to behave much more competitively than in peak hours (the rest of the hours). According to Lagarto et al. (2014) in what regards to differences in behavior among generating firms, Iberdrola was the one that behaved more competitively in both peak and non-peak hours, while Union Fenosa was the one that behaved less competitively. Also, Gil-Alana et al. (2020)

found out a close relation between energy consumption and energy prices in the MIBEL spot market.

There are several methodologies to address market power in electricity markets. The HHI (Herfindahle Hirschman Index), is defined as the sum of the squares of the firms' market share and is related with the potential exercise of market power. When the HHI values exceeded 2000 and a company market share is greater than 25%, the market is considered to be concentrated (García et al., 2017). The more concentrated is the market the more prone is to the exercise of market power and problems of horizontal competition may arise. According to Marques et al. (2008) *“a low concentration measure may simply point out that the producers with more installed capacity have strategically chosen to produce less than they could, so as to raise prices and benefit from low demand elasticity”*. Also, Lagarto et al. (2014) refer that the use of the HHI in electricity markets has been subject to criticism, since it is a static measure of concentration which does not reflect electricity market dynamics. Moreover, cooperative games which focus coalitions form, the joint actions that groups take and the resulting collective payoffs, often analyzed through the framework of cooperative game theory, may be developed by companies (Schwabeneder et al., 2019). Another index used to study market power is the Lerner index, which is a behavioral index. Other methodologies use simulation models, such as the Cournot models, where the decision variable of firms is their quantity. These last models are criticized in what regards to market outcome (Lagarto et al., 2014).

The objective of generating firms that bid in the market is maximize its operational profit, which is defined as the difference between its revenues and costs (Lagarto et al., 2014). The market equilibrium is obtained by computing the profit maximization problem of each generating firm. Each generating firm defines a given quantity to produce, which is the sum of the quantities produced by each of their power plants, which are subjected to minimum and maximum output constraints. Marques et al. (2008) argue that *“at low price hours, the producers bid large amounts, related to base load units, and with the increase of prices, the bid reflects the higher variable costs units which have a lower capacity installed, the peak load units”*.

Lagarto et al. (2014) also refers that one of the reasons generating firms become more competitive in off-peak hours is the fact that, despite the lower market price they decide to keep their baseload power plants running to avoid shutdown and the subsequent startup costs.

There is a diversified mix of electricity generating technologies. Generating companies own different types of power plants that may range from low variable cost technologies, such as renewable and nuclear, to high variable cost technologies, such as open-cycle gas turbine. The technology generation that participate in the wholesale market, impact the supply curve of the electricity market and impact the clearance price.

A possible explanation is given by Lagarto et al. (2014) in page 293: *“Once the pool pricing system in electricity markets is usually marginal pricing, that is, the price offer of the last power plant required to meet demand, a generating firm might be tempted to withdraw capacity from their cheapest power plants in order to increase the system marginal price to raise profits.”*. In fact, generating firms may decide to keep or not their baseload power plants running. If they decide per the first option the market price become close to the marginal cost of production or even lower and they become more competitive thus they offer energy at a lower price in the day-ahead market. But if on contrary, they decide to stop baseload power plants in off-peak hours, they incur in shutdown costs and subsequently in startup costs, which may reduce their profits and offering their energy at a higher price. Baseload units, create an opportunity for generating firms that operate this type of power plants.

In tables 3.3, 3.4 and 3.5 it is possible to assess the hours where load-shift was optimum considering a 15% and 5% scenario for hour 22 on the three analyzed markets. When analyzing the load-shift effect on prices in other hours e.g. hour 11 or 15, the optimum load-shift impacts on prices will coincide. This means that regardless the hour where the load is shifted, the optimum load-shift impact on prices will tend to occur at the same periods of hours. In Table 3.6 and 3.7 is possible to observe that there are a group of hours with optimum load-shift impact on prices for hour 22 considering both 5% and 15% scenario. This group are usually considered non-peak hours. In some markets, and in some specific years, during the months of November, December and January is not possible to perform optimum load-shift impact on prices. These months are marked with an x.

Table 3.6 – Hour with optimum load-shift impact on prices for hour 22 considering a 5% scenario.

5% Scenario											
2019											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

PT	x	16	17	17	17/18	17	17	17	17	16	16	5/16
DE	5	13	14/15	15	15/16	15	15	15	15	5/14	5	4/5
ES	x	16	16	17	x	17	17	17	17	15	5/15	15
2018												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PT	16/17	15	16	15	15/16	17	13/17	13/17	x	16	x	x
DE	5	14	14	15	15	15	15	15	15	14	x	5
ES	5	16	17	17	14	14	14	14	15	14	x	
2017												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PT	x	16/17	16	17	17	17/18	18	17	17	17	16	x
DE	4	5	15	15	14	15	15	15	15	14	4	3
ES	x	5/17	14/17	17	17	18	18	14	17	17	16	5/16
2016												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PT	5	16	17	17	5/17	17	17/18	17	17	16/17	16	x
DE	4/5	16	15	15-16	15	15	15	15	14	15	3	4
ES	5	16	17	17	5/17	17	20	17/19	17	16	14/15	x
2015												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PT	2/16	16	16/17	16/17	17	16/17	17	16/17	16	16/17	16	3
DE	4	15	14	15	15	15	15	15	15	15	4	5
ES	16	16	17	17	17	16	17	17	17	16	5	5/16

Table 3.7 – Hour with optimum load-shift impact on prices for hour 22 considering a 15% scenario.

15% Scenario												
2019												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PT	x	16	17	17	17/18	17	17	17	17	16	16	5
DE	5	13	14/15	15	15/16	15	15	15	15	5/14	5	4/5
ES	x	16	16	17	x	17	17	17	17	15	5/15	15
2018												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PT	16/17	15	16	15	15/16	17	13/17	13/17	x	16	x	x
DE	5	14	14	15	15	15	15	15	15	14	x	5
ES	5	16	17	17	14	14	14	14	15	14	x	
2017												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PT	x	16/17	16	17	17	17	18	17	17	17	16	x
DE	4	5	15	15	14	15	15	15	15	14	4	3/4
ES	x	5/17	17	17	17	18	18	14	17	17	16	5/16
2016												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PT	5	5	17	4/17	5/17	17	17	17	17	16/17	16	x
DE	4/5	4	15	15/16	15	15	15	15	14	15	3	4
ES	5	5	17	5/17	5/17	17	20	17-19	17	16	14	x
2015												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PT	x	3-5	17	17	17	17	17	17	16	16/17	16	3
DE	4	5/14	14	15	15	15	15	15	15	15	4	5

ES	16	5	17	17	17	16-17	17	17	17	16	5/12-15	5
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When analyzing the prices variation to assess Demand Response economic potential, it seems clear that is possible to perform Demand Response from non-peak hours to peak-hours in a larger number of hours than from peak hours to non-peak hours.

Despite load-shifting and other load reduction mechanisms per principle aim to move load from peak to non-peak hours, it is mostly during non-peak hours that exists higher price volatility meaning higher possibilities to perform Demand Response in an economically viable way. These results may indicate that generating companies that bid in the wholesale market establish prices during peak hours in order to increase their profits. During non-peak hours the expected decreases in consumption lead generating companies to decrease prices and increase competition.

In Tables 3.8 and 3.9 it is possible to observe the days with maximum and minimum optimum load-shift impact on prices considering a 5% scenario and 15% scenario. There are a large number of days of the week that coincide with minimum potential to perform DR and a large number of weekend days and holidays that coincide with maximum potential to perform DR. Lagarto et al. (2014) study results also indicate that the difference between peak and off-peak hours is higher in the working days than in the weekend days.

Table 3.8 – Maximum and minimum optimum load-shift impact on prices considering a 5% scenario.

5% Scenario													
2020													
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PT	Max	25	17	28	15	29	6	-	-	-	-	-	-
	Min	15	29	7,17,18	5,18,22,26	12	18	-	-	-	-	-	-
DE	Max	11	16	5	10,25	23	27	-	-	-	-	-	-
	Min	18,19,29	6,10,11,18,25,26	1,3,6,7,9,11,12,16,17,18,22,23,26,30	4,7,12,17,18,27,28	9	15/26	-	-	-	-	-	-
ES	Max	25	17	21	19	29	6/16/29	-	-	-	-	-	-
	Min	3,15,20,21	26,27,29	7,17,18	8,18	12	18	-	-	-	-	-	-
2019													
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PT	Max	13	23	17,25	18	4,23,27	20,30	20	15	9	6	19	8

	Min	28,31	2	20	21	12	23,25	23/25	30	2	16	3,10,2 3	20
													5
	Max	7	4	12	19	3,24	21	7	4,10,1 8	1,15	24	10	
DE				3,4,5,7 8,10,1 1,13,1 7,18,1 9,20,2 1,25,2 6,28,3 0	16,21, 24	7,29	5,14,2 4	25	16,22, 24,27, 28,29	2,14,1 9,22,2 3,28,3 0	4,5,6,7 8,9,10 12,14, 15,17, 19,20, 21,22, 26	10,28	20,28, 31
	Max	1	24	3	18	23,27	9	1,7	5,19	1,4	6	20	8
ES	Min	28	1,2	20	14	5,9	7	25	30	2	16,17	3,4	3, 9,17,2 0,27,2 8
2018													
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PT	Max	6,22	4,28	29	15	1	10	20	13	23	30	26	9
	Min	20	20	3	8,21	5,10,3 1	27	26,31	30	25	21	10	16
DE	Max	1	14	31	23	7	21	7	5	7	28	25	18
	Min	16,25	3,17	25	3	10,22	5,6,7	1,2,27	6,22	23	1	1	22,23, 26
ES	Max	22	28	29	27	8,9	17	20	4	23	30	26	9
	Min	15	21	3,6,10, 13,15	4,7,12, 21,26	5	27	26	24	25	2	10	16
2017													
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PT	Max	6	25	30	15	12,15, 19,23	3,27	10,21, 31	16	4	1	26	25
	Min	15	5	6	1	6	16	6	12	2	29	5	30
DE	Max	26	1	12	19	7	9,16	16	3	3	24	4,16,1 7,21	22
	Min	4,12	24	4,5,6,7 10,11, 13,15, 16,18, 21,22, 23	6,11	17	14,19, 21	6,18	14,22, 23,28, 29	11,16, 21,22, 24,26, 30	1,2,6,8 9,14,1 6,17,1 8,28,2 7,29	24	5,25
ES	Max	6	26	31	17	22	3	20,21, 31	1,16	1,13,3 0	1	8,26	25
	Min	5,15	4,5,8,9	6,12,1 3,22	1	1,6	16	6	12	2	20	2,12,1 8,23,2 5	11,16, 30
2016													
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PT	Max	8	6	18	22	28	19	1,4	4,15	3,19	20	21	26
	Min	10,17	15,18, 25,29	3,8	19	7	8	21	30	8	15	1,6,20	17
DE	Max	22	5	1	23	5	5	19	6	4	27	4,12	25
	Min	3,4,24	3,11,1 4,24,2 8	3,5,6,1 0,14,1 6,17,1 8,19,2 2	14,28, 29	6,31	6,7,14, 23,28, 30	31	26,31	6,7,8,1 2,15,1 8,20,2 2,24,2 6,28	1,6,7,8 9,10,1 2,15,1 6,20,2 3,31	15	4,26
ES	Max	8,11	6	18	22,24	18	3,19,2 1,29	1,2,11, 12,22	4,9,15, 22	4	13,20	21	26
	Min	10,16, 17,18	9,10,1 5,18,2 4,25,2 9	2,3,8,2 5	29	7	15	2	30	26	15,29	6,20	17
2015													
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PT	Max	11,31	21	8	4,11	9	28	12	12	2,4	7,20	8,28	25,30
	Min	1	3,9	14	5	1	26	6	19	13	8,13	1,23	7,14
DE	Max	26	1	21	4	3	12	9,19	9	12	9	15	24
	Min	?	9	29	29	11	5,30	2,4,20, 21	11	1,5,30	2,21	19	13,25, 27

ES	Max	31	21	19	11	9,19	2,6,15, 17	8,12,1 4,24,3 1	12	4	20	8	30
	Min	13,18, 19	3,7,9,1 7,26	9,14,2 7	5,15	1	26	6	24,26	16,27	8,13,1 4	23,26	14

Table 3.9 – Maximum and minimum optimum load-shift impact on prices considering a 15% scenario.

15% Scenario													
2020													
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PT	Max	25	17	28	15	29	6	-	-	-	-	-	-
	Min	15	29	7/17/1 8	5/18/2 2/26	12	18	-	-	-	-	-	-
DE	Max	4	16	5	25	23	27	-	-	-	-	-	-
	Min	18/19/ 29	6/10/1 1/18/2 5/26	1/6/7/9 /11/12/ 16/17/ 18/19/ 23/26/ 30	4/7/17/ 18/27/ 28	9	15/26	-	-	-	-	-	-
ES	Max	19	17	21	19	29	6/16/2 9	-	-	-	-	-	-
	Min	15/20/ 21	27/29	7	8	12	18	-	-	-	-	-	-
2019													
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PT	Max	13	23	17	18	23	8	20	15	2	6	19	8/12
	Min	31	2	20	21	9	28	23/25	30	1	17	10	19/29
DE	Max	7	22	12	19/28	3	7	7	10	1/15	24	22	5
	Min	3/5/6/2 0	10/17/ 23	3/7/8/1 0/11/1 3/17/1 9/20/2 1/25/2 6/28/3 0	16/24	7/29	24/25	24/25	16/22/ 24/26/ 28/29	2/14/1 9/22/2 3/28	4/5/6/7 /8/9/10 /12/14/ 15/17/ 19/20/ 21/22/ 26	10/27	20/28/ 31
ES	Max	13	23	24	18	27	9	1	19	1	6	20	22
	Min	28	1	20	14	9	28	25	30	2	17	3/10/1 4/23/2 8	3/9/14/ 17/27/ 28
2018													
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PT	Max	11	4	29	15	1	10	15	4	23	27	26	25
	Min	12	20	3	8	7	27	26	24/29	25	2	10	16
DE	Max	1	14	31	23	10	1	7	5	9	28	25	18
	Min	16	3/11/1 7	25	3	7/22	5/6/7	2/27	6/22	23	1	1	26
ES	Max	15	4	29	27	8/9	17	22	5	23	27/30	26	9
	Min	22	20	3/6/10/ 13	4/7/12/ 21/26	7	27	26	24	25	2	10	16
2017													
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PT	Max	6	26	30	15/17/ 29	22	3	31/10	16	4	1	26	25
	Min	15	8/16	14	1	6	16	6	12	2	29	23	30
DE	Max	26	1	12	19	7	16	16	3	3	5/29	26	22
	Min	4/12	24/28	4/5/6/7 /10/11/ 13/16/ 18/21/ 22/23	11	17	8/14/1 9/21	18	14/22/ 23/28/ 29	11/16/ 21/22/ 24/26/ 30	1/2/6/9 /14/16/ 17/18/ 25/27	24	5
ES	Max	6	26	31	17	22	3	10/21	16	13/30	1	26	25
	Min	5/15	4/8/9	12	1	6	16	6	12	2	20	2/18	9/23/3 1

2016													
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PT	Max	8	6	18	22	28	19	1	4/9/15	4	12/30	21/27	26
	Min	14	15/18/ 25/29	3	19	7	22	21	30	27	15	1	17
DE	Max	22	5	28	23	5	5	27	6	4	27	4/12	25
	Min	3/4/24	3/11/1 4/24/2 8	3/5/6/1 0/14/1 6/17/1 8/19	12/13	6/31	6/7/14/ 23/28/ 30	19	26/31	6/7/8/1 2/15/1 8/20/2 2/24/2 6/28	1/2/6/8 /9/10/1 2/15/1 6/20/2 3	15	4
ES	Max	8	6	18	24	18	3/19/2 1/29	1/2/11/ 12/22	4/9/22	4	13/20	21	26
	Min	10/18	1/9/10/ 15/18/ 24/25/ 29	3	29	7	15	21	30	26	15/29	20	17
2015													
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PT	Max	11/31	8	8	3/4/11	9	28	12	12	4	4/31	8	25
	Min	18/19/ 30	3/9	13	5	4	26	7	19	13	8/13	1/23	14
DE	Max	26	1	30	4	3,11	12	9,19	9	12	9	15	6
	Min	1/2/3/4 /5	9	29	29	9	1,5,30	2,4,20, 21	11	1,5,30	2,21	19	13
ES	Max	31	8	19	11	9/19	2/6/15/ 17	12/24/ 31	12	4	2/4/7	8	30
	Min	19	3/7/9/1 7/26	13/14	5/8/15	1	26	2/7	24	16	8/13/1 4	23/26	14

3.4.1. THE PORTUGUESE CASE

Despite the efforts to increase the share of renewable generation, the Portuguese wholesale energy market still relies on a significant participation of fossil generated loads (Table 3.10). Moreover, as a direct consequence of a more reduced generation portfolio, in Portugal the impact on non-renewable electricity generation on electricity prices tends to be more significant as a consequence of the country dependence of fuel prices such as coal, natural gas and fuel oil. Moreover, non-renewable power plants have inefficient energy production process with associated losses, which in Portugal are estimated to represent about 400 million Euros (Vasconcelos, 2019).

Table 3.10 – Energy per technology (%) - Portugal. Source: OMIE (2020), OMIE (2017), OMIE (2015)

	2019	2018	2017	2016	2015
Coal	9.4	19.7	24.1	20.6	26.7
Combined cycle	20.7	23.4	17.4	12.5	9.9
Import	12.5	5.0	5.1	3.2	8.5
Hydro Power	15.7	20.6	11.2	25.9	16.3
Wind	24.2	21.2	20.7	21.2	21.2
Solar photovoltaic	1.9	1.4	1.5	1.4	1.4
Special regime production	15.6	14.7	14.0	15.2	16.0

When analyzing the sum of energy *per* technology in Portugal during the analyzed time range, the years with lower renewable energy produced coincide with the years with higher energy produced by non-renewable energy sources. The years of 2016 and 2019 corresponded to the years with lower shares of non-renewable production, respectively, with 33.1% and 30.1%. In these years, there were the highest shares of renewable production from 2015 till 2019, respectively, with 48.5% and 41.8%. In Portugal, facilities under special regime are sold to a provider of last resort who incorporates the production in its demand bids as lower demand, and do not participate in the production market (MIBEL Regulatory Council, 2009).

On the opposite, for 2015 and 2017, the shares of non-renewable production were higher, corresponding to the years with higher potential to perform DR. Often, the years with the lowest renewable sources production, are more favorable in what regards to economic DR potential. This is in line with other studies conclusions that mention that high shares of hydro generation tend to decrease DR potential. In years with highest shares of non-renewable generation, particularly of coal generation, the DR potential tends to increase as well as the average spot price in day ahead market (Table 3.11).

Table 3.11 – Average Spot Price in day ahead market (€/MWh) – Portugal. Source: OMIE (2020), OMIE (2017), OMIE (2015)

	2020	2019	2018	2017	2016	2015
January	40.93	62.69	51.63	71.52	36.39	51.82
February	36.04	54.71	54.98	51.39	27.35	42.57
March	27.73	49.20	39.75	43.95	27.70	43.22
April	17.77	50.66	42.66	44.18	23.50	45.49
May	21.36	48.75	55.08	47.12	24.93	45.18
June	30.64	47.71	58.48	50.22	38.28	54.74
July	-	51.46	61.84	48.60	40.36	59.61
August	-	44.96	64.29	47.43	41.14	55.59
September	-	42.14	71.30	49.16	43.61	51.92
October	-	47.21	65.38	56.97	52.78	49.89
November	-	42.13	62.01	59.36	56.25	51.46
December	-	33.68	61.87	59.49	60.27	52.92
Year Average	29.08	47.87	57.45	52.48	39.44	50.43

From this analysis a paradox emerges: a significant part of the DR benefits is associated both to smoothing peak loads and to RES integration. However, apparently, when the production of renewable sources is higher and DR mechanisms could potentiate these loads integration, the economical potential is lower. Müller and Möst (2018) concludes that DR reduces

RES curtailment but it could not integrate large amount of RES surplus over a long period. DR availability and flexibility are considered limited, once applications depend on several different variables, such as the ambient temperature, time of day and/or technical restrictions commitment such as the load-shifting period. Yilmaz et al. (2019) found out that households with a load profile characterized by a relatively high peak at noon and a low peak in the evening, are those who receiving money incentives were more likely to shift electricity use towards the middle of the day (11am-3pm).

3.4.2. THE SPANISH CASE

In Spain, similar to Portugal, the data demonstrate a clear disinvestment in fossil technologies along the years, particularly in coal technology (Table 3.12). However, the differences between Portuguese and Spanish generation portfolio are significant. Spain has a more diversified energy portfolio, particularly in non-fossil technologies. Also, nuclear energy production represents a significant production share in Spain. Despite its lower emission level this type of technology cannot be consider as a renewable one. Moreover, its generation share reveals a constancy through the years considered in this study, meaning it was not a critical technology for DR potential. In Spain nuclear power plants and plants under special regime usually are present in the lower part of the curve, as their opportunity cost is very low (MIBEL Regulatory Council, 2009).

According to MIBEL Regulatory Council (2009): *“Adjustable hydroelectric power stations tend to appear in the upper part of the curve, since their opportunity cost is high depending on the price that they expect to receive at another time in the market or depending on replaced technology. To the contrary, run-of-river plants usually appear on the lower part of the curve, as they cannot store water for other times. The middle section of the supply curve includes combined cycle plants and coal plants organized based on their revenue and on the terms of their supply contracts. The highest end of the supply curve has fuel oil plants, which in Portugal have served to cover demand in extreme times of the year. This section of the supply curve also includes the part of hydraulic power with scant reserves.”*

According to Schwabeneder et al. (2019), in Spain, the price-setting power plants are mainly operated by natural gas. Moreover, Spain has a 26 GW of hydropower capacity and around 7

GW of nuclear energy for the base load. Spain generation assets by technology in the wholesale market, includes wind (20.2%), solar photovoltaic (3.4%), thermal solar (2.0%), nuclear (21.2%), thermal coal (4.1%) and fuel/gas power plants (19.3%), large hydro (7.4%) and cogeneration, waste and mini hydro (15.7%) (OMIE, 2020). Despite the generation assets in the wholesale market are the same, in 2019 thermal coal power plants participation in the total mix decreased about 9%. *Per* other side fuel/gas power plants participation in the total mix increased 9.6%.

Table 3.12 – Energy per technology (%) – Spain. Source: OMIE (2020), OMIE (2017), OMIE (2015)

	2019	2018	2017	2016	2015
Coal	4.1	13.1	15.9	13.0	19.1
Combined cycle	19.3	9.7	12.6	9.3	9.1
Import	6.7	8.0	8.4	7.6	4.4
Nuclear	21.2	19.9	20.5	21.0	20.8
Hydro Power	7.4	10.3	5.5	12.0	9.2
Wind	20.2	18.7	17.8	18.0	18.4
Solar photovoltaic	3.4	2.8	3.0	2.8	3.0
Thermal solar	2.0	1.8	2.1	2.0	2.1
Waste and mini hydro	15.7	15.8	14.2	14.3	13.9

In dry years there is an increase tendency in fossil fuels generation in order to attenuate the difference caused by hydro generation scarcity. In Spain the hydro generation does not have such a relevant impact as in Portugal that has higher shares of hydro participation in the market. For this reason, theoretically, the economic DR potential for Spain was expected to be higher than the economic DR potential for Portugal. However, the model results emerge the opposite conclusion. Despite the small differences between these two countries, Spain aggregated results demonstrate lower potential for DR. A possible reason for these results, is the aggregated share of non-fossil in the market. Despite Spain has lower hydro shares than Portugal, the total share of non-renewable in the market is superior than in Portugal, which tends to increase the potential for DR. Apparently, there is an inverse relationship between the economic potential for DR and the share of renewable energy.

Despite the technology generation share differs for Portugal and Spain, the aggregated DR potential is similar in both countries. The year with highest potential for DR in Portugal corresponds to the year highest potential for DR in Spain, and the year with lowest potential for DR in Portugal corresponds to the year lowest potential for DR in Spain.

In most of the time, both Portugal and Spain have a common market, whose results conduct to a same spot price both for Portugal and Spain (Table 3.13). For this reason, the average spot prices in Portugal and Spain are very similar. Despite the energy market price similarity there is a divergence in what regards the DR potential.

Table 3.13 – Average Spot Price in day ahead market (€/MWh) – Spain. Source: OMIE (2020), OMIE (2017), OMIE (2015)

	2020	2019	2018	2017	2016	2015
January	41.10	61.99	49.98	71.49	36.53	51.60
February	35.87	54.01	54.88	51.74	27.50	42.57
March	27.84	48.82	40.18	43.19	27.80	43.13
April	17.65	50.41	42.67	43.69	24.11	45.34
May	21.26	48.39	54.92	47.11	25.77	45.12
June	30.62	47.19	58.46	50.22	38.90	54.73
July	-	51.46	61.88	48.63	40.53	59.55
August	-	44.96	64.33	47.46	41.16	55.59
September	-	42.11	71.27	49.15	43.59	51.88
October	-	47.17	65.08	56.77	52.83	49.90
November	-	42.19	61.97	59.19	56.13	51.20
December	-	33.81	61.81	57.94	60.49	52.61
Year Average	29.06	47.68	57.27	52.24	39.67	50.32

Both countries tend to have similar climacteric conditions, and during dry years, without large shares of large hydro contribution, electricity generation resources based on fossil fuels tend to increase their share and as consequence both electricity prices and electricity generation emissions tend to increase. Despite the continuous investments in renewable sources, large hydro contribution is dependable on variable climatic conditions and will impact prices formation in wholesale energy markets.

3.4.3. THE GERMAN CASE

In the last years, German renewable energy generation portfolio has been gradually increasing (representing 46.9% in 2019), despite the largest percentage of electricity consumption is still generated from non-renewable sources (Table 3.14).

Table 3.14 – Energy per energy source (%) – Germany. Source: Fraunhofer (2020)

	2019	2018	2017	2016	2015
Brown Coal	19.6	24.0	24.3	24.5	25.3
Hard Coal	9.5	13.2	14.8	18.1	19.3
Gas	10.2	8.2	8.9	8.5	5.5
Uranium	13.7	13.2	13.1	14.6	15.8
Hydro Power	3.8	3.6	3.7	3.8	3.5
Biomass	8.7	8.2	8.1	8.2	8.1
Wind	24.4	20.4	19.1	14.5	14.7
Solar	9.0	8.4	7.2	7.0	7.1

According to Schwabeneder et al. (2019), Germany price-setting power plants are mainly lignite, hard coal, and occasionally, natural gas. Additionally, it has a high share of the variable RES wind and solar PV, and additionally, nearly 10 GW of nuclear capacity. Power plants using coal (brown and hard coal) represent the major contribution for the energy mix. Along the consecutive years this importance is being offset by the continuous integration and increase share of renewables generation, particularly of wind and solar energy. Comparing with 2017, in 2018, wind energy production was 5.4% higher, producing 111 TWh, and solar generation increased 16% compared to the previous year, producing 45.7 TWh. In 2018, the renewable energy sources produced approximately 219 TWh, representing 40.6% of the total energy mix (Fraunhofer Institute for Solar Energy Systems ISE, 2019).

The continuing integration of renewable energy associated to its generation specificities, such as intermittency and daily ramping increase and decrease, will increase energy market future challenges. In 2019, renewable energy corresponded to 46.5% of total electricity generation in Germany. Moreover, 22% of the energy mix supplied to EPEX spot largest market was from renewable sources and this percentage is expected to continue increasing till 35% by 2020 reaching 80% by 2050 (IRENA, 2015). Germany generation mix is quite diversified. In 2018, generation assets by energy source included wind (20.4%), solar (8.4%), brown coal or lignite (24%), hard coal (13.2%), nuclear (13.2%), oil and gas (8.2%), hydro (3.6%) and biomass (8.2%). The strongest source of energy is lignite, with a production of 131.3 TWh in 2018,

about less 2% than the previous year. Despite lignite-fired power plants are inflexible to the high share of feed-in from renewable generation, they reacted more flexibly to low exchange electricity prices and reduce their output to below 6 GW, mainly at low or negative exchange electricity prices.

The vast deployment of volatile RES in Germany through the subsidization of wind and solar technologies, turn wind generation the second strongest source of energy in 2018, which imply consequences for resource adequacy, namely, in conventional generation technologies, curtailing particularly in gas-fired plants (Liebensteiner and Wrienz, 2020). A net reduction of 9.1 TWh in electricity generation from gas-fired plants in 2018, associated to other fossil-fuels electricity generation reduction, in the long run, will result in missing dispatchable electricity generation and increase the missing money problem. This refers to the inability of competitive wholesale electricity markets to transmit correct energy prices, in order to promote new investments for a reliable performance of the electric service (Hogan, 2017).

The potential for DR profile in Germany, is very similar to the other analyzed countries. However, there is an exception in years 2017 and 2018, which is in line with the previously found for the Portuguese and Spanish energy market. Nevertheless, a larger economic potential for DR was expected thus the total share of non-renewable technologies is still considerable and superior to the non-renewable shares both in Portugal and Spain. The existence of negative prices may be a contributor for decreasing DR potential in this energy market. According to Nicolosi (2010), the occurrence of negative prices is not problematic, only if these are an indicator for a tight market situation, demonstrating flaws in the market design. Also, De Vos (2015) consider that negative prices are a correct signal representing the system's scarcity of downward flexibility, but also result from a market distortion caused by renewable support mechanisms.

Indeed, the more negatives are the prices the lower is the potential for DR. However, according to the model results it is possible to perform load-shifting during some negative hours. So negative prices are not an impeditive condition for performing load-shifting. Even so the lower are the prices the difficult is to perform the load-shifting. As a title of example, during the day 13th April 2020, in the day ahead market for the subsequent 24 hours period there were hours with positive spot prices, almost null prices, slightly negative spot prices and extremely

negative prices. While for the first three was possible to perform load-shifting, for the hours with extremely negative prices it was not possible to perform load-shifting for any hour.

When considering the total aggregated potential in 2019, both in Spain and Portugal there is a higher DR potential than the one observed in Germany. In a general way, DR potential has been decreasing along the years from 2015 till 2019. This was the year with lower economic potential for performing DR. Simultaneously, it was observed that this year has lower share of fossil and higher share of renewables. As expected, generation portfolio shares have impact on spot prices as it is possible to see in Figure 3.4 and 3.5. The first represent the relation between spot prices and the total load in 2015, while the second represent the same relation for 2020. While in 2015 the spot prices vs load values are very concentrated and there were few occurrences of negative prices, during 2020 the values are much more dispersed and there are more occurrences of extreme negative prices. The increasing penetration of renewables in the energy market is considered to be the reason for the increasing number of hours with negative prices (Paraschiv et al., 2014). *Per* other side, according to this study results the increasing number of hours with extreme negative prices tend to lower the potential to perform DR.

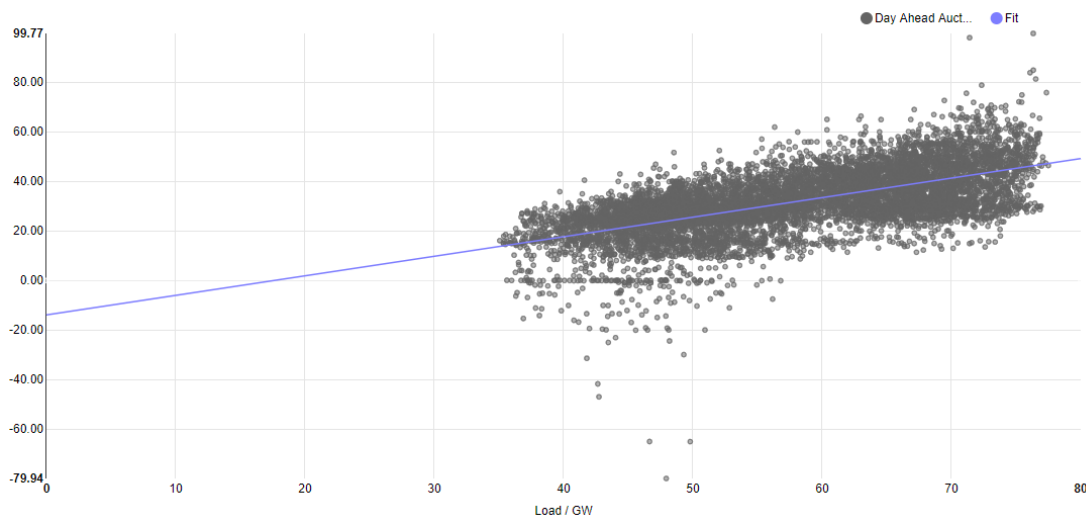


Figure 3.4 – Spot prices vs. load in Germany in 2015. Source: Fraunhofer (2020)

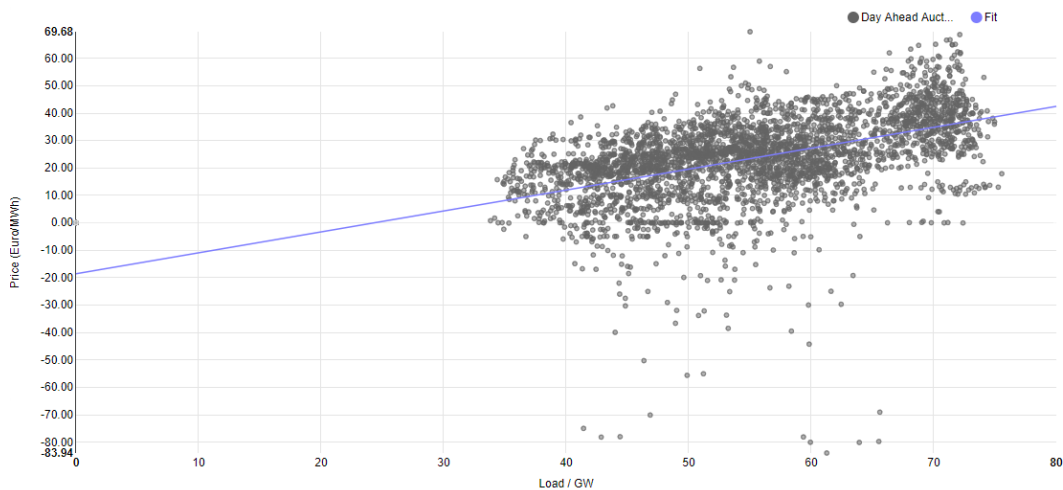


Figure 3.5 – Spot prices vs. load in Germany in 2020. Source: Fraunhofer (2020)

Smolen (2019) analyzed the impact of solar generation in Germany on average daily electricity price and demand patterns in the period of 2007–2017. During this period solar generation in Germany increased 6.3%. Results indicate that increasing solar electricity supply in Germany has completely changed the average daily price profile and there is a clear relationship between the amount of solar generation and daily peak price premiums over the average daily price. Smolen (2019) refers that solar generation in Germany is changing peak hour electricity price patterns: *“With increased solar generation, peak hour electricity price premiums are gradually decreasing while in 2007 and 2009, noon hours registered the highest prices of the day, the pattern has already changed if looking at the more recent periods. Chart shows that in 2015 and 2017, the midday electricity prices on the German market were already lower compared to morning and evening prices.”*

Table 3.15 – Average Spot Price in day ahead market (€/MWh) – Germany. Source: Fraunhofer (2020)

	2020	2019	2018	2017	2016	2015
January	35.37	47.08	27.90	50.53	28.77	27.93
February	21.57	41.87	39.73	38.44	21.53	36.66
March	21.70	28.70	36.17	31.39	23.83	30.63
April	15.94	35.21	31.35	27.41	24.07	29.04
May	17.21	37.38	32.61	29.69	21.46	25.32
June	26.15	31.84	42.09	29.31	27.79	30.16
July	-	39.73	49.24	32.63	26.80	34.53
August	-	36.27	55.89	30.22	26.92	31.54
September	-	35.00	53.85	34.00	30.35	31.47
October	-	36.67	52.11	26.44	36.88	39.78

November	-	40.93	56.62	39.19	37.36	31.71
December	-	30.91	46.13	28.46	34.95	27.23
Year						
Average	29.06	36.64	43.26	32.89	28.20	31.20

The results could also demonstrate an inverse proportional relation between load and DR potential. It was expected that markets with higher loads represented higher DR potentials, but again, research conclusions found the opposite relationship. As happens in Spain and Germany, energy markets with highest loads tend to have more diversified generation portfolios. This may originate higher level of competition between fossil and non-fossil generation technologies. According to the data and the results found, markets with largest shares of technologies with lower fix costs and lower marginal costs, demonstrate lower capacity for DR potential.

Other possible explanation may be associated with internal concurrency market conditions. The characteristics of each market and its design properties may overlap load profile and generation portfolios. Markets with lower concurrency levels may influence negatively the DR potential.

3.5. CONCLUSIONS

Due to EU environmental regulations and economy decarbonization targets, there is an increasing participation of RES – I in the energy market share. This participation will increase prices volatility due to RES – I stochastics nature (Nicolosi and Fürsch, 2009).

DR implementation would allow to smooth spikes and extreme fluctuations on spot prices, increasing market operation efficiency and energy-trader's confidence regardless the market design. Moreover, during contingencies DR may act as a reserve capacity, offering load reductions to solve short-term constraints in the system representing a possible planning resource. Söder et al. (2018), refer that Demand side flexibility offers an interesting approach to the balancing issues.

Usually, the installed capacity is planned according to peak demand. This creates a much higher system reserve margin during off-peak periods, when the demand is lower than in peak periods

when the system reserve has no margin. DR may help to increase reliability of the energy system, absorbing some shock on generation mix and proving flexibility during system tightness periods. Moreover, an increasing penetration of load shifting suffers from the same economic self-cannibalism as energy storage. Also, Fernandez et al. (2020) refer the effects of load-shifting on the market are qualitatively similar to that of renewables, describing a merit-order effect of load-shifting. Nevertheless, if the full integration of DR in day ahead markets may not be totally accomplished, flexibility integration may be used in other time scales such as intraday markets, real-time markets or balancing markets. Goutte and Vassilopoulos (2019) argue that intra-day markets might provide more economic benefit for load shifting than day-ahead markets.

According to the literature, apparently, energy markets dominated by non-controllable energy sources, such as RES with high fixed costs and marginal costs that tend for zero, have a lower tendency for DR potentials. This is the case of energy markets dominated by hydropower facilities, such as the case of Portugal.

If on one hand, the continuous integration of RES in the energy markets supply tends to decrease the clearing market prices, on the other hand, tends to increase the uncertainty and the risk. DR will continue to represent an added value for future energy markets deployment thus it introduces flexibility and might transmit confidence signals to markets agents. This flexibility might be particularly useful during system instability periods. System instability and excessive fluctuations may cause several disturbances, such as capacity constraints, outages, transmission bottlenecks, peak demands and the potential for market power exercise. Energy market structures where market power was identified, such as in MIBEL, may suffer from higher day-ahead prices volatility. The seasonal spikes in MIBEL spot prices might be associated with the exercise of market power during certain periods, with a relevant hydropower generation contribution on energy market, or with both.

Notwithstanding, spot prices formation cannot be dissociated from other variables such as seasonality, demand consumptions or with the generation portfolio composition of supply in the day-ahead market. This emerges a “*chicken-and-egg*” problem category.

The electricity system tightness, is relevant to neighboring countries energy importation and exportations. Within the implementation of a single European energy market, this variable will

assume a future larger importance. Constraints caused by system tightness, might be overcome if DR consumers are called to curtail or shift their load consumption in an emergency period. Today there are still major barriers in what this matter concerns, both regarding the establishment of a harmonized regulation for DR and for a single European energy market. In future, DR mechanisms integration on markets might be a support risk control tool.

Despite the necessary regulatory framework development, DR implementation need to be viable both from the technical and economic point of view. This is a complex issue, due to the large number of variables involved both on technical and economic DR perspective. In order to achieve viability, every parties involved should recognize DR value and be rewarded for their flexibility and efforts.

Present energy markets mechanisms are distorted and a transition to new a new energy market is argued. The existing energy market design was based on thermal technologies flexibility offer. With the increasing RES-I base load, power plants may provide electricity at negative prices in times of overload supply. Peak load power plants with high variable costs are not able to compete in an overcrowded market. In competitive markets, the existing marginalist system does not guarantee an efficient remuneration, affecting the competitiveness of the economy. As consequence, depreciated power plants may be overpaid, and there is no margin for an appropriate remuneration for the renewable energy sector, which guarantees greater energy independence but is still not enough to guarantee supply security. Capacity markets are seen as possible solution to finance new generation capacity avoiding price peaks.

Flexibility is seen as a possibility to maintain system reliability and simultaneously the balance between supply and demand. VRE introduced a paradox in the market. *Per* one side VRE reduce the flexibility resources in the energy market by displacing traditional supply side providers, but *per* other side its stochastic nature increases the need for flexibility. This gap may be overcome with new solutions both from supply and demand side (Figure 3.6).

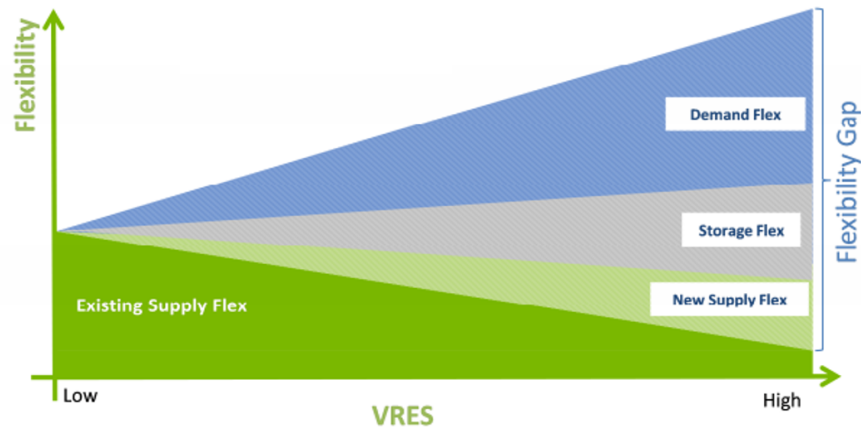


Figure 3.6 – Flexibility gap in European electricity systems with increasing RES-I. Source: Papaefthymiou et al. (2014)

Results demonstrate that the variables found in the literature such as seasonality and characteristics of generation, influence the potential for DR in MIBEL and EEX. In the future, changes on supply in the day-ahead market caused by generation technology and seasonality will remain on time. It is expected that peak load periods during specific hours or during some specific months or times of the year with extreme temperatures, high demand solicitations may occur. Seasonality associated to demand or to climatic conditions also modify the composition of supply in the day-ahead market by generation technology, with impact both on market clearance prices and risk. Energy markets thus need to adapt to this reality in order to accommodate to these characteristics.

According to the performed literature survey, DR increases their potential to decrease market clearing prices in energy markets dominated by fossil fuels technologies. The inability to stop traditional thermal generators from reducing outputs may preserve these generation technologies in the supply composition of the EEX day-ahead market. Moreover, the increasing participation of non-fossil technologies along the years, is associated with the increasing number of hours with extreme negative prices. This supply excess may set at negative prices the market clearing price and remain generation mix inflexibility with start-up costs that prevent traditional thermal generators from reducing outputs besides prices go below their marginal costs. According to this study such market design characteristics, have implications for DR

future implementation thus negative prices tend to reduce DR mechanism potential. The variables with both positive and negative DR potential impact are summarized in Figure 3.7.

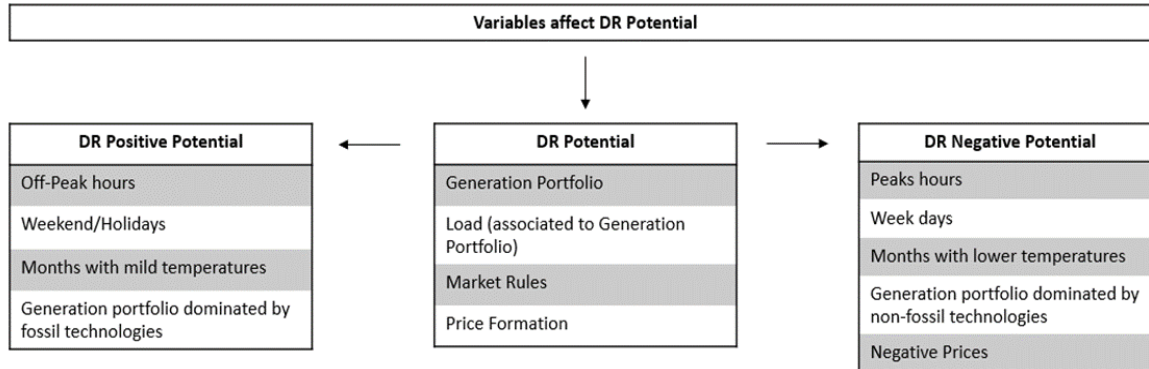


Figure 3.7 – Variables with DR potential impact. Source: From the author

This study results may have implications to aggregators, considering the regulation framework in each of the three energy markets analyzed countries. In contrast to the Portuguese and Spanish market, in the German market aggregators' participation is already partially allowed. Despite the reduced positive potential to perform load-shifting, particularly at negative prices periods, there is a significant number of hours in which it is viable to perform DR in Germany. It is possible for aggregators to participate both in day-ahead as well as in intra-day in the German energy market. DR flexibility mechanisms are already used in this market but with the increasing shares of renewable loads, DR can be seen as product in capacity markets.

In Portugal and Spain, DR is dependent of the creation of the necessary framework for enabling DR technology. The concept of aggregator is still not foreseen in the Spanish regulation, and in Portugal Demand Response participation is only eligible for large industrial consumers (SEDC, 2017). Both in Spain and Portugal aggregated DR does not have access to the day-ahead market, intra-day market, balancing market, neither to ancillary services. Only in tertiary control market, DR resources are considered.

Despite this study's finding shows that the potential for load flexibility in day-ahead wholesale market tends to be more positive in MIBEL, it is one of the few energy markets in Europe that

still does not consider aggregators fully participation and still does not have a proper framework set for these to fully participate on energy markets.

3.6. REFERENCES

- Aalami, H. A., Moghaddam, M. P., & Yousefi, G. R., 2010. Demand response modeling considering interruptible/curtailable loads and capacity market programs. *Applied Energy*, 87(1), 243-250. <https://doi.org/10.1016/j.apenergy.2009.05.041>
- Aghaei, J., & Alizadeh, M. I., 2013. Demand response in smart electricity grids equipped with renewable energy sources: A review. *Renewable and Sustainable Energy Reviews*, 18, 64-72. <https://doi.org/10.1016/j.rser.2012.09.019>
- Ahmadihangar R., Rosin A., Palu I., Azizi A., 2020. On the Concept of Flexibility in Electrical Power Systems: Signs of Inflexibility. In: *Demand-side Flexibility in Smart Grid*. SpringerBriefs in Applied Sciences and Technology. Springer, Singapore
- Anjo, J., Neves, D., Silva, C., Shivakumar, A., & Howells, M., 2018. Modeling the long-term impact of demand response in energy planning: The Portuguese electric system case study. *Energy*, 165, 456-468. <https://doi.org/10.1016/j.energy.2018.09.091>
- Arteconi, A., Patteeuw, D., Bruninx, K., Delarue, E., D'haeseleer, W., & Helsen, L., 2016. Active demand response with electric heating systems: Impact of market penetration. *Applied energy*, 177, 636-648. <https://doi.org/10.1016/j.apenergy.2016.05.146>
- Bergaentzle, C., Clastres, C., & Khalfallah, H., 2014. Demand-side management and European environmental and energy goals: An optimal complementary approach. *Energy Policy*, 67, 858-869. <https://doi.org/10.1016/j.enpol.2013.12.008>
- Bossmann, T., & Eser, E. J., 2016. Model-based assessment of demand-response measures—A comprehensive literature review. *Renewable and Sustainable Energy Reviews*, 57, 1637-1656. <https://doi.org/10.1016/j.rser.2015.12.031>

Conchado, A., & Linares, P., 2012. The economic impact of demand-response programs on power systems. A survey of the state of the art. In *Handbook of networks in power systems I* (pp. 281-301). Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-23193-3_11

Conchado, A., Linares, P., Lago, O., & Santamaría, A., 2016. An estimation of the economic and environmental benefits of a demand-response electricity program for Spain. *Sustainable Production and Consumption*, 8, 108-119. <https://doi.org/10.1016/j.spc.2016.09.004>

Crampes, C., & Léautier, T. O., 2015. Demand response in adjustment markets for electricity. *Journal of Regulatory Economics*, 48(2), 169-193. <https://doi.org/10.1007/s11149-015-9284-0>

Cruz, M. R., Fitiwi, D. Z., Santos, S. F., & Catalão, J. P., 2018. A comprehensive survey of flexibility options for supporting the low-carbon energy future. *Renewable and Sustainable Energy Reviews*, 97, 338-353. <https://doi.org/10.1016/j.rser.2018.08.028>

De Ridder, F., Hommelberg, M., & Peeters, E., 2009, May. Four potential business cases for demand side integration. In *2009 6th International Conference on the European Energy Market* (pp. 1-6). IEEE. <https://doi.org/10.1109/EEM.2009.5207197>

De Vos, K., 2015. Negative wholesale electricity prices in the German, French and Belgian day-ahead, intra-day and real-time markets. *The Electricity Journal*, 28(4), 36-50. <https://doi.org/10.1016/j.tej.2015.04.001>

Deane, P., Collins, S., Gallachóir, B. Ó., Eid, C., Hartel, R., Keles, D., & Fichtner, W., 2015. Quantifying the "merit-order" effect in European electricity markets. <https://doi.org/10.5445/IR/1000065976>

Dranka, G. G., & Ferreira, P., 2019. Review and assessment of the different categories of demand response potentials. *Energy*, 179, 280-294. <https://doi.org/10.1016/j.energy.2019.05.009>

Duan, Q., Liu, J., Zeng, K., Zhong, J., & Guo, Y., 2019. Integrated scheduling of generation and demand shifting in day-ahead electricity market. *International Transactions on Electrical Energy Systems*, 29(7), e2843. <https://doi.org/10.1002/2050-7038.2843>

ENTSO-E, 2020. ENTSO-E Transparency Platform; Jan 2020. Retrieved from: <https://transparency.entsoe.eu/transmission-domain/r2/dayAheadPrices/show> (accessed 2nd January 2020).

Fernandez, J. M. R., Payan, M. B., & Santos, J. M. R., 2020. The Merit-Order Effect of Load-Shifting: An Estimate for the Spanish Market. *Environmental and Climate Technologies*, 24(1), 43-57. <https://doi.org/10.2478/rtuct-2020-0003>

Feuerriegel, S., & Neumann, D., 2016. Integration scenarios of Demand Response into electricity markets: Load shifting, financial savings and policy implications. *Energy Policy*, 96, 231-240. <https://doi.org/10.1016/j.enpol.2016.05.050>

Fraunhofer Institute for Solar Energy Systems ISE, 2019. Net Public Electricity Generation in Germany in 2018. Retrieved from: https://www.ise.fraunhofer.de/content/dam/ise/en/documents/News/Stromerzeugung_2018_2_en.pdf (accessed 2nd January 2020).

Fraunhofer, 2020. Retrieved from: https://www.energy-charts.de/energy_pie.htm (accessed 2nd June 2020).

García, A., García-Álvarez, M. T., & Moreno, B., 2017. Transición en el Sector Eléctrico Ibérico: hacia un mercado más sostenible y liberalizado. Retrieved from: https://sites.tufts.edu/gdae/files/2019/10/17-01Garcia_ElectricidadSostenibleLiberalizada_SP.pdf (accessed 2nd January 2020).

Gil-Alana, L. A., Martin-Valmayor, M., & Wanke, P., 2020. The relationship between energy consumption and prices. Evidence from futures and spot markets in Spain and Portugal. *Energy Strategy Reviews*, 31, 100522. <https://doi.org/10.1016/j.esr.2020.100522>

Gils, H. C., 2014. Assessment of the theoretical demand response potential in Europe. *Energy*, 67, 1-18. <https://doi.org/10.1016/j.energy.2014.02.019>

Goutte, S., & Vassilopoulos, P., 2019. The value of flexibility in power markets. *Energy policy*, 125, 347-357. <https://doi.org/10.1016/j.enpol.2018.10.024>

Hajati, M., Seifi, H., & Sheikh-El-Eslami, M. K., 2011. Optimal retailer bidding in a DA market—a new method considering risk and demand elasticity. *Energy*, 36(2), 1332-1339. <https://doi.org/10.1016/j.energy.2010.11.006>

Hogan, M., 2017. Follow the missing money: Ensuring reliability at least cost to consumers in the transition to a low-carbon power system. *The Electricity Journal*, 30(1), 55-61. <https://doi.org/10.1016/j.tej.2016.12.006>

IRENA, 2015. Renewable Energy Prospects: Germany, REmap 2030 analysis. International Renewable Energy Agency (IRENA), Abu Dhabi, www.irena.org/remap. Retrieved from: https://greenenergy.report/Resources/Whitepapers/ab28e890-56b2-4a83-88ae-4ac348036371_IRENA_REmap_Germany_summary_2015_EN.PDF (accessed 2nd January 2020).

Joskow, P. L., 2019. Challenges for wholesale electricity markets with intermittent renewable generation at scale: the US experience. *Oxford Review of Economic Policy*, 35(2), 291-331 <https://doi.org/10.1093/oxrep/grz001>

Katz, J., Andersen, F. M., & Morthorst, P. E., 2015. Load shift incentives for household demand response: A model to evaluate effects from a Danish field experiment. In 10th Conference on Sustainable Development of Energy, Water and Environment Systems. Retrieved from: <https://core.ac.uk/download/pdf/43252248.pdf> (accessed 27th May 2020).

Kirschen, D. S., Strbac, G., Cumperayot, P., & de Paiva Mendes, D., 2000. Factoring the elasticity of demand in electricity prices. *IEEE Transactions on Power Systems*, 15(2), 612-617. <https://doi.org/10.1109/59.867149>

Kwon, P. S., & Østergaard, P., 2014. Assessment and evaluation of flexible demand in a Danish future energy scenario. *Applied Energy*, 134, 309-320. <https://doi.org/10.1016/j.apenergy.2014.08.044>

Lagarto, J., Sousa, J. A., Martins, Á., & Ferrão, P., 2014. Market power analysis in the Iberian electricity market using a conjectural variations model. *Energy*, 76, 292-305 <https://doi.org/10.1016/j.energy.2014.08.014>

- Liebensteiner, M., & Wrienz, M., 2020. Do intermittent renewables threaten the electricity supply security?. *Energy Economics*, 87, 104499. <https://doi.org/10.1016/j.eneco.2019.104499>
- Märkle-Huß, J., Feuerriegel, S., & Neumann, D., 2018. Large-scale demand response and its implications for spot prices, load and policies: Insights from the German-Austrian electricity market. *Applied Energy*, 210, 1290-1298. <https://doi.org/10.1016/j.apenergy.2017.08.039>
- Marques, V., Soares, I., & Fortunato, A., 2008, May. Measuring market power in the wholesale electricity Iberian market through the residual demand curve elasticity. In 2008 5th International Conference on the European Electricity Market (pp. 1-7). IEEE. <https://doi.org/10.1109/EEM.2008.4579034>
- Merrick, J., Ye, Y., & Entriken, R., 2017. Assessing the system value of optimal load shifting. *IEEE Transactions on Smart Grid*, 9(6), 5943-5952. <https://doi.org/10.1109/TSG.2017.2699921>
- Metz, B., Davidson, O., Bosch, P., Dave, R., & Meyer, L., 2007. *Climate change 2007: Mitigation of climate change*. Cambridge Univ. Press.
- MIBEL Regulatory Council, 2009. Description of the operation of the mibel. Retrieved March, 19, 2014. Retrieved from: https://www.mibel.com/wp-content/uploads/2018/08/Estudio_MIBEL_EN_v2.pdf (accessed 2nd January 2020).
- Müller, T., & Möst, D., 2018. Demand response potential: available when needed?. *Energy Policy*, 115, 181-198. <https://doi.org/10.1016/j.enpol.2017.12.025>
- Nicolosi, M., & Fürsch, M., 2009. The impact of an increasing share of RES-E on the conventional power market—the example of Germany. *Zeitschrift für Energiewirtschaft*, 33(3), 246-254. <https://doi.org/10.1007/s12398-009-0030-0>
- Nicolosi, M., 2010. Wind power integration and power system flexibility—An empirical analysis of extreme events in Germany under the new negative price regime. *Energy policy*, 38(11), 7257-7268. <https://doi.org/10.1016/j.enpol.2010.08.002>

OMIE, 2015. Informe de Precios 2015. Retrieved from: https://www.omie.es/sites/default/files/2020-02/omie_informe_precios_2015_espanol_0.pdf (accessed 27th May 2020).

OMIE, 2017. Informe de Precios 2017. Retrieved from: https://www.omie.es/sites/default/files/2020-02/informe_precios_omie_2017.pdf (accessed 27th May 2020).

OMIE, 2020. Informe Annual 2019. Retrieved from: https://www.omie.es/sites/default/files/2020-02/informe_anual_2019_es.pdf (accessed 27th May 2020).

Papaefthymiou, G., Grave, K., & Dragoon, K., 2014. Retrieved from: Flexibility options in electricity systems. Project number: POWDE14426, Ecofys. <https://www.ourenergypolicy.org/wp-content/uploads/2014/06/Ecofys.pdf> (accessed 2nd January 2020).

Paraschiv, F., Erni, D., & Pietsch, R., 2014. The impact of renewable energies on EEX day-ahead electricity prices. Energy Policy, 73, 196-210. <https://doi.org/10.1016/j.enpol.2014.05.004>

Parvania, M., Fotuhi-Firuzabad, M., & Shahidehpour, M., 2012, July. Demand response participation in wholesale energy markets. In 2012 IEEE Power and Energy Society General Meeting (pp. 1-4). IEEE. <https://doi.org/10.1109/PESGM.2012.6344591>

Peng, D., & Poudineh, R., 2017. Electricity market design for a decarbonised future: An integrated approach. <https://doi.org/10.26889/9781784670948>

Schwabeneder, D., Fleischhacker, A., Lettner, G., & Auer, H., 2019. Assessing the impact of load-shifting restrictions on profitability of load flexibilities. Applied Energy, 255, 113860. <https://doi.org/10.1016/j.apenergy.2019.113860>

SEDC, 2017. Explicit demand response in europe-mapping the markets 2017. SEDC: Brussels, Belgium. Retrieved from: <https://www.smart.eu/wp-content/uploads/2017/04/SEDC->

[Explicit-Demand-Response-in-Europe-Mapping-the-Markets-2017.pdf](#) (accessed 2nd January 2020).

Sezgen, O., Goldman, C. A., & Krishnarao, P., 2007. Option value of electricity demand response. *Energy*, 32(2), 108-119. <https://doi.org/10.1016/j.energy.2006.03.024>

Smolen, J., 2019. Electricity price and demand pattern changes due to increases in solar generation in German electricity markets. <http://hdl.handle.net/11159/2717>

Söder, L., Lund, P. D., Koduvere, H., Bolkesjø, T. F., Rossebø, G. H., Rosenlund-Soysal, E., ... & Blumberga, D., 2018. A review of demand side flexibility potential in Northern Europe. *Renewable and Sustainable Energy Reviews*, 91, 654-664. <https://doi.org/10.1016/j.rser.2018.03.104>

Spees, K., & Lave, L., 2008. Impacts of responsive load in PJM: Load shifting and real time pricing. *The Energy Journal*, 29(2). <https://doi.org/10.5547/ISSN0195-6574-EJ-Vol29-No2-6>

Steriotis, K., Tsaousoglou, G., Efthymiopoulos, N., Makris, P., & Varvarigos, E. M., 2018. A novel behavioral real time pricing scheme for the active energy consumers' participation in emerging flexibility markets. *Sustainable Energy, Grids and Networks*, 16, 14-27. <https://doi.org/10.1016/j.segan.2018.05.002>

Stötzer, M., Hauer, I., Richter, M., & Styczynski, Z. A., 2015. Potential of demand side integration to maximize use of renewable energy sources in Germany. *Applied Energy*, 146, 344-352. <https://doi.org/10.1016/j.apenergy.2015.02.015>

Su, C. L., & Kirschen, D., 2009. Quantifying the effect of demand response on electricity markets. *IEEE Transactions on Power Systems*, 24(3), 1199-1207. <https://doi.org/10.1109/TPWRS.2009.2023259>

Torriti, J., Hassan, M. G., & Leach, M., 2010. Demand response experience in Europe: Policies, programmes and implementation. *Energy*, 35(4), 1575-1583. <https://doi.org/10.1016/j.energy.2009.05.021>

Vallés, M., Reneses, J., Frías, P., & Mateo, C., 2016. Economic benefits of integrating active demand in distribution network planning: a Spanish case study. *Electric Power Systems Research*, 136, 331-340. <https://doi.org/10.1016/j.epsr.2016.03.017>

Vasconcelos, J., 2019. *A Energia em Portugal*. Fundação Francisco Manuel dos Santos. Lisboa. p. 55

Vlot, M. C., Knigge, J. D., & Slootweg, J. G., 2013. Economical regulation power through load shifting with smart energy appliances. *IEEE transactions on smart grid*, 4(3), 1705-1712. <https://doi.org/10.1109/TSG.2013.2257889>

Wang, Q., Zhang, C., Ding, Y., Xydis, G., Wang, J., & Østergaard, J., 2015. Review of real-time electricity markets for integrating distributed energy resources and demand response. *Applied Energy*, 138, 695-706. <https://doi.org/10.1016/j.apenergy.2014.10.048>

Yilmaz, S., Weber, S., & Patel, M. K., 2019. Who is sensitive to DSM? Understanding the determinants of the shape of electricity load curves and demand shifting: Socio-demographic characteristics, appliance use and attitudes. *Energy Policy*, 133, 110909. <https://doi.org/10.1016/j.enpol.2019.110909>

Yu, D., Xu, X., Dong, M., Nojavan, S., Jernsittiparsert, K., Abdollahi, A., ... & Pashaei-Didani, H., 2020. Modeling and prioritizing dynamic demand response programs in the electricity markets. *Sustainable Cities and Society*, 53, 101921. <https://doi.org/10.1016/j.scs.2019.101921>

Zarnikau, J., & Hallett, I., 2008. Aggregate industrial energy consumer response to wholesale prices in the restructured Texas electricity market. *Energy Economics*, 30(4), 1798-1808. <https://doi.org/10.1016/j.eneco.2007.11.003>

4

CO₂ EMISSION IMPACT ASSESSMENT FOR THE DEMAND RESPONSE POTENTIAL

4.1. INTRODUCTION

Over the past five thousand years, humanity had to adapt and take opportunity of an inhospitable natural environment to assure its well-being. During the mid-19th century, the Industrial Revolution introduced an accelerated economic growth and the increasing use of fossil fuels that continued during the 20th and the first two decades of the 21st century. These factors, together with massive population growth, made humanity itself to become a central and the most influencing factor of depleting global ecological systems, increasingly approaching environmental critical thresholds or “*tipping points*” (Schneidewind et al., 2013). Currently, human activities in the environment correspond to an open cycle that starts from an initial environmental balance and ends with a condition of environmental imbalance, thus consumed resources are not able to be reproduced (Orecchini and Naso, 2011). Anthropogenic emissions – emissions caused by human activities – have been increasing over the years due to human activities that produce greenhouse gases. This increase is mainly associated with CO₂ emissions which is the largest source of emissions, but there are other gases that contribute to the greenhouse effect such as Methane (CH₄), Nitrous oxide (N₂O), Hydrofluorocarbons (HFC), Perfluorocarbons (PFC), Sulfur hexafluoride (SF₆) and Nitrogen trifluoride (NF₃).

Indeed, the energy sector is the largest contributor for CO₂ emissions, thus energy use is a key issue for climate change and sustainable development. With the increasing share of RES-I generation and with processes efficiency increasing along the years, the energy sector has been reducing significantly the associated GHG emissions. Table 4.1 demonstrates the general

decrease associated to energy industries from 2015 to 2018 for both the Iberian countries and Germany.

Table 4.1 – GHG emissions from Energy Industries. Source: PORDATA, 2020

	DE	ES	PT
2015	335 719	86 412	18 396
2016	332 573	71 034	17 396
2017	311 543	81 291	20 806
2018	295 192	72 236	17 869

Greenhouse gases increased about 25% worldwide during the first decade of the 21th century as a consequence of continuing gases emissions (Vasconcelos, 2019). One of the most commonly accepted definition for “*sustainable development*” has been formulated by the Brundtland Commission: “*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*” (United Nations, 1987). Usually, “*sustainable development*” concept is divided into three major components: economic, environmental and social sustainability.

Economic sustainability concept highlights the sustainability of the economic benefit from natural assets, which should be preserved so that it can be shared by future generations. The possibility of a substitution between man-made assets and natural assets creates, respectively, weak or strong economic sustainability concepts. The first approach just reinvests the revenues from selling natural resources in man-made capital, while the second is based on the premise that natural and man-made capital offer only limited substitution possibilities and thus require the preservation of natural resources. Strong sustainability permits the use of fossil resources if the value of the remaining resources does not decrease (Schrattenholzer et al., 2004).

Environmental sustainability requires the preservation of the ecological function of the environment, while the most prominent indicator of social sustainability is social equity, but other indicators such as cultural assets, nuisance, traffic flow or others may also be considered (Schrattenholzer et al., 2004).

Along humanity path there were several major energy transitions. Sustainability-related transition processes, such as the “*Energy Transition*”, are changes of socio-technical systems, which include technological, social, institutional and economic dimensions, as their

interrelations, thus technologies and infrastructures are influenced by economic structures (i.e. by the availability of capital), which in turn are influenced by institutional framework conditions. These reflect norms and values shared by a society (Schneidewind et al., 2013).

In the past, economic revolutions were associated with major changes in the mode energy can be controlled. Energy transitions are associated to technologic advances and shifts from a major form of energy to another. From animal power and biomass to burning coal during the 18th century first industrial revolution - from 1760 to around 1820 or 1840 - to the increasing use of oil and gas, nowadays the world is still on a major energy transition shift from fossil fuels to non-fossil primary fuels, therefore technological change and their evolution scenarios are frequently discussed. In addition, environmental literacy requests a holistic approach with the combination of interdisciplinary competences such as: natural science, economic, institutional, and cultural analyses thus these are interlinked (Schneidewind et al., 2013). Many countries have adopted policies to reduce GHG emissions and most of them are “*command-and-control*” measures. The EU declared its intention to reduce GHG emissions in order to accomplish the Paris Agreement targets. As a consequence of European policies, most member states implemented and deployed RES technologies essentially in the form of wind and solar power, and its implementation is expected to continue. In Germany, RES is expected to represent 30% by 2030 and to 60% by 2050 in total energy production, reducing emissions by 80%–95% by the year 2050 relative to 1990, according to its Climate Action Plan 2050 (Gugler et al., 2019). Werner et al. (2013) state that it would be technically achievable to get GHG-neutral Germany with annual per-capita emissions of 1 tonne of CO₂eq in 2050, which is equivalent to a 95% reduction of emissions levels when compared to 1990.

The accelerated shift efforts towards a rapidly decarbonization of electricity supply, through renewable and carbon capture technologies development in order to compensate the sharp decline of coal-fired power generation has major importance in order to reduce CO₂ emissions by three-quarters by 2040 and make the transition to a low-carbon energy sector (IEA, 2019). Nonetheless, there is still a contradiction between the scientific evidence highlighting the need for global greenhouse gas emissions extreme reductions and the continuous undesired records reached by continuous increasing greenhouse gas emissions. Despite the global conscience and awareness for the need of a renewables-driven energy transition, most of energy systems worldwide are still dominated by fossil fuels. In 2015, about 195 countries signed the Paris

Agreement in order to limit the global temperature rise to well below 2 degrees Celsius by 2100 (Euroelectric, 2020). The concerns about greenhouse gas emissions are a long concern problem, thus in 1997 industrial countries listed in Annex I of the UN framework signed the Kyoto Protocol and agreed to reduce their greenhouse gas emissions by 5.2 per cent by 2012 compared to the reference year 1990 (Quaschnig, 2016).

Despite the efforts done so far, the concentration of CO₂ has been rising as well as the average temperature of the planet, representing about 0.74 degrees Celsius rise over the past century (Abdallah and El-Shennawy, 2013). The rising sea levels, higher frequency of forestry fires and extreme climatic phenomena, are among the consequences of exceeding the temperature bound. According to the IPCC: “(...) *further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems. (...)*” are the effects of continued greenhouse gases emission (IPCC, 2014). Despite of the enumerated dangers associated to climate change and the existing scientific evidence, the efforts to limit carbon emissions nowadays remains insufficient and it is expected that CO₂ emissions need to reduce at least 80% by 2050 (European Climate Foundation, 2010).

Also, over the past two centuries, mankind has increased the concentration of CO₂ in the atmosphere from 280 to more than 380 parts per million by volume, and it is continuously growing faster (Abdallah and El-Shennawy, 2013). According to the Fifth Assessment Report from the Intergovernmental Panel on Climate Change there is a clear influence of human activity on the climate system (IPCC, 2014). Among these activities, the production of energy represents the largest source of greenhouse gases. According to Abdallah and El-Shennawy (2013) about 40% of global CO₂ emissions are associated to electricity generation. Electricity sector is the major source of the total global CO₂ emissions, followed by transportation, industry and other sectors, as shown in Figure 4.1. The combustion of fossil fuels, such as oil and gas to produce heat is a necessary condition for power steam turbines to work, however, burning generates entropy, and thus, is an inefficient process.

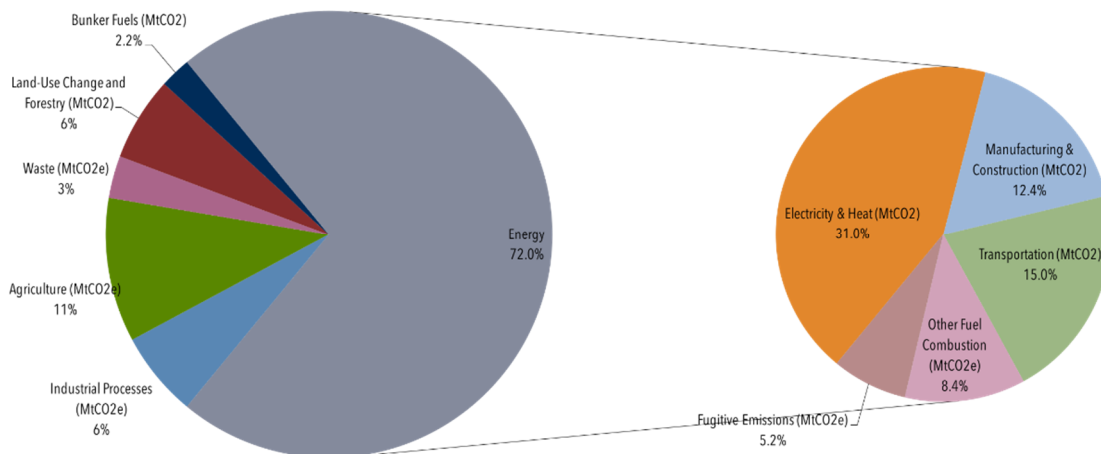


Figure 4.1 – CO₂ emissions per economic sector. Source: C2ES, 2020

Despite the fact that, in the last centuries, CO₂ concentration in the atmosphere has increased substantially, it is expected that in the future, electricity will play an even larger role, reaching 31% of final energy consumption (IEA, 2019). Different reasons may help to explain this continuing increasing in electricity consumption. While in advanced economies, the increasing digitalization and electrification mainly associated to electric vehicles will increase electricity consumption, in developing economies, is the continuing expansion of industrial and services sector that will increase electricity consumption and demand. According to projections, developing economies will contribute nearly to 90% of global electricity demand growth to 2040, despite the demand per person in these economies remains 60% lower than in advanced economies (IEA, 2019).

The growing relevance of electricity in the near future, due to the increasing share of electricity in final consumption in most of the economic sectors makes it imperative to decarbonize the electricity sector and per direct consequence the economy. Projections indicate that the leading drivers of global electricity demand growth are motors in industry (over 30% of the total growth to 2040), space cooling (17%), and large appliances, small appliances and electric vehicles (10% each) (IEA, 2019). Despite almost a significant part of developing countries population still do not have access to electricity, providing electricity access for the first time to 530 million people would only represent 2% of electricity demand growth (IEA, 2019).

With the increasing of energy consumption projections, both on advanced and developing countries, if fossil fuels are not phased out, and if there is a continuing consumption of fossil resources, this will originate higher level emission of greenhouse gases but also to a continuing path towards extreme climate phenomena. Decarbonization of the power industry represent an opportunity for achieving not only global climate mitigation and environmental issues but also for achieving a larger spectrum of opportunities in other areas such as social and economic.

According to Anderson and Bernauer (2016) the choice of reducing GHG at the source, or whether to do it domestically and internationally, will represent an important climate change mitigation policy-design choice. This is indeed a source control problem (Figure 4.2): if the primary energy fuels used into the energy conversion process are non-emitting, the continuous electricity consumption may be fulfilled without environmental negative impacts. The alternative path for reducing the greenhouse gases is to reduce substantially the levels of the energy consumption and production. Zhang et al. (2011) considers reduction in energy demand, expansion in nuclear power and the increase in renewable energy production the three different ways for achieving CO₂ emission reductions and potential zero-carbon energy in the future for Japan. The reduction in energy demand should be primarily achieved through energy intensive reduction caused by a general and massive increase on efficiency roll out by the most efficient technologies across all economic sectors. In a simulation study about changes in load profiles when energy efficiency measures were applied, Yilmaz et al. (2020) conclusions reveal that evening peak will reduce in 2035 thanks to improvement of the efficiency of the building stock. Despite there is a substantial work still to be done in what concerns energy efficiency measures, to achieve its full implementation in all the economic sectors, time will be needed thus the worldwide reality is diverse and complex. Decarbonization of the power industry would accelerate the pathway towards the reduction of GHG at the source in order to achieve global climate mitigation.

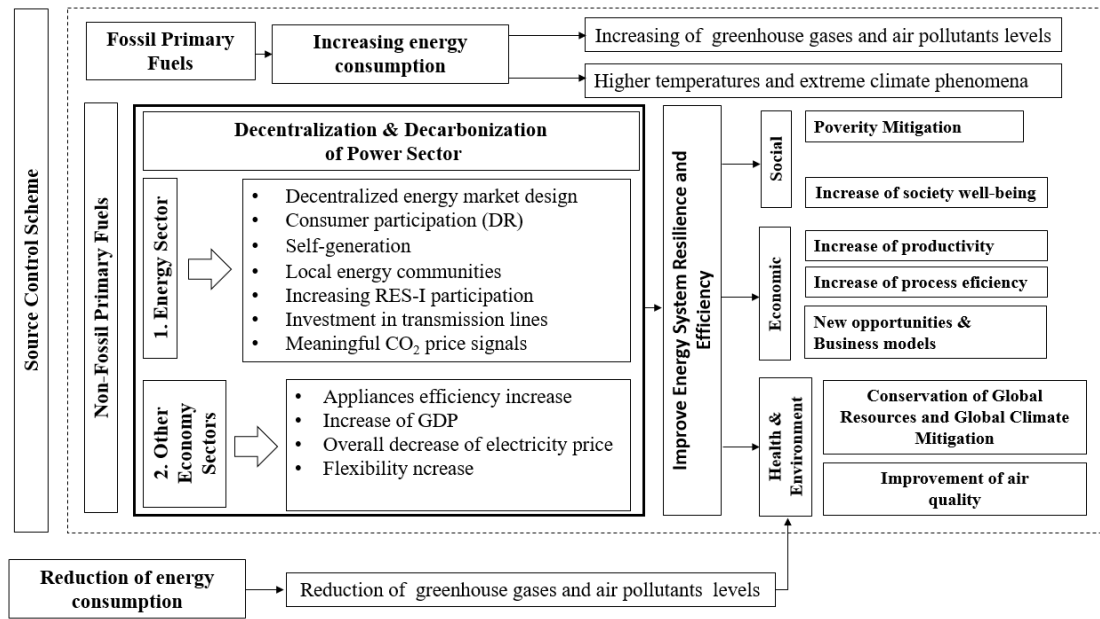


Figure 4.2 – The role of decentralization and decarbonization of power sector. Source: From the author

The non-decarbonization consequences are not just related with an increase in the cumulative emitted CO₂ but will imply the scale up of supply chains, potentially leading to short term shortages of building capacity, materials and resources (European Climate Foundation, 2010). Moreover, delaying the decarbonization process will bring a scale up on costs. From about 30 billion Euros in 2010 to about 65 billion Euros a year in 2025 and when delayed by ten years, in 2035, the required annual capital spent are estimated to go up to over 90 billion Euros per year (European Climate Foundation, 2010).

In Europe, about 70% of emissions come from energy use across economic sectors, and thus the European Council endorsed the EU objective to reduce GHG emissions (Gerbaulet et al., 2019). It has imposed particularly stringent targets for the low-carbon energy transformation reducing by 40% the greenhouse gas emission until 2030 (comparing with the 1990 levels) (Gerbaulet et al., 2019). The European goals for 2050 are even more stringent representing about 80–95% reduction with an almost complete decarbonization of the electricity sector with only 2% of the 1990 CO₂ emissions (Gerbaulet et al., 2019). These goals imply that fossil energy supply will be gradually phased out and should only represent approximately 5% of total

energy supply by 2045 (Euroelectric, 2020). The power sector GHG emissions in the EU are expected to fall 48–66 % by 2030 and 90–98 % by 2050 compared with 2005 (EEA, 2016).

In order to achieve this transformation, a nearly zero-carbon power supply is required but also a transformation across all energy chain emitting sectors is needed, from energy generation to smart grids, electric vehicles and heat pumps. Moreover, it is needed an adequate market design to address the investment and operational challenges of a high RES based power system and an active involvement of citizens in a more decentralized power market, which includes Demand Response, self-generation, local energy communities, as well as increased social acceptance for as well as increased social acceptance for larger renewable capacity installation and the build of new transmission lines. Meaningful CO₂ price signals will also be required to sufficiently incentivize full decarbonization and induce needed investments both on the energy supply and demand side. Also addressing taxes and levies in electricity to ensure fair competition between clean energy carriers will be *a must* to achieve consumers' uptake.

In order to guarantee security of supply, particularly in regions without hydro or nuclear generation, gas will still account for about 15% of total installed capacity in order to secure system reliability (Euroelectric, 2020). It is expected that European regions have different levels of power sector decarbonization, according to regional fuel profiles and status and age of their fossil fuel capacities. These differences are associated to regional differences in the electricity supply mix. For instance, while in Norway the power sector is almost carbon-free representing approximately only a 10% greenhouse gas emission, Poland still relies on coal for about 80% of total energy supply (Euroelectric, 2020). In years with lower renewable generation, renewable offset will tend to be compensated with higher production of combined cycle and coal-fired power stations, which will necessarily increase CO₂ emissions.

European countries can be aggregated according to its generation capacity into four clusters. The Northern European and the Baltics - NEB - Denmark, Estonia, Finland, Ireland, Latvia, Lithuania, Sweden and United Kingdom, the Central-eastern European countries - CEE - Bulgaria, Croatia, Czech Republic, Hungary, Poland, Romania, Slovakia, Slovenia, the Central-western European countries - CWE - Austria, Belgium, France, Germany, Luxembourg and Netherlands and the South Eastern European countries - SSEE - Cyprus, Greece, Italy, Malta, Portugal, Spain (EEA, 2016). In Spain, coal fueled thermal power plants share have been

constantly decreasing achieving the lowest share value in 2019. Per the contrary, gas fueled power plants shares have been increasing substantially along the years (Table 3.12). Moreover, GHG emissions in 2018 are estimated in 334,3 MtCO₂-eq in 2018, corresponding 18% of this amount to electricity generation (REE, 2020). According to REE, 2020 GHG emissions have been going down in Electric Spanish System, for two main causes: an increasing share of renewable energy, and the reduction of coal production share. Between 2015 and 2019, there was an emission decrease higher than 30% from 80 MtCO₂-eq in 2015, to about 50 MtCO₂-eq in 2019 (REE, 2020).

In general, the tendency in Portugal generation assets is the same, coal fueled thermal power plants share have been constantly decreasing and gas fueled power plants shares has been increasing (Table 3.10). Both countries have invested significantly in the increasing of RES generation, but the impact of fossil fuels is still notorious particularly during dry years mostly due to the importance of hydropower generation.

Table 4.2 – Percentage of total expected regional capacity profile, by fuel type, EU-28.

Source: EEA (2016)

	Coal	Gas	Oil	Uranium	Waste Treatment	Lignite	BioFuels
CEE	53	17	3	26	1	-	-
NEB	22	39	4	31	4	-	-
CWE	33	21	4	40	1	-	1
SSEE	21	53	9	6	4	3	-

The technology diversification and its age differ significantly according to the cluster region. While in the NEB countries uranium and gas fuels represent the majority of fossil fuels units, in the CEE countries the fossil fuels units are predominantly coal dominated. According to EEA, 2016 the CWE countries are also coal dominated, but uranium is the prevalent technology, while in the SSEE countries gas units are predominant. The age of the assessed capacity also differs considerably by region, with the oldest capacity located in CEE and the newest found in SSEE. Across all regions, plans for new fossil fuel capacity are similar, but the greatest expansion in gas-fired capacity would be in NEB, representing 23 GWe, which would see almost no new solid fuel-based capacity. The greatest expansion in solid fuel-fired capacity is expected to occur in CEE. However, CEE does not appear to run the risk of a significant solid

fuel-fired capacity lock-in thus a large proportion of the old capacity is expected to be decommissioned by 2030. The risk of a solid fuel-fired capacity lock-in is lower also in SSEE. According to Papaefthymiou, G., Grave, K., & Dragoon, K. (2014) flexibility potential of supply, demand and energy storage are usually easier to quantify, by exploring the flexibility characteristics of the related technologies, per the contrary the potential of network and system depend on the characteristic of the specific system (Table 4.3).

Table 4.3 – Flexibility potential of demand, supply and energy storage. Source:
Papaefthymiou et al. (2014)

DEMAND	
Industrial	Short-term and cost-efficient solution, additional potential for complete shut-down in minutes, but at high costs (VOLL).
Services and Households	Might turn out to be the game changer in electricity markets when flexible demand set the marginal price in wholesale markets.
EV	Potential role for provision of balancing and reserve power. Also, a possible solution for localized problems.
Power to Heat	The electrification of the heat sector shifts demand from the heat to the power sector and may add significant flexibility to the system. Combining electrical storage with electric heat may increase the flexibility of the power grid and may represent an additional place to put the surplus from VRES and reduce carbon by displacing fossil-fuel power plants
SUPPLY	
Biogas power plant	Biogas offers a renewable energy option with promising flexibility options. The most promising flexibility options are due to biogas storage and CHP operation according to electricity production needs. Biogas plants can ramp up and down according to changes in residual demand. However, the flexibility of biogas production itself is limited. Moreover, ramps and part load operation might lead to higher emissions and methane is a potent greenhouse gas.
Fossil generation	Fossil generation refers to power plants that use fossil fuels for generation, namely coal, gas and oil. The key technologies are steam turbines, combined cycle gas turbines and internal combustion engines. Gas turbines and internal combustion engines are the most flexible units while CCGT and steam turbines are subjected to more constraints. Key flexibility constraints come from the technical restrictions defined by ramping capability, must-run requirements and minimum load.

	Technology developments in power generation and refurbishment of old units may allow increasing the flexibility of thermal generation. Ramps and part-load operation may lead to lower efficiencies and higher CO ₂ emissions.
Nuclear generation	Nuclear power stations are mainly used as base load units and are highly inflexible. However, nuclear power plants that use pressurized water reactors (PWR) can ramp down to 20% of their installed capacity. This is seldom used because the variable costs are very low and saving from reducing output are small. Despite nuclear represent some environmental risks due to radioactive fuels and waste disposal, some countries are investigating whether flexibility from nuclear can support nuclear/VRES support for CO ₂ free systems
Combined heat and power	Due to their dependence “ <i>for primary task</i> ” that is heat production, often they are must-run plants, which means that they have a significant inflexible capacity. Combined heat and power produce electricity by waste heat that is generated from a central process. Still, if heat storage system is applied to CHP plants these can respond to changes in the residual demand and their operation can be optimized.
VRES	VRES are seen as key drivers for the system transportation and the need for new flexibility resources. Their participation in providing flexibility may represent a solution with major potential for systems with high varying shares. However, there are still some barriers due to the associated uncertainty and regulatory and market barriers still need to be overcome. The active control of VRES is a common practice in small systems with limited flexibility resources and in areas with high shares of congestions levels. Due to marginal cost of zero active power control can be used as a cost-effective ancillary service such as providing negative reserve control. Reduction of peaks in production due to a small level of curtailment may decrease the need of additional grid capacity.
STORAGE	
Pumped hydro storage	The storage technology is mostly used has an energy management technology ideal for levelling peak shaving, time shifting, power quality measures and emergency supply.
Advanced Adiabatic Compressed Air Energy Storage (AA-CAES)	Large-scale application for medium term energy storage, time shifting
Flywheels (Rotating	

masses that storage electricity in the form of kinetic energy)	
	Flywheels are often used to provide inertia in islands systems. Applied most of all as short term storage with frequent and intensive cycling, often used to stabilize weak grids
Batteries	
	Mainly small-scale application at moderate levels of RES penetration. High potential for technical development and cost-reduction. Could be used on distribution grid level, while pump storage and other big scale technologies work on transportation big level.
	Li-ion High energy density, power quality, network efficiency, off-grid, time-shifting, EV.
	Lead Acid: Off-grid, emergency supply, time-shifting, power quality.

The GHG emissions are highly dependent on the electricity production unit and fossil systems. Power plant GHG emissions are clearly highest for industrial gas, followed by lignite, hard coal, oil and natural gas. The GHG emissions for biomass are in the middle range, with lower magnitude than coal, and higher than for nuclear or wind power. Nuclear, wind and solar photovoltaic have a neglected contribution for GHG emissions when comparing with the other systems. The same applies to typical hydro plants. However, there are some exceptions such as dams operating under special conditions, and hydro-electric developments in tropical regions, which may emit during operation between 5 and 20 times more GHG emissions. At the higher range is comparable to emissions from fossil sources resulting in very large direct emissions from reservoirs (Dones et al., 2004).

The evolution of generation portfolios differs significantly, considering is associated to a large number of variables such as the increase in demand, natural resources, energy crisis and political decisions. Until 1950, Portugal electricity production was based in small power plant units using coal as energy source but with the increasing demand from industry in the mid of the 20th century, hydro-electric production units together with the use of lignite move forward. Carregado, Barreiro and Setúbal set a new era marked by petroleum products. The years of 1973/74 and 1979/81 were marked by international oil crisis that set a political shift towards imported coal - Sines and Pêgo power plants, started operating in 1985 and 1993 respectively (APA, 2019).

With the increasing penetration of RES, the pressure on conventional power plant profitability and plant revenues below the fixed operation, together with maintenance costs considering both fuel and carbon dioxide prices, Gas turbines Combined Cycle Gas Turbines (CCGT) or Combustion Turbines (CT) are Europe's most displaced power plants. RES-I displace generation with higher variable costs, at the far right of the merit order curve or by contributing to the appearance of negative prices. This results in an unsustainable situation for gas plant operators that run plants incurring the loss or hardly recouping fixed costs (Goutte and Vassilopoulos, 2019). Several have announced early retirement or decommissioning such as the recently announcement for Sines and Pêgo. These thermal plants are two of the most polluters in Portugal and represent about 15% of the Portuguese GHG emissions. The decommissioning of these plants opens the path for another political shift towards largest shares of RES-E. Weisser (2007) study accounted for national, regional and international mitigation policies over the entire life-cycle. The results presented here indicate that the most significant GHG avoidance (in absolute terms) can be made from technology substitution. The introduction of advanced fossil fuel technologies can also lead to improvements in life-cycle GHG emissions. Overall, hydro, nuclear and wind energy technologies can produce electricity with the least life-cycle global warming impact.

Both Matos (2015) and APA (2019) listed the thermal Portuguese power plants, as presented in Table 4.4 with their respective characteristics.

Table 4.4 – Portuguese Thermal Production Centrals and their Characteristics. Source: APA (2019)

Power Plant	Start	Situation	Fuel	Power	Technology	Treatment of Gas Effluents
Tapada do Outeiro	1959	Deactivated (2003)	Lignite + Fuel-oil	150/100/47* MWe	Boiler + Steam Turbine.	Yes
Portgen (new Tapada do Outeiro)	1998	Working	Natural gas + Diesel-oil + Liquid petroleum gas	990 (3x330) MWe	Combined Cycle.	Yes
Soporgen	2001	Working	Natural gas	67 (44+23) MWe	Co-generation. Combined Cycle	Yes
Energin	2002	Deactivated (2014)	Natural gas	43.7 MWe	Co-generation. Combined Cycle	-
Mortágua	1999	Working	Wood waste + Natural gas + Diesel-oil	30 MWe	Boiler + Steam Turbine.	Yes
Pêgo	1993	Working	Hard-coal + Fuel-oil +	628 MWe	Boiler + Steam Turbine.	Yes

			Diesel-oil + Liquid petroleum gas			
Pêgo	2010	Working	Natural gas + Diesel-oil	800 MWe	Combined Cycle	Yes
Carregado	1968	Deactivated (2011)	Fuel-oil + natural gas + Diesel-oil + Liquid petroleum gas	750 (6x125) MWe	Boiler + Steam Turbine.	Yes
TER	2004	Working	Natural gas + Diesel-oil	1170 MWe	Combined Cycle.	-
Carriço	2006	Working	Natural gas + Diesel-oil	487 MWe	Co-generation.	-
Alto do Mira	1975	Deactivated (2003)	Diesel-oil	132 MWe	GasTurbine.	-
Barreiro	1978	Deactivated (2010)	Fuel-oil + Liquid petroleum gas	65 (32+33) MWe	Co-generation.	-
Fisigen	2009	Working	Natural gas	121 MWt	Co-generation.	-
Setúbal	1979	Deactivated (2013)	Fuel-oil + Diesel-oil + Liquid petroleum gas	1000 (4x250) MWe	Boiler + Steam Turbine.	Yes
Sines	1985	Working	Hard-coal + Fuel-oil	1256 (4X314) MWe	Boiler + Steam Turbine.	Yes
Tunes	1973	Deactivated (2013)	Diesel-oil	199.2 (2x16.3 + 2x83.3) MWe	Gas turbine.	-
Lares	2009	Working	Natural gas + Diesel-oil	1428 MWt	Combined Cycle.	-
Constância	2009	Working	Wood waste + Fuel-oil + Liquid petroleum gas	39.2 MWt	Boiler + Steam Turbine.	-
Figueira da Foz	2009	Working	Wood waste + Natural gas	31.2 MWt	Boiler + Steam Turbine.	Yes
Cacia	2009	Working	Wood waste + Natural gas + Diesel-oil	49.75 MWt	Boiler + Steam Turbine.	-
CB Setúbal	2009	Working	Wood waste + Natural gas + Diesel-oil	49.75 MWt	Boiler + Steam Turbine.	-
Rodão	2008	Working	Wood waste + Fuel-oil + Liquid Petroleum gas + Diesel-oil	39.1 MWt	Boiler + Steam Turbine.	-
Artelia	2011	Working	Natural gas + Biogas	269.7 (135.9 + 33.8 + 100) MWt	Combined Cycle.	Yes

The transformation of power sector in order to become a nearly zero-carbon emission sector, will set profound implications for all the economic sectors at a macro-level. Some studies defend that electricity should become almost entirely from renewable sources, nuclear power

plant units and fossil fuel power plant units equipped with CCS technology (Jägemann et al., 2013). Nevertheless, nuclear energy and CCS do not reunite unanimity among countries, considering some member states are not willing to accept the associated risks of these technologies. One third of the total EU's electricity supply for consumption comes from nuclear energy and the majority of member states are presently using this type of energy source. There are different political approaches regarding nuclear energy expansion among countries. While Germany and Belgium are example of countries that have decided to phase out their nuclear power plants, France and Slovakia intend to continue to expand their nuclear supply capacities (Jägemann et al., 2013).

In order to achieve GHG targets by 2050, despite the end of largely fossil fuel-based plants, the power sector decarbonization initiatives must include a huge economic cross-sectoral transformation programme, namely, energy efficiency tactics, the development of low carbon technology, the grid integration and interconnection as well as an integrated market operation and a shift in transport and buildings fuels. Additionally, energy markets design based on marginal cost pricing, must be revised in light with the capital-intensity of low-carbon technologies. In future market design, stability and clarity are fundamental conditions for low-carbon investors develop the necessary confidence that their investments will be profitable under a future market with a wide range of complexity and technologies. The future innovative approaches will include the use of digital tools to shift electricity demand to lower prices periods and to lower emissions-intensive hours of the day. More than reducing electricity bills, DSM will help to keep system balancing and to reduce CO₂ emissions (Dabur et al., 2012).

Despite Spain and Portugal tend to have similar climactic conditions, the Spanish generation portfolio is more diversified than the Portuguese. The generation technologies share is in a constant change. At a micro-level the generation variation impacts vary hour after hour, whereas, at a macro-level the generation variation impacts vary year after year. These changes have a direct impact on electricity prices, Ward et al. (2019) summarize the factors that influence electricity market prices and generator utilizations into three categories (Table 4.5). These categories directly and indirectly affect the potential DR effect as well as the electricity generation portfolio at a certain moment affect emissions.

Table 4.5 – Factors that influence electricity market prices and generator utilizations. Source:
An adaptation of Ward et al. (2019)

	Financial	Stochastic	Technical
Renewable feed-in	x	x	
Electricity demand	x	x	
Fuel and Carbon prices	x	x	
O&M and start-up costs	x		x
System balancing	x		x
Other market factors	x		
Tx constrains		x	x
Plant efficiency		x	x
Ramp rates			x
Outages			x

The rising need for flexible operation of power systems and its digitalization associated to technological developments will compel energy policies to regulate innovative approaches and issues such as the market design for storage and the interface between electric vehicles and the grid.

The development of new tools such as DR in order to encourage consumers to shift electricity consumption to cheaper and less emissions-intensive hours of the day, will help to both reduce electricity bills for consumers and to keep the system balancing, while also helping to reducing emissions from pollutant power plants. However, this may expose consumers to new risks associated with data privacy. Moreover, according to Chandran et al. (2019) DR programs program success is dependent on consumer satisfaction and tolerance since load management technologies could be understood as a consumer right violation, particularly if perceived as a restriction for using resources.

4.2. MODELLING REVIEW

In the future, Demand Response technologies will represent an important role towards the power systems structural change with a relevant role in emissions and costs reduction associated with emission reduction activities (Parvania et al., 2011). Its importance is usually associated

to the dispatch of generation and the decommissioning of older fossil-fuels power plants. Theoretically, Demand Response participation in power system markets for ancillary services, wholesale electricity, and particularly the capacity market is supposed to have a greater impact on decommissioning peaking plant. However, Demand Response does not necessarily imply a reduction in energy consumption thus the load can be simply shifted and be consumed in another period. More than the availability for economic and technical potential it is critical for Demand Response full deployment and implementation to enable more renewable energy consumption. Demand Response implementation will imply consequences for the entire chain from consumers to generating companies. These consequences are not always positive, and if Demand Response does not achieve the necessary impact, particularly in what regards the impact on renewables integration, it might have a negligible or negative impact on emissions, depending on the marginal emissions factors of the power system in question (McKenna and Darby, 2017). Also, Strbac (2008) refer that the evaluation of the improvements in the performance of the system and other low-carbon energy sources for electricity generation system determine the value of storage and DSM. As described by Schwabeneder et al. (2019), in each country, there is a specific portfolio of power plants operating at different output levels that changes every hour and depends on the production of RES, demand and production cost of flexible power plants. The CO₂ emissions will vary per hour according to the different generation output of each power plant, meaning that marginal system emissions is a sensible indicator of the influence of load shifting.

McKenna and Darby (2017) refer there is a wide range of impacts depending if studies are based on short-run or long-run estimates. The methods and assumptions of the first ones indicate that Demand Response can have a negligible effect in certain power systems, while in long-run studies Demand Response can achieve considerable reductions in carbon emissions through changing the dispatch of generation, reducing renewable generation curtailment, but particularly due to the decommissioning of polluting peaking generation. Moreover, methodologies for assessing DR emissions impact and its conclusions differ considerably according to the study coverage. While some are national or market-wide study focused, others try to evaluate the emissions impact of a specific designed program.

A study concerning EU DR potentials performed by Torriti et al. (2010) estimated that, by 2020, DR would represent a 100 TWh annual energy savings resulting in a 30 million tons of CO₂

reduction. Anjo et al. (2018) bottom up model results for Portugal, indicate that the implementation of DR is consistent in reducing the cost and total installed capacity for all the three assessed scenarios.

Silva et al. (2012) developed a three variable Structural Vector Autoregressive (SVAR) model which includes the share of RES on Electricity generation, CO₂ emissions per capita and GDP per capita to assess the relationship between energy, economic growth and carbon emissions. The study concluded that an increase in the RES-E share for all countries would be beneficial for economic growth with exception for the USA, where the increasing share of RES-E had an economic cost, even if would contribute to the CO₂ emissions reduction. This study also concludes that RES should be support with other policies such as demand-side management and energy conservation particularly in Portugal, Spain and Denmark.

Schnaars (2019) results that estimates the emission displacement effect of renewables in Germany for 2017 suggest that the marginal offsetting effect is positive. However, the responsiveness differs according with the technology. While in non-conventional technologies as wind electricity offsets more emissions than solar at the margin in conventional technologies, lignite plants barely reduce their emissions in response to renewable production, while coal plants are used heavily for providing flexibility. Goutte and Vassilopoulos (2019) tried to understand how volatility in short term prices could create the economic conditions to maintain enough flexible capacity to balance the power system. The results indicate that flexible plant can increase its revenues by ramping up/down close to real-time and/or quarter by quarter to react to the short-term price variations in the day-ahead and intraday markets. Volatility of short-term prices provides an additional revenue to the flexible resources able to react quickly. The difference between day-ahead and intraday revenues for a flexible resource has been increasing. Furthermore, according to the performed analysis the calculated foregone emissions savings due to grid congestion were significant. Abrell et al. (2019) study the exogeneity of weather conditions to evaluate renewable energy (RE) subsidies in Germany and Spain in terms of their short-run direct program costs for reducing carbon dioxide emissions. The study estimates that the costs for reducing 1 ton of CO₂ through subsidies for solar are 411 to 1944 € while subsidies for wind have significantly lower costs, ranging from 82 to 276 €. The results heterogeneity indicates that both aggregate costs and distribution costs vary according with the technology reflecting production costs, temporal availability of natural resources, and market

conditions. Abaravicius and Pyrko (2006) evaluated the possible environmental benefits of load management and evaluate their significance, primarily focusing on CO₂ emissions reduction on two levels: at national level considering the Swedish electricity market, and at local level considering one electric utility in southern Sweden. The results provided different conclusions: while at national level, load management measures can hardly provide significant environmental benefits, due to the high hydropower production, at site-specific or level-specific, energy efficiency measures have the potential to decrease emissions, both due to lower load demand as well as the energy demand.

The results of a study considering the uncertainty involved in the decision-making processes to determine the investment decisions in generation and storage capacity to be made until 2050 to attain the CO₂ emission targets in Europe, and second, to analyze the market outcomes of the resulting power system, conclude that the DSM level has a low impact on the capacity to be built in renewable-dominated power systems if a significant storage capacity is available (Domínguez and Carrión, 2019). Large availability of significant storage capacity is the case of countries where load demand follows high hydropower production.

At market level, Dahlke and Prorok (2019) study estimated consumer savings, CO₂ emissions reductions and price effects from increasing DR dispatch in the Midcontinent Independent System Operator (MISO) electricity market. In this study consumer savings from increased market-based DR can vary from \$1.5 million to \$18.5 million under typical peak operating conditions, depending on the amount of DR resources available for market dispatch and the frequency of deployment. Results indicate that DR deployment often reduces CO₂ emissions but may vary thus they depend on the emissions content of marginal generation at the time and location of deployment as well as the magnitude of demand shifting. Also, Schwabeneder et al. (2019) study found differences in marginal CO₂ emissions caused by load shifting. Results demonstrate that, in most situations, there is a decrease in the CO₂ emissions caused by flexibility. The years 2018 for Sweden and France, and the year 2016 for Romania were exceptions. Also, for Germany, Romania and Spain in 2016, flexibility increased CO₂ emissions based on the marginal system emissions. A reduction of marginal CO₂ emissions in almost all scenarios was observed for France, while the highest increase in carbon dioxide production caused by load shifting was observed for Germany. According to this study, shifting demand to reduce electricity procurement cost from markets does not necessarily reduce CO₂

emissions, and in what regards the impact of load shifting on carbon emissions no simple conclusion is possible to be established thus the impact of Demand Response on CO₂ emissions varied substantially. Corchero et al. (2012) studied the influence of both the allowances and emission reduction plan and the incorporation of the derivatives medium-term commitments in the optimal generation bidding strategy to the day-ahead electricity market. Results of the numerical test provides a reduction of the overall CO₂, SO₂ and NO_x emissions by 70% together with 30% increase in the expected total profit, availing of the CO₂ emissions rights market. Hintermann (2016) has estimated the level of emissions cost pass-through to wholesale electricity prices in Germany, based on spot market data and concluded that carbon costs are passed to electricity prices by at least 84%, with a central range of 98–104% for different load periods, suggesting that there is no economic reason for free allowance allocation to the electricity sector, consistent with the European Union Emissions Trading Scheme (EU ETS). Gugler et al. (2019) utilize daily electricity generation data at the plant level from all gas and coal power stations in Germany and the UK, to compare the effectiveness of two sets of environmental policies and estimate the offsetting effects of RES – in the form of wind and solar power – on carbon emissions from fossil-fuel thermal power plants. This study main finding is that putting a carbon price on emissions is the most cost-effective way of reducing emissions and subsidizing wind is preferable to subsidizing solar power. These two countries follow significantly different carbon abatement policies. While Germany relies excessively on direct subsidization of wind and solar energy, the UK introduced a unilateral carbon price support (CPS) in addition to the EU ET that is gradually increasing the carbon price. The study results indicate that the marginal effectiveness of wind and solar increases with the carbon price in Germany, but decreases in the UK because increasing carbon prices in Germany puts more coal at the margin to be replaced by wind or solar, while in the UK coal is already largely replaced by gas and given further increases in the carbon prices, wind pushes more gas out of the merit order, reducing its effectiveness.

Heydarian-Forushani et al. (2017) study demonstrated that different generation mixes have distinct and partly conflicting impacts. According to this study the lack of enough flexibility may lead to wind generation outputs curtailment and consequently to an increase of emissions. Some DR programs implementation, particularly TOU, has a higher impact decreasing either the operation cost as the pollutant emission. Anjo et al. (2018) study also reached results for

scenario LowCO₂, indicating that flexibility is a key tool for systems with a high share of renewables.

When analyzing the short-term environmental impact associated to load variance of a RTP program Holland and Mansur (2008) concluded that the environmental impacts of such program may actually increase emissions in some U.S. regions. Also, the study performed by Ruokamo et al. (2019) demonstrates that dynamic RTP contracts have not gained considerable market share in Finland even though they have been available for some years. The author points the low electricity spot prices in the Nordic power market as one possible reason for that. Madaeni and Sioshansi (2012) results indicate Demand Response reduces some of the emissions benefits of wind, although combining wind and Demand Response provides more cost-effective emissions abatement than wind alone. Because real-time prices and electricity demand are correlated, RTP affects load profiles by reducing on-peak and increasing off-peak demands. According to this author *“RTP reduces the emissions benefits of wind, the associated cost savings more than compensates for these losses and reduces the wind-uncertainty cost incurred per kg of emissions averted by wind.”*

Zeng et al. (2013) performed an integrated methodology to optimized the allocation of renewables, non-renewable DG units (gas turbines) and smart metering simultaneously with network reinforcement, for minimizing the total economic and carbon-emission costs over planning horizons, where Demand Response is enabled by real-time pricing (RTP). The results indicate there is a further improvement of economic and environmental benefits achieved with DR in comparison to the corresponding situation without DR. The mitigating CO₂ footprint of distribution systems was found to be optimal when the wind, solar, gas and SM resources are considered simultaneously, with the total expected cost of \$10.18 M and CO₂ emissions reduction of 186 000 tons.

In a more specific approach, Fallahi and Smith (2017) studied the potential of using Demand Response for electricity purchase reduction and emission reduction in four types of commercial buildings. The authors demonstrate the potential emission-saving effects of Demand Response at the grid level, which is viable when combining multiple buildings: *“a stand-alone large office building cannot self-sufficiently produce its electricity consumption. As part of the microgrid, the excess PV electricity generation from other smaller-sized buildings can be used for the large*

office building". This study demonstrate that is possible to use the excess of electricity generation to other buildings, with 1.37% reduction in indirect CO₂ emissions.

4.3. MODEL DESCRIPTION

The specific portfolio of power plants operating at different output levels will change every hour and the CO₂ emissions will vary per hour and country according with the different generation output of each power plant. Flexible consumers and Demand Response load-shifting will alter the load, resulting in different values of the annual carbon dioxide emissions related to the generation of each power plant type and overall consumer's electricity demand impact.

Despite demand load flexibility is particularly relevant during peak hours, when it is possible for consumers to shift consumption due to higher electricity prices, according to the previous model results, clearing market prices tend to be lower and companies tend to behave much more competitively during off-peak hours (hour 1 to hour 8) than during peak hours.

These results affected the conception of the model, thus instead of reducing non-renewable production during peak-hours, the concept was developed in the opposite manner. Once that it is expected that during peak-hours the load average consumption is still going to be higher than in non-peak hours, a non-renewable percentage of the load during off-peak hours should be shifted to peak hours of non-renewable production. The load percentage should correspond to the load shifting scenario. This will offset a load percentage production of non-renewables during non-peak periods remaining essentially renewables production during off-peak periods. Whereas, during peak-periods, the overall consumption does not increase and the global emissions are reduced thus there is a decrease in non-renewable production particularly during non-peak periods. Despite the unconventional analysis, this interpretation still allows to implement DR during peak-load periods. Figure 4.3 is a schematic representation of the exposed.

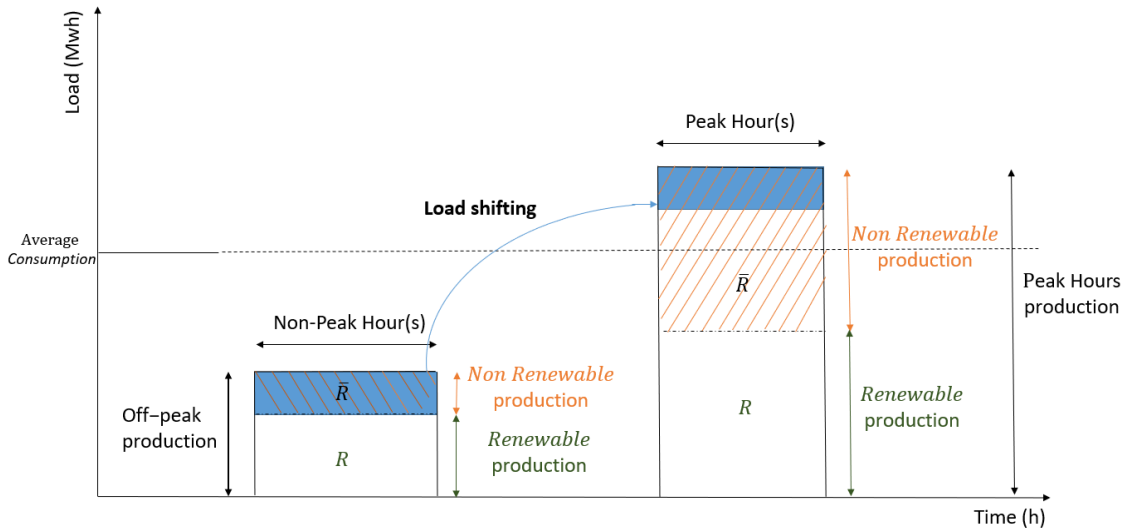


Figure 4.3 – Representation of DR implementation during peak-load periods. Source: From the author

During a load shifting process between two hours h_i and h_{i+n} , it is expected and possible to admit a reduction in the production of energy Q .

Considering that a certain percentage of the energy produced in the hour h_i is stored and then applied in the hour h_{i+n} , then the equivalent amount of energy stored in hour h_i will no longer be produced in the hour h_{i+n} .

Supposing that the energy produced in the hour h_{i+n} is provenient from different energy sources, f_i . Each energy source will have a certain mass emission of carbon dioxide per unit of produced load, $\alpha(f_i)$. Moreover, each source will have a percentual contribution, ε_i , that will differ according to the total load production. It is then possible to estimate the carbon dioxide mass associated during the energy production of each energy source f_i :

$$m_i = \alpha(f_i) \varepsilon_i Q \quad (4.1)$$

Where:

m_i correspond to carbon dioxide mass associated to each hour [T.CO₂];

$\alpha(f_i)$ correspond to the mass emission of carbon dioxide per unit of produced load [T/MWh];

ε_i correspond to the percentual contribution attributed to each source;

and Q correspond to the total load produced in a certain hour [MWh].

It is then possible to have an expression for the total mass of carbon emitted in a charge production Q , thus the terms of mass emitted by each source can be added:

$$M = \sum_i m_i = \sum_i \alpha(f_i) \varepsilon_i Q \quad (4.2)$$

The total mass of CO₂ emissions per hour corresponds to the sum of the generation of each power plant type weighted according to the average CO₂ emission factor in kg CO₂ /kWh (Table 4.6). It should be noted that when the production sources are exclusively renewable, the mass emission coefficients of carbon per unit charge produced are identically zero. When the energy production is originated by renewable sources the coefficient $\alpha(f) = 0$ thus renewable energy produce 0 Tons/MWh. Despite the nuclear production is included in the thermal energy production, this model conception aimed to quantify the level of emissions. The mass emission of carbon dioxide prevenient from nuclear energy production is considered to be practically residual, when compared with other fuels, such as coal or gas (IAEA, 2016).

The coefficient $\alpha(f)$ should be considered for non-renewable energy sources with relevant emission of carbon dioxide such as carbon, fuel generation technology and combined cycle generation technology. The specific CO₂ emission factors of various fuels were retrieved from Quaschnig (2016). The coefficient applied were, respectively, $\alpha(f) = 0.35$ and $\alpha(f) = 0.20$. The first was considered to be the average of mass emission of carbon dioxide from hard coal (0.34) and brown coal (0.36). Different emission factors of electricity generation may be found according to the methodology. In Spain the GHG emission factors differ for the mainland system and for islands or isolated systems. These emissions factors may be found in REE, 2020. The information on the Spanish emissions of CO₂ (t CO₂ eq / MWh) generated by each of the Spanish electricity systems among other pollutant agents, for power plants with an installed nominal thermal power equal or higher than 50 MWt is available until 2018 in Registro Estatal de Emisiones y Fuentes Contaminantes (PRTR). For Portugal the emissions factors considered in APA, 2020 differ substantially from the ones considered in Spain. Other authors such as Dones et al. (2004) define the ranges of GHG Emissions per kWh electricity production from European and Country-Specific Energy Sources and in the study performed by Moro and Lonza

(2018) upstream emission factors were considered. Also, EIA - US (2013) defines the Carbon Dioxide Emissions From Energy Consumption by Source. The emission factors differ considerably according to the source, therefore in this study a simplification was done considering the emission factors defined at Quaschnig (2016).

Table 4.6 – Specific CO₂ emissions factors of various fuels. Source: Quaschnig (2016)

Energy Source	kg CO ₂ /kWh
Wood	0.39
Peat	0.38
Lignite	0.36
Hard Coal	0.34
Fuel Oil	0.28
Diesel Fuel	0.27
Crude Oil	0.26
Kerosene	0.26
Petrol	0.25
Refinery Gas	0.24
Liquid Petroleum Gas	0.23
Natural Gas	0.20

By replacing the total charge Q with the amount of charge that is no longer produced, it is then possible to calculate the mass of carbon that is no longer emitted due to the load shifting process:

$$\delta M = \sum_i \alpha(f_i) \varepsilon_i \delta Q \quad (4.3)$$

This new load considered, δQ , is the load transposed during a load shifting process. For example, if 5% of the load produced at a given hour h_i is transferred to another hour h_j , at this new hour h_j the load that is no longer produced, δQ , is proportional to the 5% transferred.

The mathematical model was tested using real daily electricity generation data from aggregated plants on combined cycle and coal (national and importations) in Portugal and Spain. The model used MIBEL historical data retrieved from the OMIE website continuously for 24 hours, for a continuous temporal analysis from 1st January 2015 till 30th June 2020.

A common method for addressing uncertainty is the use of scenarios, and this approach was used in this study, with two load shifting reference scenarios, namely 5% and 15%.

The present model has some limitations thus it represents a simplified model focused on the estimation of the CO₂ emission impact for the DR established scenarios. The model is based on an hourly aggregated approach and does not integrate the specific reality of individual power plant that participated in the day-ahead market. Some power plants operate with more than one fuel, so in order to obtain more rigorous results, the specific type of fuel and the power produced in that hour for all the market participating plants, would be a necessary input data. Also, Abaravicius and Pyrko (2006) referred that is therefore impossible to establish the direct relation between load demand and emissions without hourly data, classified according to electricity production source.

4.4. RESULTS AND DISCUSSION

Electricity generation varies constantly according with the demand, which, in turn, varies with the hour of the day, the day of the week and/or period of the year. On the other hand, electricity generation, is associated to climatic condition that are difficult to predict and control. Electricity sector emissions production from generating units has emission caps that should not exceed the allocated emission allowance testing both the system capacity from long-term resource planning and the short-term generation scheduling to meet the power demand.

Electricity consumers' interest in the reduction of the cost of their power bills through load manipulation by means of demand-side management has been raising. This cost is associated both to the electricity price but also to the environmental cost associated to greenhouse gas (GHG) emissions (Tsagarakis et al., 2016). According to projections, wind and solar PV will provide more than half of the additional electricity generation till 2040, and the costs reduction associated to renewables and advances in digital technologies will open the pathway towards an energy transition. Even so, new dilemmas associated to security supply, among others, will emerge.

DR programs are commonly associated to load reductions during peak hours. For consumers, this type of programs only makes sense when there is a notable decrease on electricity prices. If prices tend to decrease in time due to the continuous penetration of generation with null or low marginal prices on wholesale energy markets, this may affect a massive implementation of

this type of DR programs. In order to reduce the number of curtailing hours from renewable generation, necessary to the decarbonization of the energy sector and economy, it is necessary that DR programs have the ability to do that integration. According to the previous model results, the economic potential for DR tend to increase during peak-hours when peak plants participate in the wholesale market. During these hours the impact of shifting load will tend to be larger. Despite the economic model result indicates a small difference impact on energy prices between the 5% scenario and the 15% scenario, the same does not happen with CO₂ emissions when comparing the 5% scenario and the 15% scenario. These results were obvious since the larger is the amount of load that is eliminated from thermal power plants the lower are emissions levels. Table 4.7 and Table 4.8 demonstrate the optimum possible results when performing a load shifting scenario of 5% and 15% respectively for Portugal and Spain. The results obtained in Table 4.7 and Table 4.8 demonstrate the sum of the individual results for each day, obtained when performing a load shifting scenario of 5% and 15% for Portugal and Spain. The model used historical data retrieved from the OMIE website, for a continuous 24 hours period during a continuous temporal analysis from 1st January 2015 till 30th June 2020. The daily results are the sum of the hourly results, both for load shifting scenario of 5% and 15% in Portugal and Spain. Daily aggregated CO₂ emissions for Portugal and Spain, both for 5% and 15% load shifting scenarios, are presented in annex.

Table 4.7 – Monthly aggregated CO₂ emissions for Portugal [T.CO₂].

2020				2019			
15%		5%		15%		5%	
January	40591,28	January	13530,43	January	75079,72	January	25026,57
February	26604,05	February	8868,02	February	46112,36	February	15370,79
March	19193,02	March	6397,67	March	38043,54	March	12681,18
April	4360,53	April	1453,51	April	42548,48	April	14182,83
May	14492,77	May	4830,92	May	44438,10	May	14812,70
June	27574,31	June	9191,44	June	64609,97	June	21536,66
July	-	July	-	July	84930,41	July	28310,14
August	-	August	-	August	42769,07	August	14256,36
September	-	September	-	September	39662,75	September	13220,92
October	-	October	-	October	52681,46	October	17560,49
November	-	November	-	November	39741,88	November	13247,29
December	-	December	-	December	26860,87	December	8953,62
Total	132815,97	Total	44271,99	Total	597478,61	Total	199159,54
2018				2017			

15%		5%		15%		5%	
January	85326,57	January	28442,19	January	97034,54	January	32344,85
February	78426,02	February	26142,01	February	72462,94	February	24154,31
March	24749,35	March	8249,78	March	71816,50	March	23938,83
April	18653,07	April	6217,69	April	75395,48	April	25131,83
May	65581,88	May	21860,63	May	97335,47	May	32445,16
June	88575,90	June	29525,30	June	104232,52	June	34744,17
July	104645,25	July	34881,75	July	110947,21	July	36982,40
August	99300,33	August	33100,11	August	116504,04	August	38834,68
September	100660,04	September	33553,35	September	103062,96	September	34354,32
October	70755,89	October	23585,30	October	90902,72	October	30300,91
November	77388,52	November	25796,17	November	96493,38	November	32164,46
December	71669,58	December	23889,86	December	82064,87	December	27354,96
Total	885732,39	Total	295244,13	Total	1118252,63	Total	372750,88
2016				2015			
15%		5%		15%		5%	
January	56925,48	January	18975,16	January	67453,55	January	22484,52
February	36019,77	February	12006,59	February	50580,51	February	16860,17
March	37892,12	March	12630,71	March	61597,78	March	20532,59
April	19955,10	April	6651,70	April	57194,27	April	19064,76
May	32798,05	May	10932,68	May	59252,61	May	19750,87
June	80997,59	June	26999,20	June	81233,60	June	27077,87
July	96120,66	July	32040,22	July	87090,08	July	29030,03
August	93674,54	August	31224,85	August	80757,27	August	26919,09
September	94604,97	September	31534,99	September	80636,92	September	26878,97
October	85935,07	October	28645,02	October	83149,40	October	27716,47
November	86071,29	November	28690,43	November	76486,29	November	25495,43
December	97050,92	December	32350,31	December	78173,62	December	26057,87
Total	818045,54	Total	272681,85	Total	863605,91	Total	287868,64

Table 4.8 – Monthly aggregated CO₂ emissions for Spain [T.CO₂].

2020				2019			
15%		5%		15%		5%	
January	85264,52	January	28421,51	January	169592,80	January	56530,93
February	70010,72	February	23336,91	February	127182,51	February	42394,17
March	14517,84	March	4839,28	March	41082,74	March	13694,25
April	4915,46	April	1638,49	April	43751,89	April	14583,96
May	16371,38	May	5457,13	May	76602,45	May	25534,15
June	78579,33	June	26193,11	June	130221,31	June	43407,10
July	-	July	-	July	203773,56	July	67924,52
August	-	August	-	August	190704,07	August	63568,02

September	-	September	-	September	151864,82	September	50621,61
October	-	October	-	October	157655,79	October	52551,93
November	-	November	-	November	87396,37	November	29132,12
December	-	December	-	December	48065,87	December	16021,96
Total	269659,25	Total	89886,42	Total	1427894,17	Total	475964,72
2018				2017			
15%		5%		15%		5%	
January	161750,34	January	53916,78	January	331435,15	January	110478,38
February	176292,23	February	58764,08	February	177746,02	February	59248,67
March	26213,80	March	8737,93	March	56784,90	March	18928,30
April	16109,31	April	5369,77	April	62009,82	April	20669,94
May	88393,37	May	29464,46	May	166555,64	May	59816,52
June	84778,43	June	28259,48	June	253939,02	June	84646,34
July	138616,54	July	46205,51	July	262217,83	July	87405,94
August	134795,25	August	44931,75	August	191889,52	August	63963,17
September	182224,22	September	60741,41	September	171890,61	September	57296,87
October	150084,61	October	50028,20	October	240667,23	October	80222,41
November	204607,21	November	68202,40	November	308807,25	November	102935,75
December	151728,72	December	50576,24	December	254691,06	December	84897,02
Total	1515594,04	Total	505198,01	Total	2478634,05	Total	830509,32
2016				2015			
15%		5%		15%		5%	
January	127128,12	January	42376,04	January	211287,53	January	70429,18
February	66800,61	February	22266,87	February	111369,47	February	37123,16
March	52087,84	March	17362,61	March	99776,25	March	33258,75
April	12095,27	April	4031,76	April	137706,12	April	45902,04
May	16304,93	May	5434,98	May	135453,45	May	45151,15
June	92115,33	June	30705,11	June	285208,31	June	95069,44
July	197854,82	July	65951,61	July	340822,99	July	113607,66
August	172362,56	August	57454,19	August	273258,45	August	91086,15
September	235065,17	September	78355,06	September	231940,26	September	77313,42
October	265166,84	October	88388,95	October	212438,87	October	70812,96
November	281863,09	November	93954,36	November	240384,19	November	80128,06
December	320010,56	December	106670,19	December	253996,42	December	84665,47
Total	1838855,14	Total	612951,72	Total	2533642,30	Total	844547,43

The obtained results were achieved through past real information, despite there are several variables that can interfere with the percentage of load shifting from technical constrains, such as the impossibility to perform the shifting or absence of DR technology. Moreover, in order to perform Figure 4.3 approach is necessary to have non-renewable generation during non-peak

hours otherwise if the generation portfolio is totally renewable during non-peak periods it is not possible to offset the emission levels. In order to achieve peak clipping and load shifting load management targets, the generation portfolio of each country and the climatic conditions have a large impact on emissions levels. Thus, it is more difficult to decrease the emissions levels, in countries where the load supply is dominated by hydropower or nuclear generation than in countries where the load supply is dominated by coal-fired power generation. According to Crampes and Renault (2019) baseload power plants with low-variable/high-fixed costs and peak load power plants with high-variable/low-fixed costs have some degree of flexibility thus they can accelerate and decelerate but at a higher cost than the normal production costs. The data benchmark of different marginal cost speed production at firms with different technologies would provide the response to the question: *“Are units inflexible because they are old and inefficient, because owners have not invested in increased flexibility or because they serve as a mechanism for the exercise of market power?”* (Crampes and Renault, 2019).

DR programs are frequently designed for load reduction or curtailing, but DR programs can also be used for consumers to increase their electricity consumption (Braithwait and Eakin, 2002). For this reason, the association of CO₂ emissions reductions and DR implementation, whether on countries, energy markets or end-users, is not a consensual issue among the performed literature. McKenna and Darby (2017) states there is a wide range of potential environmental impacts depending on the methodology and assumptions of the studies that aim to assess the potential impact of DR. There are two main study approaches: one based on short-run estimations; the other on long-run structural impacts. While for the first, Demand Response can have a negligible effect in certain power system and may even increase emissions, for long-run structural impacts, Demand Response can achieve considerable reductions in carbon emissions, particularly in changing generation dispatch, reducing RES curtailment hours and decommissioning and replacement of peaking generation per less polluting ones.

Indeed, even at the European reality, generation mixes differ significantly among countries and these follow significantly different carbon abatement policies. The marginal effectiveness of RES may increase or decrease carbon prices depending on the generation technology that will replace wind or solar. If solar and wind is replaced by efficient gas power stations there is a different effectiveness from coal inefficient power plants. The significant differences among countries reality is a possible reason for the negligible effect of certain power systems.

Moreover, countries also rely in importation from other countries which is another factor that may influence the real potential assessment of DR impact in emissions.

The reduction of CO₂ emission levels associated to DR implementation is something that cannot be guaranteed, thus DR mechanisms have the purpose of a reaction from consumers to economic incentives, to change electricity consumption patterns in response to economic signals, such as market prices, price incentives in grid tariffs or other incentives. According to U.S. Department of Energy “*demand response (DR) is a tariff or program established to motivate changes in electric consumption by end-use customers in response to changes in the price of electricity over time*” (Qdr, 2006). Moreover, the implementation of a DR program may curtail or reduce a certain amount of load during a certain period but in the subsequent periods this may have a rebound effect testing short-term generation capacity to meet the power demand. If to meet the power demand fossil and aged peak generation is required, the emission levels may increase both due to the increase of demand and the generation profile. A successful reduction of CO₂ emission levels associated to DR implementation, depends both on the percentage of curtailing or load shifting during a certain period but also of the generation assets that are producing power during that period. The study conducted by Abaravicius and Pyrko (2006) at Sweden concluded that on the national level, load management measures such as clipping and load shifting can hardly provide significant environmental benefits through emissions decrease, as the load following supply source in Swedish system is hydropower. Also, Müller and Möst (2018) investigate DR potential on an hourly basis for future years.

The alternative approach comprises investigating the DR potential as in an electricity system with different RES shares. Results indicated that DR reduces RES curtailment but it cannot integrate high amount of RES surplus over a longer period thus availability and flexibility of most applications depend on the ambient temperature, time of day and technical restrictions, e.g. shifting time.

Most DR programs are focused on load-profiles. Another possible approach could be based on generation source control, prioritizing non-fossil primary generation on electricity markets. A possible solution in order to implement DR in hours with larger RES penetration, could be to developed DR programs associated to CO₂ emissions. DR programs are mostly oriented towards consumer load profiles. These will continue to have their utility for curtailing or

shifting the load mechanisms from peak hours to non-peak hours and valley filling mechanisms from peak to non-peak hours.

Indeed, there is a lack of consumer conscience about their associated emissions and the respective generation portfolio. The final consumer does not have perception about the marginal generation costs as electricity consumers are not exposed to real short time-varying costs of electricity production. Consumers are not aware for real time electricity varying costs of production considering they are exposed to fixed tariffs. Thus, they tend to over-consume during periods with high production costs and to under-consume during periods with low production costs in an inefficient system load operation. However, if they were aware of both production costs and the emission levels of the associated generation portfolio, environmental benefits of load management could possibly emerge. Also, Ruokamo et al. (2019) states that environmental aspects have become increasingly important for community due to climate change concerns but few contracts provide real incentives to change consumption patterns based on environmental information that will require a combination of technological, monetary, and other value-based incentives.

4.5. CONCLUSIONS

DR presents several advantages for the entire value chain of the power system from the producers to the end-users. According to the obtained results, DR cannot be directly associated to emission reductions, even though, it helps to reduce investments in generation, transmission and distribution networks and simultaneously reducing the stress on polluting power plant resulting in a clear reduction of harmful green gas emissions. Moreover, this emission reduction is dependent on the emissions of marginal generation at the time and location of deployment as well as the magnitude of demand shifting.

DR is often seen has an operational and reliability concern. From the numerous existing definitions of DR, none explicitly associates DR to emissions reductions, but most associate it to shift in consumer behavior patterns in response to price signals. Notwithstanding some definitions associate DR to the use of more efficient technology, the reduction in emissions may represent a direct output result from these efficient technologies, and, indirectly be associated

to DR. One of the most common use of DR load management techniques is to load shifting demand in peak-price periods to low-price periods through rescheduling. This would be the optimum approach to reduce the peak-load generation and the emissions at that periods. According to the previous results, from an economic perspective, it is the more viable method to do the opposite (reduce emissions). If performing the reduction of emissions produced by non-RES load during non-peak-hours and, to shift this load to peak-hours, this would result in a reduction of fuel consumption that would lead to CO₂ emissions reduction. This approach would allow to reduce fuel consumption during peak-periods, considering it is less viable to decrease load consumption and avoid emissions from peak load generation units during these hours. According to Strbac (2008) this is the additional value created by DSM as a result of reduced fuel consumption.

This is an optimistic perspective, thus if the marginal generation at the period of the shifting produces null emissions, it is not viable to perform load shifting. When performing the reduction of emissions from non-peak to peak periods, there should be no need to activate peak generating units. From the emission point of view, the reduction of electricity demand during peak-price periods without consuming it later is certainly more environmentally friendly than performing load-shifting. Moreover, despite the emissions of the generation portfolio associated to the specific period and amount of the shifting, load shifting may produce a rebound effect during the other periods and thus, end-users may tend to overconsume electricity during these. The reviewed literature results are not conclusive. There are a large number of variables that change from country to country that may influence positively or negatively DR associated emissions outcomes, such as the supply characteristics, importation from other countries, the demand behavior. Notwithstanding, if DR programs are to be an enabler for a growing integration of renewable energy, reducing the curtailing hours of RES, DR may indeed be used to largely reduce emissions. Additional policy support schemes should enable environmental issues such as programs and auctions concerning low carbon investments.

4.6. REFERENCES

- Abaravicius, J., & Pyrko, J., 2006. Load management from an environmental perspective. *Energy & environment*, 17(4), 583-601. <https://doi.org/10.1260%2F095830506778644189>
- Abdallah, L., & El-Shennawy, T., 2013. Reducing carbon dioxide emissions from electricity sector using smart electric grid applications. *Journal of Engineering*, 2013. <https://doi.org/10.1155/2013/845051>
- Abrell, J., Kosch, M., & Rausch, S., 2019. Carbon abatement with renewables: Evaluating wind and solar subsidies in Germany and Spain. *Journal of Public Economics*, 169, 172-202. <https://doi.org/10.1016/j.jpubeco.2018.11.007>
- Anderson, B., & Bernauer, T., 2016. How much carbon offsetting and where? Implications of efficiency, effectiveness, and ethicality considerations for public opinion formation. *Energy Policy*, 94, 387-395. <https://doi.org/10.1016/j.enpol.2016.04.016>
- Anjo, J., Neves, D., Silva, C., Shivakumar, A., & Howells, M., 2018. Modeling the long-term impact of demand response in energy planning: The Portuguese electric system case study. *Energy*, 165, 456-468. <https://doi.org/10.1016/j.energy.2018.09.091>
- APA, 2019. Portuguese National Inventory Report On Greenhouse Gases, 1990–2017. Retrieved from: https://www.apambiente.pt/_zdata/inventario/2017/20170530/nirglobal20170526.pdf (accessed 12th August 2020).
- Braithwait, S., & Eakin, K., 2002. The role of demand response in electric power market design. *Edison Electric Institute*, 1-57. Retrieved from: http://assets.fiercemarkets.net/public/smartgridnews/sgnr_2007_12014.pdf (accessed 12th August 2020).
- C2ES, 2020. Retrieved from: <https://www.c2es.org/content/international-emissions/> (accessed 12th August 2020).

- Chandran, C. V., Basu, M., & Sunderland, K., 2019, September. Demand Response and Consumer Inconvenience. In *2019 International Conference on Smart Energy Systems and Technologies (SEST)* (pp. 1-6). IEEE. <https://doi.org/10.1109/SEST.2019.8849062>
- Corchero, C., Heredia, F. J., & Cifuentes, J., 2012, May. Optimal electricity market bidding strategies considering emission allowances. In *2012 9th International Conference on the European Energy Market* (pp. 1-8). IEEE. <https://doi.org/10.1109/EEM.2012.6254676>
- Crampes, C., & Renault, J., 2019. How many markets for wholesale electricity when supply is partially flexible?. *Energy Economics*, 81, 465-478. <https://doi.org/10.1016/j.eneco.2019.04.019>
- Dabur, P., Singh, G., & Yadav, N. K., 2012. Electricity demand side management: Various concept and prospects. *International Journal of Recent Technology and Engineering (IJRTE)*, 1(1), 1-6. Retrieved from <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.686.6816&rep=rep1&type=pdf> (accessed 12th August 2020).
- Dahlke, S., & Prorok, M., 2019. Consumer savings, price, and emissions impacts of increasing demand response in the Midcontinent electricity market. *The Energy Journal*, 40(3). <https://doi.org/10.5547/01956574.40.3.sdah>
- Domínguez, R., & Carrión, M., 2019, September. Impact of the Demand Side Management in the Planning and Operations Towards 2050. In *2019 16th International Conference on the European Energy Market (EEM)* (pp. 1-6). IEEE. <https://doi.org/10.1109/EEM.2019.8916414>
- Dones, R., Heck, T., & Hirschberg, S., 2004. *Greenhouse gas emissions from energy systems: comparison and overview* (No. CH--0401).
- EEA, 2016. Transforming the EU power sector: avoiding a carbon lock-in. EEA Report No 22/2016. Retrieved from: <https://www.eea.europa.eu/publications/transforming-the-eu-power-sector> (accessed 12th August 2020).

EIA – US, 2013. How much carbon dioxide is produced when different fuels are burned. Retrieved from: <https://www.eia.gov/tools/faqs/faq.php?id=73&t=11> (accessed 12th August 2020).

Euroelectric, 2020. Decarbonisation Pathways euroelectric. Retrieved from: <https://cdn.euroelectric.org/media/3457/decarbonisation-pathways-h-5A25D8D1.pdf> (accessed 05th November 2020).

European Climate Foundation, 2010. A Practical Guide to a Prosperous, Low-Carbon Europe. Retrieved from: http://www.roadmap2050.eu/attachments/files/Volume1_fullreport_PressPack.pdf (accessed 12th August 2020).

Fallahi, Z., & Smith, A. D., 2017. Economic and emission-saving benefits of utilizing demand response and distributed renewables in microgrids. *The Electricity Journal*, 30(9), 42-49. <https://doi.org/10.1016/j.tej.2017.10.008>

Gerbaulet, C., von Hirschhausen, C., Kemfert, C., Lorenz, C., & Oei, P. Y., 2019. European electricity sector decarbonization under different levels of foresight. *Renewable Energy*, 141, 973-987. <https://doi.org/10.1016/j.renene.2019.02.099>

Goutte, S., & Vassilopoulos, P., 2019. The value of flexibility in power markets. *Energy policy*, 125, 347-357. <https://doi.org/10.1016/j.enpol.2018.10.024>

Gugler, K., Haxhimusa, A., & Liebensteiner, M., 2019. Effective Climate Policy Doesn't Have to be Expensive. <https://epub.wu.ac.at/id/eprint/7166>

Heydarian-Forushani, E., Golshan, M. E. H., & Siano, P., 2017. Evaluating the benefits of coordinated emerging flexible resources in electricity markets. *Applied Energy*, 199, 142-154. <https://doi.org/10.1016/j.apenergy.2017.04.062>

Hintermann, B., 2016. Pass-through of CO₂ emission costs to hourly electricity prices in Germany. *Journal of the Association of Environmental and Resource Economists*, 3(4), 857-891.

Holland, S. P., & Mansur, E. T., 2008. Is real-time pricing green? The environmental impacts of electricity demand variance. *The Review of Economics and Statistics*, 90(3), 550-561. <https://doi.org/10.1162/rest.90.3.550>

IAEA, 2016. Nuclear Power and the Paris Agreement. Retrieved from: <https://www.iaea.org/sites/default/files/16/11/np-parisagreement.pdf> (accessed 12th August 2020).

IEA, 2019. Retrieved from: <https://www.iea.org/reports/world-energy-outlook-2019/electricity> (accessed 12th August 2020).

United Nations, 1987. Report of the World Commission on Environment and Development: Our common future. Accessed Feb, 10.

IPCC, 2014. IPCC (Intergovernmental Panel on Climate Change). (2014). Synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change. *Geneva Switzerland, 2014*, 151.

Jägemann, C., Fürsch, M., Hagspiel, S., & Nagl, S., 2013. Decarbonizing Europe's power sector by 2050—Analyzing the economic implications of alternative decarbonization pathways. *Energy Economics*, 40, 622-636. <https://doi.org/10.1016/j.eneco.2013.08.019>

Madaeni, S. H., & Sioshansi, R., 2012. Using demand response to improve the emission benefits of wind. *IEEE Transactions on Power Systems*, 28(2), 1385-1394. <https://doi.org/10.1109/TPWRS.2012.2214066>

Matos, H. C. S., 2015. *Central termoelétrica de Setúbal a património industrial por reutilização adaptativa* (Doctoral dissertation). <http://hdl.handle.net/10451/17941>

McKenna, E., & Darby, S. J., 2017. How much could domestic demand response technologies reduce CO2 emissions?. *European Council for an Energy-Efficiency Economy*.

Moro, A., & Lonza, L., 2018. Electricity carbon intensity in European Member States: Impacts on GHG emissions of electric vehicles. *Transportation Research Part D: Transport and Environment*, 64, 5-14. <https://doi.org/10.1016/j.trd.2017.07.012>

OMIE, 2020. Retrieved from: https://www.omie.es/es/file-access-list?parents%5B0%5D=/&parents%5B1%5D=Mercado%20Diario&parents%5B2%5D=Subtotales&dir=Energ%C3%ADa%20total%20desglosada%20tras%20del%20mercado%20diario&readdir=pdbc_stota (accessed 27th May 2020).

Orecchini, F., & Naso, V., 2011. *Energy systems in the era of energy vectors: a key to define, analyze and design energy systems beyond fossil fuels*. Springer Science & Business Media.

Papaefthymiou, G., Grave, K., & Dragoon, K., 2014. Retrieved from: Flexibility options in electricity systems. *Project number: POWDE14426, Ecofys*. <https://www.ourenergypolicy.org/wp-content/uploads/2014/06/Ecofys.pdf> (accessed 27th May 2020).

Parvania, M., Fotuhi-Firuzabad, M., & Shahidehpour, M., 2011, July. Assessing impact of demand response in emission-constrained environments. In *2011 IEEE Power and Energy Society General Meeting* (pp. 1-6). IEEE. <https://doi.org/10.1109/PES.2011.6039627>

PORDATA, 2020. Emissões de gases com efeito de estufa: total e por alguns sectores de emissões de gases. Indústrias de energia. <https://www.pordata.pt/Europa/Emiss%C3%B5es+de+gases+com+efeito+de+estufa+total+e+por+alguns+sectores+de+emiss%C3%B5es+de+gases-1481-313037> Retrieved from: (accessed 20th August 2020).

Qdr, Q. J. U. D. E., 2006. Benefits of demand response in electricity markets and recommendations for achieving them. *US Dept. Energy, Washington, DC, USA, Tech. Rep.* Retrieved from: <https://eetd.lbl.gov/sites/all/files/publications/report-lbnl-1252d.pdf> (accessed 2nd January 2020).

Quaschnig, V., 2016. Future Energy Demand and Climatic Protection, p.41: In *Understanding renewable energy systems*. Earthscan Publications Ltd., Routledge.

REE, 2020. CO₂ emissions of electricity generation in Spain. Retrieved from: <https://api.esios.ree.es/documents/591/download?locale=es> (accessed 27th July 2020).

- Ruokamo, E., Kopsakangas-Savolainen, M., Meriläinen, T., & Svento, R., 2019. Towards flexible energy demand—Preferences for dynamic contracts, services and emissions reductions. *Energy Economics*, 84, 104522. <https://doi.org/10.1016/j.eneco.2019.104522>
- Schnaars, P., 2019. The Real Substitution Effect of Renewable Electricity: An Empirical Analysis for Germany. Available at SSRN 3411782. <https://dx.doi.org/10.2139/ssrn.3411782>
- Schrattenholzer, L., Miketa, A., Riahi, K., & Roehrl, R. A., 2004. Sustainable development and climate change p.3: In *Achieving a sustainable global energy system: identifying possibilities using long-term energy scenarios*. Schrattenholzer, L., Miketa, A., Riahi, K., & Roehrl, R. A. (Eds.). Edward Elgar Publishing.
- Schwabeneder, D., Fleischhacker, A., Lettner, G., & Auer, H., 2019. Assessing the impact of load-shifting restrictions on profitability of load flexibilities. *Applied Energy*, 255, 113860. <https://doi.org/10.1016/j.apenergy.2019.113860>
- Silva, S., Soares, I., & Pinho, C., 2012. The impact of renewable energy sources on economic growth and CO2 emissions: a SVAR approach. <https://www.um.edu.mt/library/oar/handle/123456789/31326>
- Schneidewind U., Augenstein K. & Scheck H, 2013. The Transition to Renewable Energy Systems – On the Way to a Comprehensive Transition Concept. In *Transition to renewable energy systems*. Stolten, D., & Scherer, V. (Eds.), 2013. John Wiley & Sons.
- Strbac, G., 2008. Demand side management: Benefits and challenges. *Energy policy*, 36(12), 4419-4426. <https://doi.org/10.1016/j.enpol.2008.09.030>
- Torriti, J., Hassan, M. G., & Leach, M., 2010. Demand response experience in Europe: Policies, programmes and implementation. *Energy*, 35(4), 1575-1583. <https://doi.org/10.1016/j.energy.2009.05.021>
- Tsarakakis, G., Thomson, R. C., Collin, A. J., Harrison, G. P., Kiprakis, A. E., & McLaughlin, S., 2016. Assessment of the cost and environmental impact of residential demand-side management. *IEEE Transactions on Industry Applications*, 52(3), 2486-2495. <https://doi.org/10.1109/TIA.2016.2516478>

Vasconcelos, J., 2019. p. 36. A Energia em Portugal. Fundação Francisco Manuel dos Santos. Lisboa.

Ward, K. R., Green, R., & Staffell, I., 2019. Getting prices right in structural electricity market models. *Energy Policy*, 129, 1190-1206. <https://doi.org/10.1016/j.enpol.2019.01.077>

Weisser, D., 2007. A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies. *Energy*, 32(9), 1543-1559. <https://doi.org/10.1016/j.energy.2007.01.008>

Werner, K., Nissler, D., & Purr, K., 2013. Germany 2050: A Greenhouse Gas-Neutral Country. Retrieved from: https://www.umweltbundesamt.de/sites/default/files/medien/376/publikationen/germany_2050_a_greenhouse_gas_neutral_country_langfassung.pdf (accessed 2nd January 2020).

Yilmaz, S., Rinaldi, A., & Patel, M. K., 2020. DSM interactions: What is the impact of appliance energy efficiency measures on the demand response (peak load management)?. *Energy Policy*, 139, 111323. <https://doi.org/10.1016/j.enpol.2020.111323>

Zeng, B., Zhang, J., Yang, X., Wang, J., Dong, J., & Zhang, Y., 2013. Integrated planning for transition to low-carbon distribution system with renewable energy generation and demand response. *IEEE Transactions on Power Systems*, 29(3), 1153-1165. <https://doi.org/10.1109/TPWRS.2013.2291553>

Zhang, Q., Mclellan, B., Utama, N. A., Tezuka, T., & Ishihara, K. N., 2011. Long-Term Scenario Analysis of a Future Zero-Carbon Electricity Generation System in Japan Based on an Integrated Model. In *Zero-Carbon Energy Kyoto 2010* (pp. 17-24). Springer, Tokyo. https://doi.org/10.1007/978-4-431-53910-0_2

5

CONCLUSIONS

5.1. FINAL CONSIDERATIONS

The rapid growth of technologies for renewable generation of electricity started in the late 90's due to the environmental concerns caused by the burning of fossil fuels. Moreover, the various energy crises – the first in the 1970s - exposed the important role of energy in the countries' economies and their respective economic security. In last two decades, the installed capacity of RES-I has been increasing sharply. The massive integration of RES is necessary for decarbonizing the economy and mitigating climate change, originating an oversupply situation in wholesale energy markets. This situation originated a decrease in prices on the wholesale electricity market, which in some markets, such as the EEX, might be negative prices during some periods. As a direct consequence, thermal power plants profitability is being reduced, to an extent where several plants have already been closed down. This might affect new investments necessary to replace or renew older power plants. However, these power plants, are still important in order to keep load balancing and guarantee security of supply, particularly during peak-load periods. Additionally, to low electricity prices, thermal plants cannot benefit from the same support schemes as RES. Renewable energy, on the other hand, benefits from support schemes such as green certificates and price guarantees. These benefits effectively work similarly to capacity mechanisms.

From a market point of view, the price setting is based on short-term marginal cost of the marginal producer, regardless if prices are low or high. However, during scarcity periods, prices tend to rise. On the assumption demand keeps increasing and more thermal power plants are decommissioned, there is a risk of strategic capacity reserves fail to meet the demand. Increasing the flexibility through Demand Response participation in competitive electricity

markets, would help during price spikes, particularly if consumers are sensible to spot price-based tariffs. Consumer participation on energy markets and response to dynamic prices, usually through third party aggregators, would increase market efficiency. If DR acts as a price setter, marginal producers would get revenues to cover their fixed costs and to perform investments in the existing generation portfolio or in new generation assets.

The success of DR programs is dependent on consumer satisfaction and acceptance. If on one hand, consumers' responsiveness is crucial for DR full implementation, on the other hand, consumers' response to electricity prices is affected by a number of factors that influence their behavior. In addition to difficulties in foreseeing and anticipating human behavior, to the privacy concerns associated to consumers energy data and their security, consumers may face difficulties in being flexible response agents, when society, particularly schools and labor working hours, are organized in a non-flexible way. The results of the first model indicate that, regardless the market, during peak-hours, week-days and periods of the year with more heating needs, DR economic potential tend to decrease when compared with the opposite scenarios. Due to other reasons, namely health ones, presently, there is being done an effort to mismatch routines. This disparity will allow a more flexible use in electricity consumption and thus, it will reduce a peak demand request for energy during very specific periods, dissolving it for a larger period of time what will help the power sector to keep the balance between the supply and the demand and reduce power system constraints.

Energy markets operation is quite complex and risk may be attributed to a large number of variables. Risk may be seen as something inherent to all economic activities. Several variables were identified to be associated to risk. Some variables were common to all market structures and others differ according to specific market structure characteristics. Some of these variables were interlinked among each other, which increases the difficulties in analyzing their possible effects, thus they cannot be interpreted separately.

These variables are associated to present and past conditions of the market. With the development of new market design structures, some of these variables associated to risk may disappear, new ones may arise, such as the climatic conditions and its impacts on generation portfolio, will persist on time. The existing differences among different market designs suggest

some difficulties in finding arguments towards a unique solution regarding market design. In some market design structures, the need to adequate or not the design might be further explored.

In future, DR mechanisms might work as a support risk control tool, thus it will help to increase both market operation efficiency and energy-trader's confidence. Moreover, DR, if properly operated, will be able to throw itself into the ancillary services, and may act as a strategic reserve during contingencies, offering load reductions to solve short-term constraints in the system, representing a possible planning resource. Despite the existing barriers towards DR, presently, there is a huge potential unexploited from load flexible consumers. The existence of a double side market would incentivize demand-side to participate in flexibility markets. Flexible consumers represent in other economic sectors an important role, such as stock release. The present energy-only characteristics of the energy market may help to explain the absence of flexibility, namely:

- The absence of price-sensitive and responsive demand,
- Electricity storage limitations,
- Market power exercise during periods of high demand.

The utilization of flexibility potential has several positive effects for the entire power sector chain, from generator companies to end-users. Moreover, flexibility emerges comprehensive benefits, thus it comprises technical, economic and social positive outcomes.

The decarbonization of the economy is key in the present European energy framework. There are several possible energy policy choices that can be done in order to regulate market structures and its design. In order to be effective, DR needs a regulatory framework to successfully integrate and harmonize three distinct vectors: the technical, the economical and the social. In addition to Respect countries autonomy to transpose the directive and develop national regulations, each region should develop harmonized regulation in order to englobe local specificities and market characteristics but having in account the connections with other markets.

The possible impact of DR on wholesale energy markets, will differ according to region thus the generation mix and the technology characteristics differs substantially. Moreover, with the

increasing integration of stochastic RES in the generation mix, climatic conditions may affect DR potentials and produce variations in CO₂ emissions associated to electricity production.

The results indicate that, during dry years, countries with more hydropower installed capacity in their generation mixes, would tend to compensate using more fossil-fuel generation technologies. During years with more thermal generation, the DR levels would tend to increase, despite, in general, for all the three analyzed markets there is not a clear tendency for DR potential. This may be explained due to the increasing renewable energy shares in all the energy markets. With the European stricter environmental and decarbonization targets it is expected that renewable generation participation will continue to expand on most energy markets. The model was developed based on the present model of the energy-only energy market. Despite DR was economically viable during some periods in all the three markets, this might indicate that the energy-only energy market design is not the one that best suits with the increasing renewable share generation participation. The present energy-only energy market was projected without having in account such larger shares of renewable generation and a relevant participation of thermal generation loads. Presently, these two types of generation compete and participate in the same market structure but they represent different types of product due to their technical and economic specific characteristics. Renewable generation has a stochastic nature and the production fluctuates intermittently, while thermal generation has more flexibility but higher production costs.

The existence of a double-side market structure would allow consumers to choose between a flexible or non-flexible profile. Presently, consumers cannot participate in the market individually or through aggregators “*offering*” their flexibility. Moreover, most are not aware of peak-prices and the existence of an auction for each hour in wholesale energy markets.

The increasing penetration of flexible loads in the energy market is commonly associated to an increase in prices elasticity. The increasing penetration of flexible loads correspond to a general decrease on wholesale energy market prices, particularly during non-peaking periods, or periods where the demand does not require relevant load amount from the generation supply capacity. However, during peak-periods, the application of flexible loads does not reveal to be crucial in order to reduce the prices. The possible exercise of market power during these periods may help to explain these results. When comparing the introduction of larger flexibility load

level with lower flexibility load level, there were similar price variation. Apparently with a lower flexibility load level the economic results would be similar. These results are favorable towards DR integration on energy markets, thus it is results that indicate it is possible to achieve similar results with lower percentages of load flexibility.

In all the three electricity markets, DR was economically viable considering the actual energy market model structure. However, in Germany the potential results were slightly below the potential of Portugal and Spain. The presence of negative prices may be a factor that help to justify the obtained results. But, per other side, during the last years the penetration of renewables has been increasing in this energy market, and this is considered to be the reason for the increasing number of hours with negative prices. The most negative tend to be the spot prices, the lower tend to be the economic potential for DR. Despite the clear differences, particularly the existence or not of negative prices, in the three analyzed countries renewable increasing participation influentiate towards a less favorable economic DR potentials.

Focusing on the emission impact associated to DR potential, according to literature the numerous existing definitions of DR, none explicitly associates DR to emissions reductions, thus most associate it to shift in consumer behavior patterns in response to price signals. Notwithstanding some definitions associate DR to the use of more efficient technology, this efficiency increase will result on CO₂ emission reduction represent a direct output from the use efficient technologies, and, may indirectly be associated to DR. However, DR cannot be directly associated to emission reductions, thus emissions are dependent of marginal generation at the time and location of deployment as well as the magnitude of demand shifting mechanisms.

However, this does not mean that DR cannot be used as source control. On the contrary, if DR mechanisms aim to target emissions reduction and if performing the load reduction or shifting during periods with fossil fuels generation to other periods, a certain emission level could be offset. When performing the total balance of fossil fuel consumption in the two hours (the one with curtailing and the one that received the load) there would be a reduction of fossil fuel consumption that would lead to CO₂ emissions reduction. In order to combine this with the economic model results, it was admitted that the load-shifting mechanism was performed from non-peak hours to peak-hours, having in mind that the opposite concept is more common. Assuming that non-renewable production will always be necessary to produce at peak hours the emission model assumes that instead producing all the non-renewable load at peak hours a part

of it could be transferred from non-peak hours. In this way a certain percentage of the non-renewable production would be offset to produce by peak generation units at these hours.

According to this study results load-shifting mechanisms full implementation may be difficult to achieve. From the emission perspective, the reduction of electricity demand during peak-price periods without consuming it later is certainly more environmentally friendly than shifting the load. But it should not be forgotten that one of the most significant promises associated to DR is related to the elasticity increase of consumers resulting in an increased efficiency of wholesale market operations. The existence of a double-side market would allow consumers to choose between a flexible or non-flexible profile.

Despite load flexibility is a recognized concept, the concept of DR is unknown for most people. DR successfully implementation is not just about potential. Regulation, economic, and technological barriers will have to be overcome towards DR implementation. It depends on a large number of variables and actors that play very different roles. But perhaps the most powerful enabler for DR is information and population education. DR affirmation will depend on the value that people attribute to it.

5.2. FURTHER WORK

Future work may be developed focusing on different perspectives. Three main groups of research were identified:

Group 1: Wholesale energy markets

The present analysis was focused on DR potential on wholesale markets. However, the developed model included some limitations. This research conducted an ex-post analysis based on real historical data from day-ahead spot market prices and demand values, for a continuous period for Portugal, Spain and Germany. The identified variables and the results for DR potential may differ if the future conditions change. To evaluate how the load flexibility potential would be affected within a dynamic model with different generation portfolio options,

including existing and perhaps new technology possibilities for generation assets, would be of particular interest.

Group 2: Intra-day and real-time energy markets

The economic benefits of DR integration in day-ahead markets were assessed in this research. This study results indicate that benefits may not be totally accomplished in the day-ahead scale. The exploration of other time scales, such as intraday markets and real time markets or balancing markets, could provide additional information regarding load flexibility potential. Economists defend that adjusting prices in real time or very close to real time could lead to a true interaction between supply and demand in the setting of the price. For this reason, intra-day markets might also provide more economic benefit for load shifting than day-ahead markets.

Group 3: Development of business models for DR

The successful integration of DR cannot be dissociated from the development of business models for EE and DR providers. Different segments of consumers as well as different market designs, may open the path for different business models that might be tailored-design to each market segment. Moreover, the development of business models for DR, will imply DR providers to be aware about consumer profile patterns. A better knowledge about consumption profiles allows utilities to develop specific DR programs to achieve specific targets of consumers. However, this will imply challenges regarding data security, to assure users data confidentiality and to deal with large amounts of information from consumers.

ANNEX

Daily aggregated CO ₂ emissions for Portugal and Spain, both for 5% and 15% load shifting scenarios [T.CO ₂]																																
PT 2015_ 5% Scenario																																
January																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
717	794	734	712	834	809	903	799	836	682	719	771	768	775	703	705	697	641	754	802	731	717	724	719	673	823	825	831	714	564	8		
February																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28					
111	588	619	611	624	695	612	593	612	892	932	993	734	589	397	604	643	615	804	733	602	8	467	386	536	623	630	604					
March																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
249	563	763	600	332	625	722	648	696	738	738	735	708	709	704	731	724	717	681	637	721	651	738	702	704	715	692	713	557	615	705		
April																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30			
449	582	670	295	157	510	599	592	671	833	743	520	606	637	773	780	860	625	597	743	615	715	833	759	606	404	587	793	842	669			
May																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
588	595	557	608	530	804	668	531	617	611	732	731	617	612	595	587	363	676	607	665	608	610	561	359	586	653	748	828	915	811	779		
June																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30			
1005	1032	963	970	925	791	739	1045	1067	955	1072	1072	770	618	813	898	736	700	767	717	738	986	1007	1012	1021	1023	833	739	1046	1020			
July																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
1029	1032	1028	946	739	1049	1078	1078	1066	1030	814	677	931	953	885	898	1017	916	810	1000	1020	689	1016	1008	827	738	985	1008	999	865	901		
August																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
786	738	978	1006	1011	1021	1017	724	614	938	1017	1014	740	901	740	738	955	963	961	967	1009	809	543	944	1012	915	740	880	787	614	836		
September																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30			
1058	1071	921	1019	799	800	1058	1044	1145	1101	977	828	494	709	782	582	825	971	738	738	1018	835	899	888	981	860	739	959	992	1049			
October																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
960	994	926	674	727	794	988	989	990	875	897	792	929	935	868	981	838	917	979	904	942	961	980	977	804	897	894	739	946	858	762		

PT 2016_5% Scenario																														
November																														
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451	671	887	951	896	975	921	698	984	986	1005	997	926	897	828	987	987	984	994	896	265	483	851	873	763	856	961	806	779	936	
December																														
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1062	1060	930	1005	932	916	857	894	987	1046	996	968	713	862	869	1010	945	769	539	556	902	885	972	778	715	688	299	582	864	649	806
January																														
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317	365	6	417	497	6	360	473	174	3	325	637	855	640	673	528	640	819	1011	1017	1010	936	836	642	878	942	860	959	834	791	526
February																														
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807	856	738	712	819	426	6	351	201	440	620	108	3	0	0	403	674	641	694	679	338	717	631	617	425	98	3	0	67		
March																														
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394	11	333	6	3	0	3	391	326	78	451	496	367	666	872	749	827	944	716	750	759	708	586	547	432	5	31	0	368	560	254
April																														
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538	349	5	290	289	319	301	77	0	0	0	9	8	301	336	5	0	0	0	288	406	655	294	5	186	327	480	481	495	210	
May																														
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3	258	305	474	537	655	9	0	70	175	346	297	5	0	0	0	606	585	491	658	5	0	486	568	817	739	818	368	6	728	923
June																														
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July																														
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1071	876	583	1158	1236	1198	1233	1228	1013	758	997	1033	986	960	1049	1029	924	1188	1203	1202	1153	1088	944	609	1054	1139	1140	1112	1161	951	764
August																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1122	1155	1178	1166	1085	816	712	712	1010	691	902	1156	1012	809	996	1175	1148	1198	889	925	757	1130	1097	1172	1162	1039	916	750	1019	1148	1179

September																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
1113	1142	1129	954	1182	1224	1201	1081	1071	983	892	1050	1053	1053	1043	969	992	745	1024	1049	1121	1132	1134	1004	856	1117	1057	1033	1069	1063	
October																														
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943	810	1057	1168	1106	1120	1098	849	721	979	872	924	984	975	798	722	984	979	1046	986	978	742	658	937	950	963	972	956	837	640	892
November																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
749	991	1034	1038	781	706	991	982	948	1030	1037	995	712	947	1001	1045	1042	1016	786	549	820	1152	1090	1092	1032	869	882	1151	1149	1073	
December																														
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1135	1165	849	746	1105	1159	1160	987	972	1023	955	1172	1166	1157	1116	1154	962	881	1158	1155	1164	1167	1159	855	787	841	1038	1012	1008	1074	1066
PT 2017 5% Scenario																														
January																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
879	1118	1178	1201	1169	930	837	777	1145	898	1083	1079	1062	885	806	1060	1071	1126	1202	1206	1079	882	1212	1170	1218	1158	1062	854	829	1084	1089
February																														
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1032	772	822	584	257	836	1021	1063	1069	1184	789	568	870	1024	1035	1046	1053	1037	526	878	812	885	957	853	921	822	759	679			
March																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1009	1118	776	379	7	505	1003	1012	892	1005	823	31	418	597	821	902	861	869	829	910	926	707	952	1029	699	347	829	1005	1006	881	788
April																														
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327	230	1001	919	766	664	887	825	658	1008	1004	1164	945	804	725	620	921	953	734	828	939	990	862	1254	1089	1044	947	1073	872	78	
May																														
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379	1144	1190	1197	955	772	893	1075	1219	1195	815	894	838	1054	1203	1299	1197	822	1076	1076	750	1163	961	1119	1234	1290	1079	863	1279	1243	1172
June																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
1224	1174	1067	787	1028	1197	1273	1279	1320	1190	764	1211	1293	1309	1301	1275	1138	1044	1238	1167	1232	1301	1277	1266	988	1244	1297	889	959	1011	

July																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
690	713	1135	1302	1251	1201	1176	1178	996	1174	1329	1381	1350	1339	1164	1076	1314	1340	1342	1315	1272	1249	973	1192	1267	1358	1372	1330	1133	855	1211	
August																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
1364	1395	1383	1375	1080	889	1332	1212	1111	1138	1075	1076	936	1330	977	1366	1371	1362	1211	896	1373	1371	1381	1380	1399	1375	1211	1371	1391	1380	1322	
September																															
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1257	1077	1204	1323	1379	1134	1284	1259	787	513	1166	1334	1345	1158	1079	1137	975	1088	1177	1180	1157	1157	1087	993	1127	1170	1241	1227	1243	1094		
October																															
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871	1104	1188	1093	1099	942	926	887	1101	1181	1174	1068	1161	1156	742	929	1080	1138	1110	1017	783	720	994	1035	1051	1029	1031	564	464	719	945	
November																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
695	981	1119	1018	1067	1067	1214	1222	1218	1222	1042	936	1008	1206	1290	1302	1300	952	774	1167	1282	1132	1035	1171	875	777	1086	998	1032	975		
December																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
899	953	893	1084	1176	1047	1095	919	961	604	792	1138	1140	935	1076	985	896	1110	1118	1165	1155	1053	858	780	634	658	559	633	625	406	7	

PT 2018 5% Scenario																																
January																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
5	443	587	616	624	591	703	1030	1011	945	885	1190	1133	999	1261	1033	1064	1316	1206	729	537	1078	1293	1208	1101	862	781	722	1156	1145	1190		
February																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28					
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March																																
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688	660	282	285	586	654	604	490	140	3	0	124	381	8	75	313	141	40	89	40	350	655	296	0	69	460	383	435	0	0	0		
April																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30			
0	0	0	0	87	2	0	0	100	379	45	279	815	653	10	564	645	714	382	2	0	0	578	428	96	101	182	56	0	100			

May																															
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June																															
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July																															
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728	1146	1226	1213	1175	1217	1173	1016	1142	1211	1185	1222	1219	1177	922	1103	1105	1161	1092	1220	1093	922	1044	1269	1262	1270	1198	1036	780	1130	1224	
August																															
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1201	1286	1316	921	785	1031	1194	1192	1190	1178	1135	857	1103	1121	962	1133	1101	596	335	859	1145	1125	1135	1065	1133	963	1162	1254	1132	1247	1241	
September																															
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976	916	1080	1138	1144	1139	1103	994	1018	1153	1202	1271	1207	1202	1140	1047	1274	1285	1300	1295	1295	1143	848	960	1011	1219	1247	1136	938	870		
October																															
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777	924	1082	1164	1016	827	283	837	1078	996	859	551	478	11	834	985	1118	939	586	369	417	665	711	1081	1233	1226	514	267	690	1069	0	
November																															
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1274	1027	914	680	810	650	765	911	637	359	358	983	1098	918	1024	1072	596	328	938	807	1081	1090	1115	856	575	709	1050	1057	1050	1064		
December																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
673	454	919	1042	1024	833	798	704	562	955	1054	1032	721	926	762	462	932	832	658	770	700	829	789	811	676	731	841	855	391	429	725	
PT 2019 5% Scenario																															
January																															
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707	851	1092	1161	1013	517	980	870	762	917	1039	810	620	982	1150	1164	1089	1118	944	612	1029	1054	549	560	958	739	6	364	410	569	387	
February																															
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368	1	193	766	872	680	613	623	478	6	590	792	814	554	708	498	309	712	836	836	384	480	491	432	653	542	576	563				

March																															
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667	525	21	414	582	0	523	814	682	458	458	458	343	611	504	407	0	378	473	397	507	574	548	19	0	0	266	501	572	505	474	
April																															
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882	972	723	753	609	21	217	709	537	694	779	1020	946	695	715	891	169	366	5	1	0	110	222	5	0	333	409	328	531	540		
May																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
173	189	316	131	126	783	657	0	192	364	491	20	558	765	994	747	209	249	217	859	1078	1202	1160	350	114	60	401	245	281	847	1035	
June																															
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868	190	1020	500	204	530	266	429	143	532	626	906	868	843	651	539	967	884	1017	959	691	563	246	957	1146	890	1129	1208	1046	718		
July																															
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890	1043	1170	1302	1362	1197	837	1159	1307	1225	1321	1330	994	553	944	1015	1078	1106	1068	305	333	908	1273	1270	802	792	237	210	302	539	437	
August																															
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565	706	499	274	641	677	704	530	274	445	127	347	386	535	195	390	267	129	372	405	502	417	432	284	198	468	480	717	904	928	456	
September																															
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141	351	510	528	197	193	160	178	550	246	338	444	465	302	224	610	807	823	836	695	241	135	556	547	584	628	589	539	203	601		
October																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
575	405	544	679	604	308	768	1078	833	754	956	181	107	379	419	406	565	525	194	117	763	702	705	498	572	171	168	905	1003	1002		
November																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
56	52	52	71	219	287	394	362	296	152	479	581	604	508	601	608	332	946	1194	1145	1079	421	104	86	879	364	363	283	551	178		
December																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
195	295	956	1227	867	810	796	109	247	491	308	131	94	95	81	392	510	170	83	51	0	0	0	72	0	120	205	135	92	200	222	

PT 2020 5% Scenario																														
January																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
82	359	441	89	249	471	687	654	547	504	423	398	554	458	444	296	495	244	2	307	364	472	846	1012	936	253	355	430	435	356	365
February																														
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4	24	461	428	497	509	520	460	12	135	433	553	519	541	202	4	210	438	479	478	477	465	235	411	9	99	57	208			
March																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0	0	46	197	73	1	151	187	313	388	469	490	408	421	100	124	173	238	306	308	325	325	274	320	323	70	70	236	61	4	0
April																														
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256	230	96	3	0	199	51	122	114	4	44	1	87	46	5	0	1	41	1	0	0	0	0	0	4	1	74	71	3	0	
May																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0	0	0	0	34	91	88	41	3	0	0	182	213	230	190	2	0	156	356	380	380	382	68	0	190	184	319	340	431	336	235
June																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
458	538	493	217	272	229	57	270	374	402	213	128	133	167	373	385	441	435	395	234	153	196	374	416	483	372	146	140	313	386	

ES 2015_5% Scenario																																
January																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
1400	1999	1924	1464	2540	2247	3011	3487	3401	2985	1080	2819	2928	3257	2200	2341	1814	1214	2298	3340	2973	2834	2926	2127	969	2869	2847	2839	1416	596	283		
February																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28					
313	1351	1086	717	1085	1465	1552	614	2081	3479	3664	3758	2871	501	322	1764	673	1703	2448	2322	313	274	390	386	394	540	529	525					
March																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
333	996	1834	513	389	1172	508	421	1888	2621	2180	1660	710	345	482	1777	1516	1516	514	521	804	441	1619	1624	715	1137	1416	987	435	988	1196		
April																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30			
490	412	371	318	313	419	829	653	1754	2565	2433	409	1280	1732	2408	2796	2608	1834	1070	2798	2128	2530	2968	3198	712	430	1235	1838	1812	1558			
May																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
523	850	921	1442	2010	1993	2422	835	1810	985	2311	2739	2421	1214	557	432	410	1874	893	1505	1306	778	456	371	1139	1344	1863	2468	2528	2536	2213		
June																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30			
3110	2965	2820	2791	3448	2448	1740	3162	3645	3678	3737	3654	3412	2864	4474	3380	3347	2331	2467	2212	2288	3470	3588	3457	3854	3724	3131	2625	3616	3633			
July																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
3638	4073	3473	3241	2486	3976	4152	3800	3882	4112	3243	3073	3977	3967	3952	4351	4280	3453	2916	4359	4355	4266	4069	3603	2631	2541	3495	3743	3567	3455	3481		
August																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
3133	2105	3382	3896	3569	3734	3454	2473	1890	3522	3681	3649	3059	2580	1939	2125	3279	3342	3281	3426	3636	2934	484	2158	3552	2905	2544	3533	2450	1783	3588		
September																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30			
3543	3617	2972	2938	2702	2479	3684	3819	3675	3654	3251	2340	334	2127	1708	437	2293	2729	1636	1517	2916	2246	2336	2671	2535	2319	1427	3302	2945	3160			
October																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
3416	3333	2769	546	910	1394	3385	3285	3235	1865	1376	1676	2142	2484	2898	3305	1218	1366	2649	2214	2346	2496	2806	2804	1926	2373	2122	1962	2428	2021	2063		

November																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
409	1673	2482	2873	2879	3073	2576	1008	3357	3567	3570	3667	3293	2548	2559	3402	3127	3251	3257	2501	472	464	2763	3621	2715	3042	3339	2414	2755	3473		
December																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
4022	3995	3860	4032	3484	2617	2450	2912	3529	4014	4065	3547	2417	3131	2802	3163	3014	3092	2062	2443	3853	3030	3220	2400	1322	942	349	488	1807	1100	1504	
ES 2016 5% Scenario																															
January																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
389	458	380	540	451	366	451	459	379	332	384	984	1630	1371	1228	769	862	1756	2674	3075	3321	2817	2000	423	2357	3463	2385	2274	2366	1459	573	
February																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28				
2548	2378	853	1128	1954	445	341	451	341	387	315	203	194	165	205	575	1627	1958	1903	525	320	1212	914	400	311	268	177	172				
March																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
235	237	269	155	140	133	163	171	175	165	169	166	133	984	1954	1381	2161	2242	1564	1164	1420	981	174	108	99	99	163	130	121	131	175	
April																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
148	160	133	166	169	237	166	165	159	117	137	150	125	99	125	100	64	101	137	92	92	316	126	95	80	72	128	103	177	95		
May																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
95	131	123	131	355	555	98	45	142	122	131	127	155	132	119	132	132	254	165	166	164	65	131	164	131	533	261	146	95	95	341	
June																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
289	1000	1027	346	381	1736	2375	2000	2095	696	759	465	483	313	135	136	808	139	96	1339	1706	906	1132	773	211	176	1265	2365	2701	2854		
July																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
2841	1404	624	2481	2979	2775	3208	2994	2012	1281	2452	2226	1691	1429	1317	1123	869	2507	3101	3198	3320	2120	997	940	2231	2477	2510	2931	3041	1988	883	
August																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
2705	3075	3147	3004	2295	686	229	229	601	365	634	1394	1189	515	797	2402	2743	2773	2451	1037	864	2367	2607	2358	1984	2447	2239	1613	2476	3022	3207	

September																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
3052	3398	2904	2551	3339	3625	3716	3339	3482	2986	2219	2798	2668	2457	2292	1817	620	435	2212	2862	3048	3101	3057	1675	1133	2763	2688	2681	2639	2798		
October																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
2227	1660	2825	3012	2852	3376	3489	2626	1559	3068	3391	2631	3572	3199	2017	1555	3268	3326	3459	3583	3648	2437	1092	3090	3418	3515	3308	3159	2718	2441	2869	
November																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
2576	3598	3840	3765	2048	1091	3407	2968	2758	3537	3623	3160	2019	2951	3683	4424	4161	3774	2651	674	2135	4187	3561	3580	3405	2056	2447	3872	4371	3631		
December																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
4823	5111	3090	1886	3532	3508	3633	2516	2750	2894	3113	4560	5042	4975	4953	4044	2114	2105	3601	3921	3999	4261	3840	2798	2046	2552	3084	2945	2909	3181	2885	
ES 2017 5% Scenario																															
January																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
2482	3874	3820	3751	1737	505	2052	2001	1720	1137	1153	779	516	874	940	2074	2201	2101	410	359	2314	2977	2951	2633	2976	2115	1736	3167	3471	2563	1450	
February																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28				
3349	1913	983	443	79	1225	2532	2865	3117	3330	2367	504	2067	2749	2909	3152	3319	2759	1546	2646	2575	2706	2841	2216	2067	1869	680	438				
March																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
1709	1979	111	77	61	96	716	1661	1655	1250	210	70	70	106	106	245	172	90	102	671	75	106	624	1382	172	59	820	1666	1703	706	462	
April																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
213	132	966	647	60	86	527	780	186	812	1436	1619	1519	247	160	61	629	556	33	33	278	592	1265	1553	1618	1150	1116	1310	1028	58		
May																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
61	1821	2146	2100	714	228	719	1973	2058	1564	370	620	667	975	2339	2937	2456	1232	1758	1571	454	2336	2059	2506	3479	3305	6447	887	2949	3393	3692	
June																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
3794	2999	2251	1221	1846	1821	1984	1737	2951	2480	1518	2363	3145	3944	3551	3158	2742	2364	3772	4740	4962	4763	4233	3329	2754	3908	2828	901	1244	1346		

July																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
1371	631	2184	2883	3235	3680	3652	2678	2262	3634	4082	3957	3345	3660	2138	1518	3543	3466	3649	3258	3093	2172	1612	2178	2062	3130	3484	3437	2495	1920	2998	
August																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
3606	3874	3820	3751	1737	505	2052	2001	1720	1137	1153	779	516	874	940	2074	2201	2101	410	359	2314	2977	2951	2633	2976	2115	1736	3167	3471	2563	1450	
September																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
1179	603	758	2253	2799	1734	1884	2097	227	153	906	1997	2045	1455	1161	586	576	1530	2434	2744	2898	2233	1960	1693	2715	3409	3660	3739	3497	2370		
October																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
1669	2663	2641	3382	3154	2119	1990	2098	3499	3997	3759	3077	3194	2684	1223	2466	2886	3048	2952	2566	1379	1227	2916	3283	3504	3395	3104	794	515	1858	3181	
November																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
1270	3374	3658	2218	2710	2710	3558	3567	3325	3487	2563	1659	2434	3527	4149	4615	4334	3695	3553	4839	4803	3591	3469	3501	2526	2759	4519	3989	4197	4335		
December																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
3411	3532	3410	5165	5841	5161	4670	3636	3272	1017	2439	4429	4429	3239	3170	2875	2598	3932	4091	3786	3498	2440	2121	1747	382	161	62	98	133	88	66	

ES 2018 5% Scenario

January																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
40	62	168	191	170	149	368	3626	3316	2168	1953	3180	2813	2104	3409	2051	2296	3076	2538	628	147	2089	3143	2948	2048	362	231	131	2412	2819	3284
February																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28			
1855	810	675	1533	2470	2289	2794	3844	3540	1306	909	2370	1873	1543	2486	3272	1215	1012	2417	1854	1481	2138	2363	3340	2542	2257	2491	2085			
March																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1293	1215	75	63	744	590	1151	499	142	101	50	86	298	79	87	117	90	61	48	89	114	683	308	86	77	53	222	144	85	40	48
April																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
58	58	62	58	88	48	24	24	24	33	75	259	1303	416	51	57	747	233	78	178	135	143	132	160	160	181	226	135	97	127	

May																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
98	98	98	98	98	98	692	936	760	775	897	134	98	98	126	98	496	837	622	709	1802	2025	2108	2001	1498	1812	1423	1931	2076	2600	2325	
June																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
2171	1498	648	1020	1681	1991	1856	1705	728	406	490	228	202	189	465	127	163	163	165	1201	1060	669	627	689	1521	1417	1374	1302	1396	1108		
July																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
778	1442	2047	1778	1096	1519	1082	547	1668	1978	1961	1975	1823	1607	1004	639	1804	1999	2191	1498	999	716	1737	2080	1960	1926	1810	863	556	1311	1812	
August																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
1207	1696	2278	2234	1790	2919	2445	1872	886	1042	776	273	966	176	104	904	101	68	18	754	1887	2696	2541	1858	834	720	2184	2389	2755	2292	2269	
September																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
983	1113	2387	2523	2770	2758	2304	1813	1763	2200	2078	1824	2028	1879	2052	1911	2370	2773	2024	1904	1746	1465	1690	1430	1880	2168	2580	2634	2073	1619		
October																															
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867	1275	1505	2097	2043	1342	310	2317	2156	1558	1654	727	774	180	1920	2621	2218	2171	1405	713	981	1787	1911	2647	3268	3078	636	50	585	2260	2973	
November																															
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1363	2048	2099	1413	2151	1833	2137	2071	951	21	208	2969	3598	2729	2987	2921	1775	950	3744	2955	3113	3353	3484	2264	1635	1653	3367	2995	2684	2730		
December																															
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1409	598	2135	2874	2538	1588	1377	1379	1097	2102	3298	2683	1784	1979	1268	729	2684	1890	1875	2255	1399	1373	1434	1622	1327	1784	1529	1546	35	12	971	
ES 2019 5% Scenario																															
January																															
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684	704	1921	2530	1554	978	1883	2245	1303	1924	2332	1409	1272	2482	3449	3577	2591	2941	2540	1957	2407	2091	1282	1907	2025	2046	56	708	1385	1389	959	
February																															
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															March																
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															April																
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															May																
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133	329	667	255	108	1068	798	80	488	670	787	111	725	1267	1310	1091	168	602	550	1299	1662	1819	1684	968	506	385	985	987	1129	1332	1572	
															June																
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															July																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
1894	2143	2246	2468	2514	1916	1644	2147	2236	2255	2701	2798	1932	1321	2179	2324	2221	2375	2389	2071	1743	2424	2651	2977	2700	2553	1549	1531	2043	2081	1897	
															August																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
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															September																
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1155	1459	2437	2243	840	893	701	1039	2366	696	725	1642	1494	1277	1165	2571	2731	2713	2708	2438	1066	625	2023	1790	2081	2355	2315	1823	955	2294		
															October																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
1616	1619	2009	2169	1735	1166	2225	2294	1974	2096	2086	921	803	1319	1853	1763	1770	1707	1225	1053	2223	2074	1721	1434	1673	1270	1390	1893	2002	1925	1544	
															November																
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															December																
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ES 2020 5% Scenario																														
January																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
190	720	566	278	279	476	1259	1410	1073	854	908	877	1316	697	832	616	802	696	198	409	1009	1472	1994	2069	1560	814	899	1057	1111	1017	190
February																														
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450	310	1043	911	973	1179	1351	1062	344	558	1027	1205	832	1155	595	290	684	1196	1318	1297	1098	825	588	1037	363	643	477	529	0		
March																														
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19	18	65	227	95	138	128	120	238	548	589	513	307	393	132	106	103	43	44	35	73	83	132	164	190	45	67	150	14	12	19
April																														
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May																														
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14	18	31	34	27	39	45	31	55	38	40	85	99	42	33	40	36	94	157	248	325	455	33	30	222	302	345	582	920	480	14
June																														
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1075	1266	1103	419	515	412	140	549	846	857	236	135	164	370	861	924	1299	1239	1167	806	322	983	1319	1413	1656	1663	982	787	1251	1434	

PT 2015 15% Scenario																																		
January																																		
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31				
2151	2382	2202	2136	2502	2427	2709	2398	2508	2045	2157	2312	2303	2325	2110	2116	2092	1924	2262	2406	2194	2151	2172	2156	2018	2469	2475	2492	2141	1692	25				
February																																		
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March																																		
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746	1689	2290	1799	997	1876	2167	1945	2089	2213	2213	2206	2125	2126	2111	2192	2171	2151	2042	1912	2164	1953	2213	2107	2113	2145	2075	2140	1672	1845	2114				
April																																		
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30					
1346	1747	2010	885	472	1529	1798	1775	2013	2498	2229	1560	1818	1912	2318	2341	2580	1875	1790	2229	1846	2146	2498	2277	1818	1212	1761	2379	2527	2006					
May																																		
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June																																		
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3015	3095	2888	2909	2774	2372	2216	3134	3202	2866	3215	3216	2311	1854	2439	2695	2209	2101	2302	2150	2213	2957	3020	3037	3062	3069	2499	2218	3137	3060					
July																																		
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31				
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August																																		
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31				
2358	2215	2934	3017	3034	3063	3051	2173	1843	2813	3052	3042	2221	2704	2219	2213	2865	2889	2882	2902	3028	2427	1629	2832	3036	2745	2219	2641	2361	1841	2509				
September																																		
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3175	3213	2763	3057	2397	2401	3173	3131	3435	3304	2930	2485	1483	2127	2345	1746	2476	2913	2213	2213	3055	2505	2697	2664	2942	2580	2217	2878	2975	3148					
October																																		
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2880	2983	2777	2021	2181	2381	2965	2966	2971	2625	2690	2377	2788	2804	2603	2943	2515	2750	2936	2713	2827	2884	2941	2931	2411	2691	2682	2216	2838	2575	2286				

November																														
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December																														
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3186	3181	2791	3015	2795	2747	2570	2682	2960	3139	2989	2905	2138	2586	2607	3029	2836	2307	1618	1667	2706	2654	2917	2335	2146	2064	896	1745	2593	1947	2418
PT 2016 15% Scenario																														
January																														
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950	1094	19	1252	1492	19	1080	1419	522	9	975	1911	2565	1919	2019	1584	1919	2456	3032	3050	3029	2808	2507	1925	2633	2826	2581	2876	2503	2373	1577
February																														
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2422	2569	2214	2136	2458	1278	19	1053	602	1319	1859	324	9	0	0	1208	2021	1923	2082	2036	1015	2152	1892	1851	1275	295	9	0			
March																														
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1181	32	998	19	9	0	9	1172	978	235	1354	1487	1101	1998	2615	2247	2480	2832	2149	2249	2278	2124	1757	1640	1296	14	92	0	1104	1681	761
April																														
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May																														
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9	773	916	1421	1612	1965	27	0	211	525	1039	891	14	0	0	0	1819	1754	1474	1973	14	0	1458	1704	2452	2217	2454	1104	19	2185	2769
June																														
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July																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
3213	2629	1748	3475	3709	3595	3699	3684	3039	2275	2991	3099	2958	2879	3147	3086	2771	3563	3610	3605	3460	3264	2832	1827	3163	3416	3419	3335	3484	2852	2293
August																														
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3366	3465	3535	3498	3255	2448	2136	2136	3029	2072	2705	3469	3036	2428	2988	3525	3443	3594	2668	2775	2270	3389	3291	3516	3485	3116	2747	2250	3058	3445	3538

September																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
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October																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2828	2429	3172	3503	3317	3360	3293	2548	2164	2937	2615	2773	2953	2925	2394	2165	2952	2938	3137	2959	2933	2225	1973	2810	2851	2888	2917	2867	2512	1919	2677
November																														
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2246	2974	3103	3113	2343	2118	2972	2945	2844	3090	3112	2986	2137	2840	3002	3136	3127	3047	2357	1647	2460	3456	3271	3275	3097	2608	2646	3452	3447	3220	
December																														
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3406	3495	2547	2237	3315	3477	3480	2961	2915	3069	2864	3517	3497	3472	3348	3461	2885	2644	3473	3465	3492	3502	3477	2566	2362	2524	3115	3036	3024	3222	3199
PT 2017 15% Scenario																														
January																														
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2636	3353	3534	3602	3508	2789	2510	2331	3434	2695	3248	3237	3186	2655	2417	3181	3213	3377	3605	3619	3238	2646	3635	3510	3655	3473	3185	2562	2486	3252	3268
February																														
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March																														
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3026	3353	2329	1137	21	1515	3010	3037	2676	3016	2468	94	1255	1792	2462	2707	2582	2606	2488	2729	2779	2122	2857	3086	2098	1042	2487	3016	3017	2644	2363
April																														
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980	691	3002	2757	2298	1991	2662	2476	1973	3024	3011	3493	2834	2412	2175	1861	2764	2860	2202	2485	2818	2970	2587	3761	3268	3131	2840	3220	2615	233	
May																														
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June																														
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July																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
2071	2138	3405	3907	3752	3604	3529	3533	2989	3523	3988	4144	4051	4016	3493	3229	3942	4020	4027	3944	3816	3748	2919	3577	3802	4073	4117	3991	3399	2565	3634	
August																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
4092	4185	4150	4124	3239	2668	3997	3635	3332	3413	3226	3229	2807	3991	2930	4099	4114	4087	3632	2689	4120	4112	4143	4141	4198	4126	3632	4114	4173	4140	3966	
September																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
3770	3231	3613	3968	4137	3401	3853	3778	2362	1540	3499	4003	4035	3475	3236	3412	2925	3265	3531	3540	3470	3472	3260	2980	3382	3509	3724	3680	3728	3282		
October																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
2614	3312	3565	3279	3298	2825	2779	2660	3304	3542	3521	3204	3483	3468	2225	2786	3241	3413	3330	3050	2350	2159	2983	3104	3152	3087	3092	1692	1391	2156	2836	
November																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
2086	2943	3358	3055	3201	3201	3642	3667	3654	3667	3125	2807	3023	3618	3869	3905	3900	2855	2323	3502	3845	3397	3106	3513	2625	2331	3257	2995	3097	2926		
December																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
2696	2859	2680	3253	3528	3141	3286	2758	2884	1811	2377	3414	3419	2804	3228	2955	2689	3330	3353	3495	3464	3158	2574	2340	1901	1974	1676	1899	1876	1218	21	

PT 2018_15% Scenario																															
January																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
14	1329	1760	1848	1873	1772	2108	3089	3034	2834	2656	3571	3398	2998	3782	3098	3192	3947	3618	2188	1612	3235	3879	3623	3302	2585	2342	2166	3468	3435	3570	
February																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28				
3122	2844	2584	2741	3320	3156	3198	3520	3357	2773	2469	3140	2785	2321	3135	3188	2314	2306	2854	2769	2450	2752	2791	2699	2301	2422	2656	2459				
March																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
2064	1980	847	855	1758	1963	1812	1470	419	9	0	371	1142	23	224	938	422	119	268	119	1049	1966	888	0	206	1380	1149	1306	0	0	0	
April																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
0	0	0	0	262	5	0	0	301	1137	136	837	2445	1959	30	1691	1935	2143	1145	5	0	0	1734	1284	289	303	545	167	0	301		

May																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
9	802	18	5	771	950	2415	2717	2472	2114	2726	802	0	1951	2140	2300	2741	3157	2726	2657	3113	3372	3146	2817	2753	2640	2531	2885	2973	2972	2903
June																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
3289	3407	2059	3153	3506	3988	3984	3813	3023	2170	2710	2382	1802	2729	3120	1532	19	1367	2482	3565	3668	3557	2789	2706	3554	3838	3827	3803	3665	3068	
July																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2185	3438	3677	3638	3525	3652	3518	3048	3425	3634	3555	3665	3658	3530	2767	3310	3314	3483	3277	3659	3278	2767	3131	3807	3786	3811	3595	3109	2339	3390	3673
August																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
3602	3859	3948	2764	2356	3093	3581	3577	3570	3535	3406	2571	3309	3362	2887	3399	3304	1787	1006	2576	3436	3375	3406	3196	3399	2888	3486	3762	3395	3740	3724
September																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
2929	2747	3240	3415	3432	3418	3308	2983	3055	3459	3605	3813	3622	3605	3421	3141	3823	3855	3899	3885	3885	3429	2543	2881	3032	3658	3740	3409	2815	2611	
October																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2332	2771	3247	3492	3048	2481	848	2510	3234	2989	2577	1653	1435	33	2502	2954	3354	2816	1757	1108	1251	1995	2132	3242	3698	3679	1541	801	2070	3206	0
November																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
3821	3080	2743	2041	2430	1950	2295	2733	1910	1077	1075	2948	3293	2753	3072	3217	1787	985	2814	2422	3244	3271	3345	2568	1725	2126	3149	3171	3150	3192	
December																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2018	1362	2757	3127	3071	2499	2393	2111	1686	2866	3163	3097	2164	2778	2286	1386	2797	2495	1973	2309	2099	2487	2368	2434	2027	2193	2524	2564	1174	1287	2175

PT 2019 15% Scenario																																
January																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
2121	2554	3277	3482	3039	1551	2941	2609	2287	2751	3116	2431	1861	2947	3451	3493	3266	3355	2832	1835	3088	3163	1647	1681	2874	2216	19	1093	1229	1708	1160		
February																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28					
1104	4	580	2297	2616	2040	1838	1869	1435	19	1771	2377	2441	1661	2125	1494	927	2136	2509	2509	1153	1439	1474	1297	1958	1625	1727	1688					
March																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
2000	1575	62	1241	1747	0	1569	2441	2045	1375	1375	1375	1029	1833	1513	1221	0	1135	1418	1191	1522	1721	1644	58	0	0	798	1504	1715	1515	1422		
April																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30			
2646	2915	2169	2260	1828	63	651	2127	1612	2083	2337	3059	2837	2085	2145	2672	508	1099	16	4	0	329	665	14	0	1000	1227	983	1594	1619			
May																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
520	567	948	393	377	2350	1971	0	576	1092	1474	60	1674	2295	2983	2240	628	746	650	2578	3233	3606	3479	1049	343	181	1202	734	844	2541	3105		
June																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30			
2603	570	3060	1500	613	1589	799	1288	428	1597	1878	2718	2604	2528	1952	1616	2901	2653	3051	2876	2074	1689	739	2870	3439	2671	3387	3624	3138	2154			
July																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
2671	3130	3510	3905	4087	3591	2511	3478	3920	3674	3963	3990	2982	1658	2833	3046	3235	3319	3204	915	999	2725	3819	3809	2407	2376	712	630	906	1616	1311		
August																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
1694	2117	1497	822	1922	2031	2112	1589	823	1336	382	1042	1159	1606	586	1171	801	388	1115	1216	1507	1250	1296	851	593	1403	1441	2151	2713	2784	1369		
September																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30			
424	1054	1531	1583	591	578	479	535	1651	738	1015	1332	1395	906	672	1830	2420	2470	2509	2086	722	404	1668	1640	1752	1885	1766	1617	609	1802			
October																																
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
1724	1215	1631	2038	1811	925	2303	3235	2498	2263	2869	542	322	1136	1256	1217	1694	1574	583	350	2290	2107	2115	1495	1715	512	505	2714	3008	3006	2028		

November																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
167	155	155	214	656	862	1183	1085	889	456	1437	1743	1811	1523	1803	1824	995	2837	3581	3436	3238	1264	312	259	2637	1093	1090	848	1653	535	
December																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
584	885	2867	3682	2601	2431	2387	326	742	1472	925	392	282	285	243	1177	1531	510	248	153	0	0	0	216	0	361	615	405	275	599	666
PT 2020 15% Scenario																														
January																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
247	1076	1324	268	747	1413	2062	1962	1640	1513	1269	1195	1663	1373	1332	887	1486	731	7	921	1093	1416	2538	3036	2807	758	1066	1291	1306	1069	1094
February																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28			
13	73	1383	1283	1490	1526	1561	1379	35	406	1298	1658	1558	1623	605	13	630	1313	1438	1435	1431	1395	705	1233	26	298	172	623			
March																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0	0	137	590	218	4	453	562	939	1165	1406	1470	1225	1263	299	371	518	714	919	924	976	974	823	959	968	209	209	709	182	11	0
April																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
768	689	288	8	0	597	153	365	342	11	132	4	262	138	15	0	4	122	4	0	0	0	0	0	11	4	222	214	8	0	
May																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0	0	0	0	103	274	263	123	8	0	0	547	638	689	569	6	0	468	1068	1139	1141	1146	205	0	571	553	956	1021	1292	1008	704
June																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
1373	1613	1479	650	816	688	171	811	1121	1207	639	384	399	500	1119	1154	1323	1306	1184	703	460	588	1123	1247	1448	1115	437	419	938	1157	

ES 2015 15% Scenario

January

01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
4199	5997	5773	4392	7619	6742	9032	1046 1	1020 4	8956	3240	8458	8784	9770	6599	7022	5441	3642	689 5	1002 1	8920	8502	8777	6380	2908	8607	8541	8518	4249	1789	850

February

01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
939	4052	3258	2151	3256	4394	4657	1842	6244	1043 7	1099 1	1127 5	8614	1502	967	5292	2020	5110	734 5	6966	939	822	1171	1159	1183	1621	1587	1575

March

01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
998	2987	5502	1538	1168	3517	1525	1263	5665	7864	6539	4981	2129	1034	1447	5331	4547	4549	154 3	1562	2413	1322	4857	4873	2146	3411	4249	2962	1304	2965	3587

April

01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1469	1236	1114	955	939	1257	2486	1959	5263	7696	7298	1226	3840	5197	7223	8388	7823	5503	321 0	8394	6385	7590	8904	9593	2135	1291	3706	5514	5437	4674

May

01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1569	2550	2763	4325	6029	5980	7267	2506	5430	2956	6933	8216	7264	3642	1671	1297	1231	5623	268 0	4516	3917	2335	1368	1112	3416	4033	5589	7405	7583	7609	6639

June

01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
9331	8894	8460	8374	1034 4	7344	5220	9487	1093 5	1103 3	1121 0	1096 3	1023 5	8591	1342 1	1014 0	1004 0	6993	740 0	6635	6864	1040 9	1076 5	1037 0	1156 1	1117 3	9393	7875	1084 9	1089 9

July

01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1091 3	1222 0	1042 0	9722	7457	1192 7	1245 5	1139 9	1164 6	1233 7	9728	9219	1193 0	1190 0	1185 7	1305 2	1284 1	1035 9	874 8	1307 6	1306 6	1279 8	1220 8	1080 8	7892	7622	1048 5	1122 8	1070 2	1036 6	1044 2

August

01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
9399	6315	1014 5	1168 8	1070 6	1120 1	1036 1	7420	5670	1056 6	1104 2	1094 8	9177	7739	5818	6376	9838	1002 6	984 3	1027 8	1090 7	8802	1451	6474	1065 6	8715	7632	1060 0	7350	5349	1076 4

September																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
1063	1085					1105	1145	1102	1096									490													
0	0	8915	8815	8107	7438	3	6	6	3	9753	7019	1002	6381	5125	1310	6878	8188	8	4552	8747	6738	7007	8012	7606	6957	4281	9907	8834	9481		
October																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
1024						1015												794													
8	9998	8306	1639	2730	4181	4	9856	9705	5594	4129	5028	6425	7451	8695	9916	3655	4097	8	6643	7037	7487	8419	8412	5778	7119	6367	5886	7284	6063	6189	
September																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
1226	5020	7445	8620	8638	9219	7727	3024	1007	1070	1070	1100				1020			977					1086			1001			1041		
								1	0	9	2	9880	7645	7677	5	9381	9753	0	7504	1415	1392	8288	2	8145	9126	7	7241	8265	9		
December																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
1206	1198	1157	1209	1045				1058	1204	1219	1064							618		1155											
6	5	9	7	3	7850	7349	8737	6	1	5	2	7250	9393	8406	9488	9042	9277	7	7330		9	9089	9661	7199	3965	2826	1047	1463	5421	3301	4513
ES 2016_ 15% Scenario																															
January																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
116																									1039				172		
6	1374	1140	1620	1354	1098	1354	1376	1136	997	1151	2953	4891	4112	3685	2308	2585	5267	8021	9225	9962	8452	6000	1269	7070	0	7155	6823	7097	4377	0	
February																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29			
764																															
3	7133	2558	3383	5862	1334	1022	1353	1022	1161	945	608	583	494	614	1726	4881	5875	5708	1575	960	3636	2743	1200	933	804	530	516	211			
March																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
705																															
	712	806	466	419	399	489	512	524	494	507	498	399	2952	5863	4144	6482	6727	4693	3491	4261	2943	521	324	298	298	489	389	363	392	524	
April																															
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
444																															
	480	399	497	507	712	499	494	478	350	410	451	374	296	376	300	192	303	410	275	277	947	379	284	239	217	383	308	530	284		

May																																	
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31			
284	392	370	392	1066	1666	293	135	426	365	392	382	466	396	358	395	395	761	496	497	492	196	392	493	392	1599	784	438	284	284	1023			
June																																	
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30				
867	2999	3081	1038	1143	5207	7124	5999	6285	2089	2277	1394	1450	940	405	407	2424	416	287	4018	5118	2717	3397	2318	633	527	3796	7094	8103	8563				
July																																	
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31			
8524	4213	1873	7442	8937	8325	9625	8983	6036	3844	7356	6679	5073	4288	3952	3369	2606	7521	9302	9593	9960	6359	2991	2819	6694	7432	7531	8793	9123	5964	2648			
August																																	
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31			
8116	9224	9441	9011	6885	2058	688	688	1802	1094	1902	4182	3567	1545	2390	7205	8228	8318	7354	3112	2593	7100	7821	7075	5952	7340	6716	4838	7428	9066	9620			
September																																	
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30				
9156	10194	8713	7654	10018	10875	11147	10016	10447	8959	6658	8394	8005	7370	6876	5451	1861	1306	6635	8586	9144	9302	9170	5025	3398	8289	8063	8043	7916	8393				
October																																	
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31			
6681	4981	8475	9036	8557	10127	10466	7877	4676	9203	10173	7892	10716	9598	6052	4664	9804	9979	10376	10749	10945	7310	3276	9269	10255	10545	9924	9478	8154	7322	8606			
September																																	
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30				
7729	10793	11521	11294	6144	3273	10221	8903	8275	10611	10869	9480	6058	8854	11048	13272	12484	11323	7952	2022	6406	12560	10683	10739	10214	6168	7342	11616	13113	10894				
December																																	
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31			
14468	15333	9270	5658	10597	10524	10900	7547	8250	8681	9338	13679	15126	14926	14860	12132	6341	6314	10804	11764	11997	12783	11520	8394	6137	7655	9252	8835	8727	9544	8654			

ES 2017 15% Scenario																																		
January																																		
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31				
744	894	1105	1143	1094	1049			1038	1019	1157	1109	1065			1007	1073	1188	1309	1322	1060		1288	1381	1505	1355	1146								
7	2	5	8	2	6	9471	7779	1	7	7	8	7	9310	8930	2	8	9	6	2	3	9161	0	3	4	6	7	8150	7453	9627	10934				
February																																		
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28							
100	574																																	
47	0	2950	1328	238	3676	7597	8595	9351	9990	7101	1513	6200	8247	8727	9455	9957	8276	4639	7939	7726	8118	8524	6649	6202	5607	2040	1313							
March																																		
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31				
512	593																																	
7	8	332	232	183	287	2149	4982	4965	3749	630	209	209	317	317	734	516	271	306	2013	224	317	1873	4147	515	177	2459	4997	5110	2117	1385				
April																																		
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30					
639	395	2897	1941	181	259	1580	2340	559	2435	4308	4858	4558	741	479	183	1887	1669	98	98	835	1775	3796	4660	4854	3449	3347	3929	3084	173					
May																																		
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31				
	546																																	
183	2	6439	6300	2143	683	2158	5919	6174	4693	1109	1860	2001	2925	7018	8812	7368	3696	5274	4713	1361	7009	6176	7518	1043	8	9914	6447	2661	8848	1017	9	11075		
June																																		
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30					
113	899																																	
82	6	6753	3663	5537	5463	5951	5211	8853	7440	4553	7088	9435	1183	1065	3	2	9475	8225	7091	1131	1422	1488	1428	1269		1172	5	8483	2703	3731	4037			
July																																		
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31				
411	189																																	
2	2	6551	8649	9706	1103	1095	8033	6785	1090	1224	1187	1003	1097	9	6414	4554	1062	1039	1094	6	9773	9280	6516	4836	6535	6186	9391	1045	1031	2	2	7484	5759	8993
August																																		
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31				
108	116	1146	1125																															
19	21	0	2	5211	1516	6156	6003	5159	3410	3460	2338	1548	2621	2820	6223	6602	6304	1231	1077	6943	8930	8852	7899	8929	6344	5208	9502	1041	2	7688	4351			

September

01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
353	180																								1022	1097	1121	1049	
7	8	2275	6758	8398	5201	5653	6290	681	460	2718	5992	6134	4366	3484	1757	1728	4591	7301	8231	8694	6700	5881	5080	8146	8	9	8	2	7109

October

01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
500	799		1014					1049	1199	1127														1051	1018					
6	0	7923	6	9461	6357	5969	6293	7	0	7	9231	9581	8052	3670	7397	8658	9145	8856	7699	4136	3682	8749	9849	3	4	9313	2381	1546	5574	9544

September

01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
381	101	1097				1067	1070		1046				1058	1244	1384	1300	1108	1065	1451	1440	1077	1040	1050			1355	1196	1259	1300
0	22	5	6654	8131	8131	5	0	9974	2	7689	4978	7303	2	6	4	2	4	9	8	9	4	6	2	7577	8278	6	8	2	6

December

01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
102	105	1022	1549	1752	1548	1400	1090				1328	1328					1179	1227	1135	1049										
34	97	9	6	2	2	9	8	9815	3051	7317	6	6	9717	9509	8624	7795	5	2	7	3	7321	6363	5240	1145	483	187	294	400	264	199

ES 2018 15% Scenario

January

01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
							1087							1022																
121	185	503	573	509	446	1104	7	9948	6505	5858	9539	8439	6312	7	6153	6888	9227	7614	1883	441	6268	9429	8844	6145	1085	693	392	7235	8457	9852

February

01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
							1153	1062															1001				
5564	2430	2025	4598	7409	6868	8382	3	0	3919	2728	7110	5619	4629	7457	9815	3646	3036	7250	5561	4443	6415	7090	9	7627	6771	7474	6256

March

01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
3878	3645	226	190	2231	1770	3453	1498	426	302	151	257	894	238	262	351	270	183	145	268	341	2048	923	258	230	159	666	431	254	121	145

April

01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
175	175	187	174	264	143	72	72	72	98	224	778	3909	1249	154	170	2242	698	233	534	406	428	395	480	480	543	677	406	290	380

May

01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
294	294	294	294	294	294	2077	2808	2279	2325	2692	402	294	294	379	294	1487	2511	1865	2126	5405	6074	6323	6003	4495	5436	4269	5793	6229	7799	6974

ES 2019 15% Scenario																														
June																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
6512	4495	1945	3059	5044	5973	5568	5115	2184	1218	1469	684	605	567	1396	380	490	488	494	3604	3181	2007	1882	2067	4562	4251	4123	3905	4187	3324	
July																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2333	4327	6142	5334	3287	4557	3245	1641	5003	5934	5883	5925	5469	4820	3012	1916	5413	5996	6573	4494	2996	2148	5212	6240	5879	5779	5431	2590	1669	3933	5436
August																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
3620	5087	6833	6702	5371	8758	7336	5615	2657	3127	2328	820	2898	528	311	2712	302	204	55	2262	5661	8088	7622	5573	2502	2159	6552	7166	8264	6877	6807
September																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
2948	3340	7161	7570	8309	8274	6911	5439	5289	6599	6233	5471	6084	5638	6155	5732	7111	8319	6071	5711	5239	4394	5070	4290	5641	6505	7741	7903	6219	4857	
October																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2600	3825	4516	6290	6128	4026	931	6952	6468	4673	4962	2181	2321	539	5760	7862	6654	6513	4215	2139	2943	5360	5734	7942	9804	9233	1909	150	1754	6779	8920
November																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
4090	6145	6296	4239	6452	5500	6411	6214	2852	62	624	8907	1079 5	8187	8961	8762	5326	2849	1123 2	8865	9340	1005 8	1045 3	6791	4906	4960	1010 1	8985	8052	8191	
December																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
4228	1795	6405	8623	7614	4764	4130	4137	3290	6307	9893	8049	5353	5937	3804	2187	8053	5669	5626	6765	4198	4118	4303	4865	3982	5352	4587	4638	106	36	2914
ES 2019 15% Scenario																														
January																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2053	2112	5764	7589	4663	2935	5648	6735	3908	5772	6996	4227	3815	7447	1034 7	1073 1	7773	8823	7621	5871	7222	6274	3846	5720	6075	6139	168	2123	4154	4166	2876
February																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28			
657	303	498	5614	8183	7867	6025	4849	719	84	4474	6451	7847	4566	5329	2468	1323	6593	7944	7944	4762	3806	4300	3246	6369	4890	4959	5108			
March																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
5222	613	136	503	1205	324	1634	3063	1385	266	1374	890	469	1134	1789	977	141	666	699	975	2729	3155	1431	221	174	186	871	2188	2766	1784	2112

April																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
4302	4036	1350	1523	847	152	205	1389	684	1635	2117	2459	2512	1333	2145	3530	605	1544	204	166	211	1231	798	162	133	930	963	400	3048	3136	
May																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
399	986	2000	766	323	3203	2393	240	1464	2010	2361	334	2174	3800	3931	3274	505	1806	1650	3896	4986	5457	5051	2905	1518	1154	2954	2962	3388	3997	4716
June																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
4262	3663	6088	4868	3564	3194	3077	3945	2358	2799	3208	4338	4105	3842	2794	3144	5741	3982	5199	4782	4794	3998	2602	5213	6675	5613	5671	7366	5559	3777	
July																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
5683	6428	6737	7404	7542	5747	4931	6442	6707	6766	8104	8395	5796	3964	6538	6973	6664	7126	7167	6212	5229	7273	7952	8932	8099	7659	4646	4593	6128	6244	5692
August																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
7020	7218	6193	4981	6881	7573	7659	6543	4709	5862	3987	4409	5839	6652	4462	6115	5154	3373	5134	5013	5942	5877	6274	5776	4086	6959	8868	8802	8913	8482	5949
September																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
3465	4376	7310	6729	2521	2678	2103	3116	7099	2088	2176	4927	4482	3830	3496	7714	8193	8139	8124	7315	3197	1875	6070	5370	6244	7066	6945	5469	2866	6883	
October																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
4848	4856	6026	6508	5206	3499	6674	6883	5922	6287	6257	2764	2408	3958	5558	5290	5309	5121	3675	3160	6669	6221	5164	4303	5020	3809	4169	5678	6006	5774	4633
September																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
1138	301	99	645	1549	4035	2616	1699	1434	278	3614	4813	4911	3449	4442	3903	2564	5848	7271	7531	6794	2181	761	540	3432	2608	1211	1662	4172	1894	
December																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
868	1992	4478	5107	3407	4047	3935	1524	2751	3681	2720	993	286	227	200	1452	2775	1778	117	3	31	10	91	105	28	254	1208	1037	766	925	1273
ES 2020 15% Scenario																														
January																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
570	2161	1699	833	837	1428	3776	4229	3219	2563	2724	2632	3947	2092	2497	1849	2406	2089	595	1227	3028	4415	5983	6207	4681	2443	2698	3171	3334	3052	2878

February																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29		
1351	929	3128	2732	2920	3536	4052	3185	1031	1674	3082	3614	2495	3464	1785	870	2051	3589	3955	3890	3295	2475	1763	3112	1090	1928	1430	1586	45		
March																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
56	54	194	682	286	414	383	359	715	1643	1768	1538	922	1179	395	319	309	129	131	104	219	250	396	492	571	136	202	451	43	37	141
April																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
348	201	204	153	110	235	259	219	241	212	229	140	219	157	114	137	78	117	43	62	64	105	183	181	175	192	188	164	102	87	
May																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
41	55	93	101	82	117	136	93	166	113	121	255	298	125	100	121	108	283	470	743	976	1364	98	90	666	905	1035	1746	2759	1441	1668
June																														
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
3225	3799	3309	1258	1545	1235	421	1647	2537	2572	708	404	492	1109	2584	2773	3897	3718	3501	2417	965	2948	3957	4238	4967	4988	2947	2362	3754	4303	