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EU energy regulatory framework: hindrance or catalyst for Demand Response in electricity?

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Plagiarism statement

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Abstract

This thesis aims to explore the influence of the European Union regulatory framework on the development of Demand Response in the electric grid. The growing share of volatile power sources in the electric grid and the electrification of uses make grid flexibility imperative. Demand Response, as part of Demand-Side Management, comprises ancillary services allowing this flexibility of the grid. To conclude on the impact of energy regulations and directives on the expansion of Demand Response, this thesis follows three steps. The first one, based on background interviews and Literature analysis, allows for the creation of a list of factors that improves Demand Response's integration with grid management. The second is a quantitative study examining the relationship between these factors and Member States' Demand Response performance in the European Union. The last step uses a qualitative methodology to examine how these aspects are covered by European Union energy legislation. These three steps ought to enable readers to determine if the European Union regulatory framework covers the variables easing the expansion of Demand Response and, consequently, is a catalyst of grid flexibility.

Keywords: European Union regulatory framework, electricity, energy transition, flexibility, Demand Response.

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Abbreviations

ACER: Agency for the Cooperation of Energy Regulators

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

CEP: Clean Energy for All Europeans Package

DR: Demand Response

DSM: Demand-Side Management

DSO: Distribution System Operator

EU: European Union

GHG: Green House Gases

IEA: International Energy Agency

MS: Member States or Member State of the EU

REMIT: Regulation on wholesale Energy Market Integrity and Transparency

RES: Renewable Energy Sources

TSO: Transmission System Operator

V2G: Vehicle-to-Grid

Introduction

In the context of climate and energy crises[1], where the electrification of uses[2] is considered both a way to guarantee energy resilience and reduce Green House Gases (GHG) emissions, the optimum management of the electricity grid is of ever-growing relevance. Smart grids allow more flexibility and efficient management of the power infrastructures. According to the definition of the International Energy Agency (IEA), a smart grid is an "electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end users." (Gonzales, 2022).

Due to the difficulty of storing electricity, the first rule of the grid is to maintain the equality of consumption and production at all times. There are three ways to assure this equality, usually used in conjunction with each other: (1) Managing production to follow grid demand and supply the proper amount of energy to match consumption, depending on the source of power, this solution may not be sufficiently responsive or not applicable in the case of intermittent sources; (2) Buying or selling electricity to neighbouring countries to share constraints, improve flexibility, and increase the efficiency of the grid; and (3) Managing consumption to lessen constraints on the grid.

The latter is called – among other names – 'Demand-side Management' (DSM) and regroups all the tools to manage and integrate flexibility in consumption. This 'umbrella' term comprises numerous market tools, actors, and technological breakthroughs; its definition differs across countries. This method of ensuring the equality between production and consumption requires the consumers to become 'prosumers' and to smoothen their consumption throughout the day to avoid peak-high demand. This portmanteau word is a merging of producer and consumer and refers not only to actors that are self-generating electricity but also to the ones that are more broadly "actively participating in the market" (Šajn, 2016). The increasing share of renewable energies in the energy mix and the recent energy crisis made DSM even more relevant since rising

[1] According to the International Energy Agency (IEA), the energy crisis is characterized by "Record prices, fuel shortages, rising poverty, slowing economies" and is the "first energy crisis that's truly global" (IEA, no date).

[2] The electrification of uses refers to replacing fossil fuels with the electricity vector. The most telling example would be the changing of car fleets with electric vehicles.

electricity prices in the European Union (EU) led to raising awareness of the nature and issues of the electricity grid. The electrification of our uses put ever-growing constraints on the grid that must be adapted to support the new load curve. DSM is crucial for three major reasons:

(1) By controlling demand, grid congestion[3] may be avoided, and the electricity network, supporting the biggest part of the European final energy consumption and, consequently, a significant portion of economic activities, can secured. Indeed, the electrification of uses requires both the development of the grid and the optimization of the existing infrastructures. The transmission of electricity is bounded by several constraints such as the most fundamental, the necessity of maintaining the frequency within a specific range around 50Hz (ENTSO-E, 2018). The European network must always and at every point of the grid adhere to these restrictions. In other words, at any time and in every European household connected to the grid, the furnished electricity must be within this specific range of frequency. Therefore, a significant amount of flexibility is required to provide fine-tuning of the frequency value. The biggest threat to the grid is the risk of a blackout. Indeed, on top of implying the process of rebooting the whole power system, blackouts are extremely expensive. The financial loss caused by the infamous blackout in Italy in 2003 was estimated to be more than €1.18 billion (Gay and Mund, 2018).

(2) Enabling more monetized flexibility offers new business models and opportunities, which in turn spur financial interest in the development of grid security services. The volatility of the production, brought by the growing share of renewable energies in the electricity mix, implies the need for an agile market. The market should match as closely as possible to real-time grid operation, therefore being responsive which calls for more flexibility.

(3) Following the merit order, the more the load curve is smoothened, the less GHG are emitted when electricity is produced. Indeed, the merit order dictates that the call for different means of production of electricity is in the growing order of marginal cost of

[3] Congestion is defined as “every constraint appearing on distribution network” (Dronne *et al*, 2021). When a transmission line becomes overloaded and unable to transport further power, the phenomenon of grid congestion occurs. To protect the system, the electric dispatcher imposes restrictions on the grid's actors which can distort the electricity market.

production. Thus, the electricity is produced in priority by must-run generators such as hydroelectric power plants, solar panels, or windmills. Power plants producing electricity at the highest price, knowing that the marginal cost includes the emissions cost, are called last. They are usually the most responsive but also emit more than the Renewable Energy Sources (RES) that are called first[4]. Therefore, smoothing the load curve allows to optimize the use of the must-run electricity and restraints the launch of carbon-intensive power plants. So, DSM has an impact on the GHG emissions linked to electricity consumption.

DSM is still not common in every Member State (MS). Indeed, as a network industry, electricity has a natural monopolistic tendency and a history of vertical state-owned corporations. For the past two decades, the liberalization of the market brought new actors and new repartition of roles (Pepermans, 2018). According to the culture, the domestic approach to the energy transition, and the history of the country, innovations like DSM are to a greater or a lesser extent common and welcomed. DSM includes several tools such as:

- Demand Response (DR)
- Offloading
- Storage (on the side of the consumer)
- Guiding the final consumer toward energy-efficient equipment.
- Virtual Power Plants[5]
- Vehicle-to-grid (V2G)[6]
- Energy performance of buildings

[4] In fact, coal power plants are called before gas-fired ones while being more carbon-intensive. However, overall, the energy sources called at the end emits more CO_2 than the ones called first which is why smoothing the curve by using DSM is a way to decrease GHG emissions.
[5] Virtual Power Plants combine "various small size distributed generating units to form a "single virtual generating unit" that can act as a conventional one and is capable of being visible or manageable on an individual basis." (Mohammadi *et al*, 2011).
[6] V2G refers to "a system in which plug-in electric vehicles, such as battery electric vehicles, plug-in hybrids or hydrogen fuel cell electric vehicles, communicate with the power grid to sell demand response services by either returning electricity to the grid or by throttling their charging/discharging rate" (Covrig and Videgain Barranco, 2021).

DR in the electric grid is the focus of this master thesis[7], Section I. of the first Chapter is dedicated to a better understanding of the meaning of DR for this study. Indeed, DR often encompasses other flexibility tools and the lexical field around DSM is not universal. The definition of DR considered in the study is the one of the IEA, describing DR as "based on two main mechanisms: price-based programmes (or implicit demand response), which use price signals and tariffs to incentivise consumers to shift consumption, and incentive-based programmes (or explicit demand response), which monetise flexibility through direct payments to consumers who shift demand in a demand-side response programme." (Bertoli, 2022)

The Literature on DR is usually technical and focuses on niche aspects of the integration of DR in smart grids. Few of the literature aims at examining the coverage of DR by regulatory frameworks. As the European electric world is undergoing major evolutions, this study could cover a loophole in the context of the remodelling of the electricity market.

Thus, the question of this thesis is:

To what extent do EU policies on electricity provide the required framework for the expansion of Demand Response in the electricity grid?

To answer this question, the characteristics easing the expansion of DR will first be listed and described. This list will be built through both a review of the literature and background interviews with three Experts on the subject. The Experts prefer to remain anonymous and will be referred to as Experts A, B, and C. Once this list of catalysts of

[7] Certain compromises on the scope of what DR includes may need to be made because the definitions of flexibility in the electrical grid can be ambiguous, include a variety of ancillary services, and overlap with other concepts depending on the region (See Chapter 1, Section I.).

DR is drawn, a quantitative analysis will be conducted. The aim is to prove, thanks to a quantitative study, the correlation between some of the factors and the potential of expansion that has been estimated in the different MS. This potential is the cornerstone of the whole study. The last chapter will be dedicated to a cross-cutting assessment of the coverage of the factors easing the development of DR by the EU legislative framework.

Context: DR and the EU regulatory framework

The evolution of the subject in the Literature is suggesting that the notion of DR becomes more mainstream. Most of the articles used in this thesis have been found in the database ScienceDirect[8]. When looking at the frequency of occurrence of articles referencing 'Demand response electricity grid'[9] for each year since 2010, one can see the number of publications increasing. The first occurrences are from the 2000s and the articles are conspicuously, and with consistency, more numerous each year[10] (See Figure 1.).

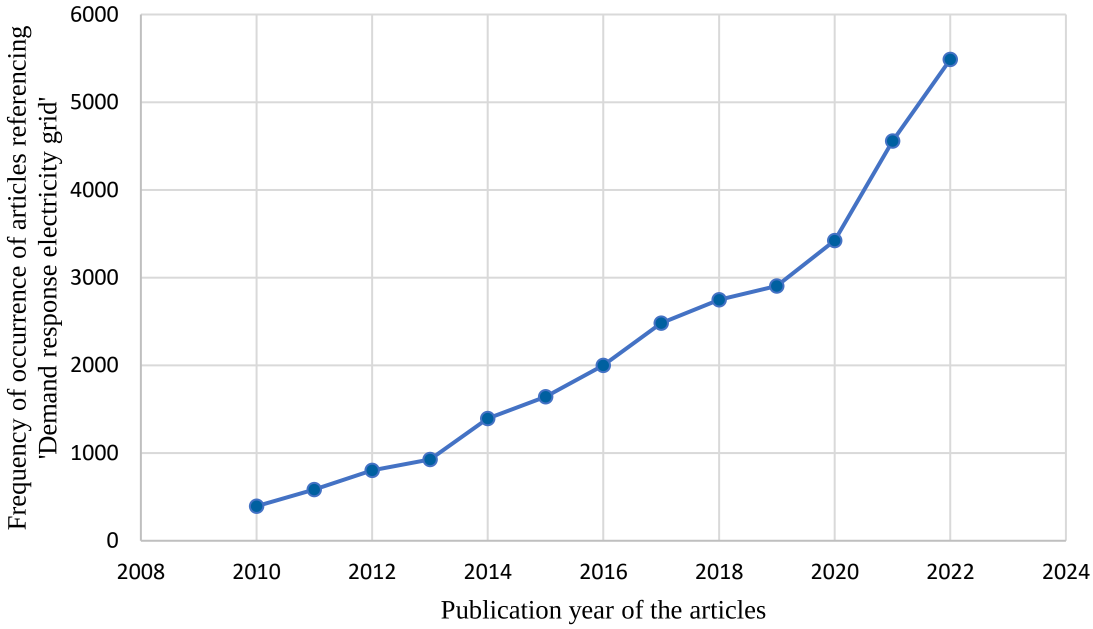

Figure 1. Evolution of the academic interest in DR

When reviewing the relevant literature, few studies consider regulatory frameworks as catalysts and enablers of the development of DR. However, the ones that do so were mostly published recently. For instance, a study on the subject "Are regulations enough to expand industrial demand response? A study of the impacts of policy on industrial

[8] The scientific and medical branch of the academic publishing company Elsevier.
[9] The results of the research are filtered to cover only the articles related to Energy, Engineering, Environmental Science, Social Sciences, and Economics. Indeed, it allows the removal of mentions of DR referring to something different than flexibility in the electricity grid.
[10] This evolution might not only be due to the increasing interest in DR but also to other factors intern to Science Direct – for example, a change in the collection of articles on this subject.

demand response in the United States" has been published in 2023 (Billings and Powell, 2023), which could be a clue that this narrative becomes more common, and that DR is now considered with lenses more and more related to public policies and not only technical, as it seems to have first been the case[11]. Electricity grid, and smart grid more specifically, are at the crossroads of many different fields and thus relevant to consider with many different angles.

The main transversal approach to the adaptation of the electricity grid is the one imagined by Dr Simon Müller[12]. This model describes the three layers (See Figure 2.) that must be adapted to change the electric system (Müller, 2017).

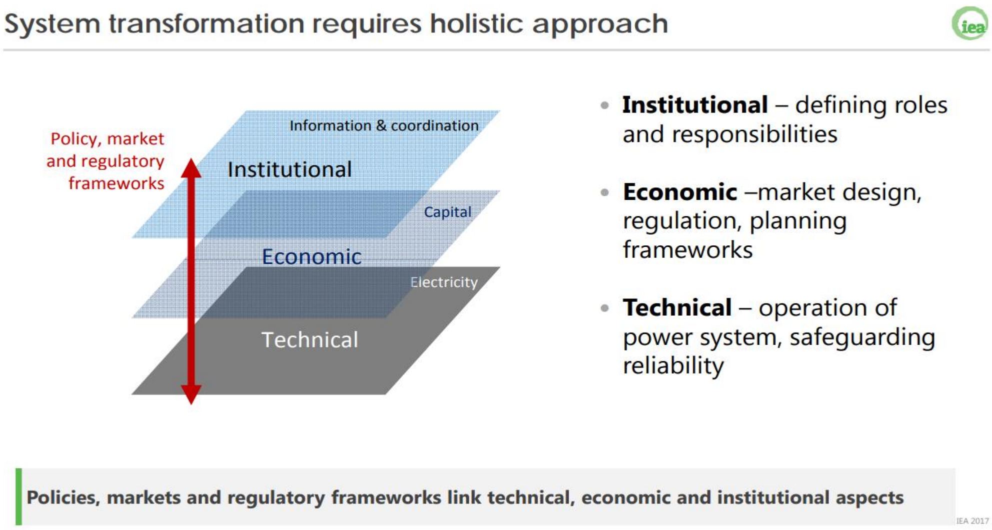

Figure 2. Dr Müller's model of the electric system transformation (Müller, 2017)

The three layers are:

- Technical: the tools allowing the grid to be monitored and managed, especially using new technologies. This comprises both the physical elements such as smart metering[13] and the digitalization of the grid that

[11] When looking at the occurrences of DR in articles over the years, one can notice that it was at first mainly studied in electrical engineering or in applied economics for energy, the paradigm of policymaking was adopted later.
[12] Dr. Müller is the Director of the German branch of Agora Energiewende, has worked with the IEA, and focuses on the grid and DR. He is considered by one of the interviewees as a reference and a pioneer in this field.
[13] "A smart metering system is an electronic system capable of measuring electricity fed into the grid, or electricity consumed from the grid, providing more information than conventional meters." (European

results from its transformation into a smart grid.

- Economic: The design of the market is governing its operation. This conditions the ability for stakeholders of flexibility to enter the market and develop a proper business model.

- Institutional: The coordination of the roles and tasks at institutional level allows the previous layers to exist and promotes their development to make the power system transformation possible.

This holistic approach is one of the cornerstones of this thesis[14].

With the energy transition and the energy crisis – and the rising prices associated – the general public has shown more interest in the workings of electricity in general. Thus, similarly to the rising frequency of the term in the academic material, albeit less blatant, the tool ‘Google Trends’ (Google Trends, 2023) reveals that the number of research on Google in the world for ‘Demand Response’ increased (See Figure 3.). This shows a growing interest in the matter.

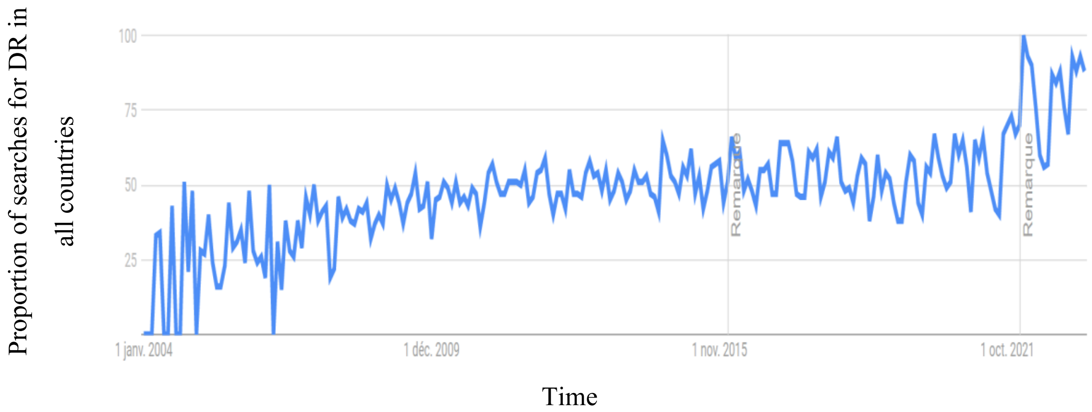

Figure 3. Evolution of Google users' interest in DR

However, despite the rising popularity of DR[15], its precise and accurate definition is

Commission, 2022a)

[14] The three layers are used in the construction of the list of factors easing the expansion of DR (See Chapter 1) which is mentioned throughout all the chapters.

[15] The subject of DR is also rising in popularity in other fields of application and is getting out of the electricity realm. The sectors of heat and clean gases have their own DR in the form of power-to-heat or

not universal. Indeed, while auto-generation and having a Positive Energy house[16] are becoming mainstream, DR and flexibility are still understood with very different associated scopes (See Chapter 1, Section I.). As a result, to maintain consistency throughout the thesis, sources from the EU are preferred, as variances in the definition of DR are also geographically dependent.

Thus, actors such as the Agency for the Cooperation of Energy Regulators (ACER), the European Network of Transmission System Operators for Electricity (ENTSO-E) and the EU DSO Entity are references for this work. Another important player for DR at the EU level is SmartEn. As "the European business association integrating the consumer-driven solutions of the clean energy transition [aiming at creating] opportunities for every company, building, and car to support an increasingly renewable energy system." (SmartEn, 2023), SmartEn, publishes every year the 'European Market Monitor for Demand Side Flexibility'[17] (Mazzaferro and Murley, 2021). This study focuses on the current and future development of flexibility in the MS. This association is highly proactive when it comes to studying the development of DR.

According to Article 4 (2) (i) TFEU, energy policy is a shared competence between the EU and its MS. Thus, even though the parties in the electrical infrastructure and market must cooperate to provide a safe and optimal grid, national regulatory frameworks, which are not covered by this thesis, play a significant role in the development of DR. Currently, the notion of flexibility in the grid is not covered by a specific piece of legislation at the EU level. However, the European Commission has set in motion the process that leads to the redaction of the first proposal for a regulation specifically targeting the development of DR (ACER, 2022). The policy framework of the EU linked to DR is analyzed in the last Chapter of this thesis. This part of the study addresses different pieces of legislation from the EU: in-force directives and regulations, proposals, and framework guidelines that directly affect

power-to-gas, for instance (Enerdata, 2022). This suggests that interest in the topic will only increase as it spreads to become a cross-disciplinary tool.

[16] Positive Energy Buildings are defined as "buildings which produce net zero green-house gas emissions and actively manage an annual or regional surplus production of renewable energy" by the Smart Cities Marketplace, a project from the European Commission (Vandevyvere, no date).

[17] This report is published in collaboration with Delta-EE – a provider of data-driven research, consultancy, technology products, and training services to companies investing in and navigating the energy transition.

the electricity market and systems are examined (See Figure 4.).

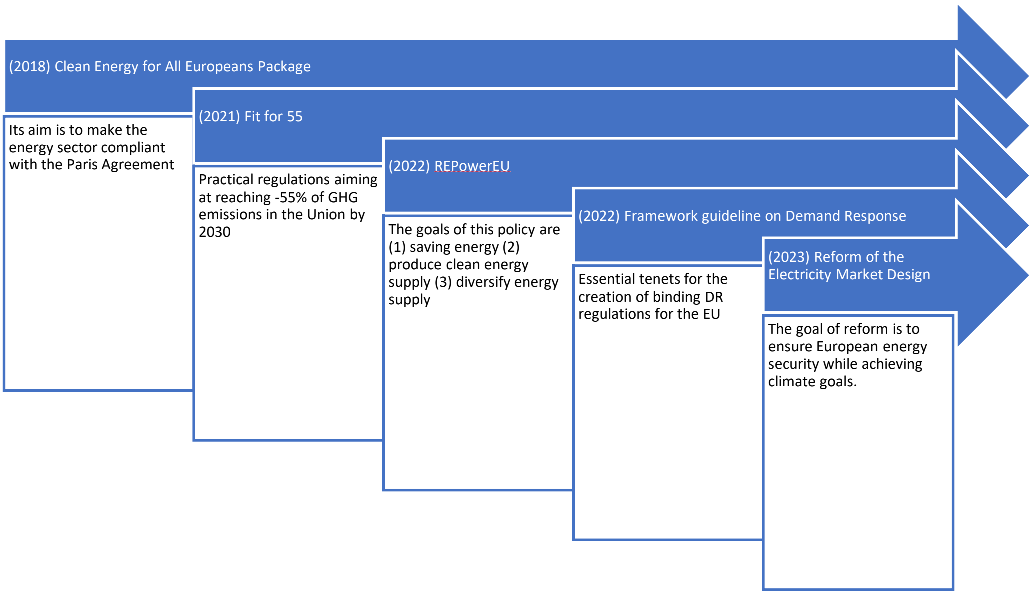

Figure 4. Overview of the EU policy framework addressing the electricity market.

Chapter 1 – DR and its catalysts

I. Scope definition

As previously explained, DR, DSM, flexibility, and sometimes even energy efficiency are terms used interchangeably to refer to different notions. Indeed, an expert on the subject Alain Malot, explains: “Power system flexibility is an umbrella term that can be seen as a subset of the even broader term ‘smart grid’. I identified at least a dozen different definitions which say different things.” (Enerdata, 2022). It is, thus essential to specify the scope and the exact definition of what is meant by DR in the following analyses.
A review of the Literature and the background interviews (See Chapter 1, Section II.) were used to build a matrix of inclusion (See Figure 5.) portraying the links chosen to be considered in this thesis[18].

The crucial notions to understand are the following:

- Tools for grid equilibrium: It regroups all tools guaranteeing grid equilibrium. For instance, interconnections between previously separated grids are part of these tools[19]. Advanced grid management systems such as Supervisory Control and Data Acquisition (commonly called SCADA systems) can also be cited as a means to ensure grid equilibrium[20]. Indeed, a more distributed generation calls for better integration and thus, technological breakthrough allowing to have an appropriate interface between the power generation and the grid management.

- Generation management: It is the traditional way of managing grid equilibrium, while the supply of electricity following the demand. When the grid was fueled by controllable responsive sources, this solution was suitable

[18] The term DR has been favored, instead of a term containing flexibility because Expert C (See Chapter 1, Section II.) explained in the background interview that policymakers were trying to ban this term from regulation due to its vagueness.
[19] Indeed, they aim at “supply[ing] electric power and power services of high quality and with high reliability to consumers on the whole territory of the interconnection.” (Voropai *et al*, 2018).
[20] SCADA systems are means to manage the collection and analysis of sets of data and are commonly used in smart grids.

to ensure the equality of consumption and generation. Traditional power sources, such as gas, fuel, or coal power plants, and, to a lesser extent, nuclear energy, were more controllable. The green transition introduces more volatile and intermitent energy sources, windmills, and solar panels for instance.

- Storage: Grid-scale storage, as called by the IEA, are "important system services that range from short-term balancing and operating reserves, ancillary services for grid stability and deferment of investment in new transmission and distribution lines, to long-term energy storage and restoring grid operations following a blackout." (Schoenfisch and Dasgupta, 2022). Positioning storage regarding DR is not easy as some actors consider it as a competition to DR[21] while others – such as the EU and the IEA – consider it to be part of DR tools. Thus, storage ancillary services are considered to overlap different categories but are included in what is called DR.

- Energy efficiency: As an indirect tool to ensure equilibrium in the grid, it comprises guiding the consumer toward energy-efficient equipment or broader operation such as massive building renovation. According to Expert A, the notion of energy efficiency can also be understood as DSM – especially in the United States of America. Though, it is excluded from DR because the timeframes of this solution are different. Indeed, energy efficiency is a long-term management of the demand whereas DR – as understood in this thesis – relates to the short-term flexibility of the consumption.

- Demand-side flexibility/DR: The defining of these concepts is key. The definition of the IEA is chosen as a reference, as it brings universality to the study. However, the compatibility with the EU definition has to be ensured. As Expert C explained, there is no precise definition of what DR is as the definition itself would be a subject of disagreement and divergence of interests. Thus, the term usually refers to what the EU and the IEA describe

[21] The Expert A (See Chapter 1, Section II.) consider Grid-scale storage to be a direct competition to to DR. In fact, storage solution such as Pumped-storage hydropower can also be considered as generation management.

as 'ancillary services'. According to the EU regulatory framework[22], "ancillary service means a service necessary for the operation of a transmission or distribution system, including balancing and non-frequency ancillary services, but not including congestion management" (Article 2 (48) of Directive 2019/944)

In its definition of DR, the IEA makes the distinction between two main types of mechanisms. The first one is implicit DR, which is price-based. It brings the consumers closer to the real price market by using price signals to manage demand. Implicit DR is sometimes not considered as an ancillary service but for simplification purposes, this study considers it as so. The second one is explicit. Contracts are signed, with or without aggregators. Examples of these mechanisms can be found in interruptibility agreements or V2G mechanism. Interruptibility agreements allow the Transmission System Operator (TSO) to offload some major consumers in exchange for a yearly allowance.

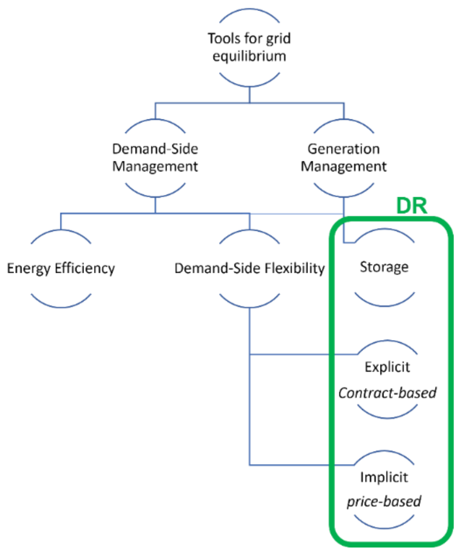

Figure 5. Matrix of inclusion

[22] 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; hereinafter Directive 2019/944.

II. Panel of experts

This thesis relies on three semi-structured interviews with experts of DR. Questions were slightly adapted according to the field of expertise of the interviewees and the progress of the interview. The detailed questionnaires are included in the Annexes (See Annexe 1.)

The interviews were conducted between the months of January and February 2023, and 5 themes were investigated:

- The framing of the subject: semantics, the scope of the covered topics, … This part was of very specific relevance to the content of Chapter 1. as it allowed to see the different definitions of DR among MS and layers of professional practice themselves.

- The link of this thesis research question with the professional practice of the interviewee. This included the historic and strategic importance given to DR by their hierarchy and in their work environment.

- The link with climate change and the energy crisis triggered by the Russian-Ukrainian war. This provided a better understanding of what sparks interest in DR, what might possibly stimulate its development.

- The factors that would ease or hinder the expansion of DR. The questions were framed to cover the three layers of Dr Simon Müller's model (Müller, 2017).

- The heart of the matter and the link drawn by the interviewees between the EU regulatory framework and the development of DR.

The selection of the Experts aims at covering technical, academic and policymaking expertise and bringing both a national and a European point of view. Two out of the three experts do not want to be cited or quoted so they shall all stay anonymous while their relevant characteristics are described (See Table 1.).

Expert A	Private sector/Academic	Both working in the private sector and the academic field, this interviewee is a senior portfolio strategy manager specializing in Demand-Side Flexibility in a multinational company.
Expert B	Technical	Working for the French TSO for almost two years, this interviewee is a junior electric dispatcher working daily on the operation of a connection between France and a neighbouring country.
Expert C	EU policies	Working for an agency of the EU, this interviewee is a team leader in the regulatory aspect of DR.

Table 1. Panel of experts

The thematical analysis of the interview material aims at:

- Determining the most exhaustive possible list of factors influencing the expansion of DR.
- Assessing whether the factor as a positive or negative influence on the expansion of DR.
- Getting a sense of what pieces of legislation changed for the development of DR and having a general sense of whether the regulatory framework tackles the variables.

III. Factors easing the development of DR

The main findings are aggregated below to clarify the common elements that the experts mentioned. A layer of 'historic and cultural' factors has been added to the model of Dr Müller (Müller, 2017) to take into account the evolution of some systems and their specification from the past that can slow down the expansion of DR.

A. Institutional – Defining roles and responsibilities.

The issue of the lack of universal harmonized semantics regarding DR was addressed when investigating the Institutional layer. Expert A explained mainly the difference between the different terms while Expert C highlighted that the vagueness of the terms is a *status quo* to which many stakeholders are attached as it allows more flexibility in the interpretation of regulations. For instance, according to Expert C, clear models of aggregation, and therefore their specification relating to DR, were planned to be described in the Clean Energy for All Europeans Package (CEP) by the ACER, without success. The issue has not changed five years later, and the same discussion continues to take place.

This leads to a second important point: the wish of the grid actors to keep room for manoeuvre. Indeed, Expert A does not believe that the introduction of binding rules[23] by the EU for MS would be very well accepted. Expert C confirmed this aversion toward any binding regulation by stating that, with simplification of the Expert words, the stakeholders recognize the need for the expansion of DR but do not believe in the necessity of rules in this regard. This point goes hand in hand with the extent to which MS regards the principles of subsidiarity and proportionality in a lenient and extensive way when considering the electricity grid. This is an aspect that might evolve as a consequence of the rising concern for energy security. A crisis like the one brought on by the invasion of Ukraine may alter the dynamic. The launch of REPowerEU[24] was prompted by concerns that a gas scarcity following the Russian assault on Ukraine may jeopardize Europeans' access to energy. The concern over unstable power access in the case of further disruptive events may lead to the acceptance of additional grid regulations.

Expert C moderates this point and mentions the cautiousness needed when harmonizing models between MS. Indeed, the Expert explains that harmonizing DR concepts at the EU level is necessary but that perfect uniformity of DR congestion management between the hundreds of German Distribution System Operators (DSO) and the few Spanish ones seems disproportionate.

Another – often mentioned in other fields – aspect would be the porosity between the technical issues and policymaking, to ensure that the regulation targets the right point without distorting a highly complex system. Indeed, the ACER, the ENTSO-E, and EU DSO Entity play a vital role in determining policies in the energy industry. As a result,

[23] When referring to new binding rules at the EU level, Expert A was directly referring to the new proposals on the Electricity Market Design: (1) Proposal for a Regulation of the European Parliament and of the Council amending Regulations (EU) No 1227/2011 and (EU) 2019/942 to improve the Union's protection against market manipulation in the wholesale energy market, COM(2023) 147 final; hereinafter COM(2023) 147. (2) Proposal for a Regulation of the European Parliament and of the Council amending Regulations (EU) 2019/943 and (EU) 2019/942 as well as Directives (EU) 2018/2001 and (EU) 2019/944 to improve the Union's electricity market design, COM(2023) 148 final; hereinafter COM(2023) 148. As regulations, they are meant to be binding in their entirety contrary to Directives that are mainly binding as to the objectives they are setting.

[24] The EU Regulatory Framework is explained extensively in the Chapter 3.

enhancing the role of these institutions—which shelter highly technical expertise—in governance would help place practical and pragmatic considerations at the center of policymaking.

B. Economic – Market Design, regulation, planning framework

One big condition to improve DR would be the opening of the market to smallholders and the transparency of the electricity markets. The construction of a business model that is viable and sustainable would also allow aggregators to incorporate more ancillary services. Expert C emphasized the necessity to adopt aggregation models that are closer to real-time electric exchanges: indeed, strengthening real-time aggregation in the forecasting of bidding zone[25] rather than simple day-ahead forecasting would be a strong catalyst of DR.

An important aspect would be the narrative behind the use of DR. Expert A sees DR as a crucial aspect in the adaptation of the grid to new constraints and regret its overall absence in REPowerEU (See Chapter 3). This absence is also felt in the investment plan to implement REPowerEU which does not mention at all the term 'Demand Response'[26].

The main point of divergence between people's opinion on DR lies in their perception of its use. This is an aspect at the crossroad of the market and the operational perspective. According to Expert C, only the implicit mechanism of DR is considered by the electricity market while the TSOs and DSOs mostly consider the explicit part, but as an emergency measure. One main difference between the answers of all the experts lies in whether DR should be considered congestion management tool. Expert A emphasizes the need to use DR before any congestion happens, not as an emergency measure but as a regular mechanism, monetized in the electricity market under the same regime as generation management.

[25] A bidding zone is the "largest geographical area within which market participants are able to exchange energy without capacity allocation" (Article 2(65) of Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity; hereinafter Regulation 2019/943)

[26] Proposal for a Directive of the European Parliament and of the Council amending Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources, Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency, COM(2022) 222 final; hereinafter COM (2022) 222.

C. Technical – operation of power system

As explained above, the debate lies in whether the DR should be used to handle emergencies or to smoothen the grid operation before overloading occurs. In fact, when grid congestion arises, using DR would alleviate the situation by reducing consumption. In his work, Expert B sees DR as a congestion management tool[27], as, when it comes to grid operation, it is the main preoccupation. According to Expert A, certain operational actors consider the idea that DR should not only be a tool for reducing congestion but rather a proper balancing scheme, to be unprofitable since it can complicate an already highly complex system. While none of the interviewees mentioned it exactly with these words, it seems like the narrative of the cost-benefit analysis of DR reflects some kind of risk aversion. Indeed, the issue could be to over-complexify the electricity field; Expert A referred to this phenomenon by using the French expression 'usine à gaz'[28].

Expert C emphasizes the need for a grid. Indeed, to simplify the expert's words, one can optimize a grid to its maximum, the presence of a grid stays a condition *sine qua non* for flexibility to exist. This is why, in nations that have traditionally relied significantly on gas and so must substantially improve their grid to accompany the electrification of uses, like the Netherlands, DR will only be widely deployed after a secure and well-designed grid is in place.

D. Historic and culture

The interviews with the three experts allowed the identification of historical and cultural aspects. They mainly relate to the evolution of institutions, markets, and technical aspects across MS. This category addresses the influence of domestic past habits on the development of the factors that could enhance the development of DR.

One essential aspect developed mainly by Experts A and C would be the monopoly tradition of the electricity sector in the MS. Depending on the MS, this custom is more

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[27] As Expert B is a technical expert, he has an operational point of view and observes that nowadays DR is mostly used as a congestion management tool.

[28] This expression designates a system very complex and hard to pilot that achieves a goal that would have been reachable with a much simple design. This expression describes a system that is difficult to use and exceedingly complicated yet achieves a goal that might have been achieved with a far simpler design. It conveys the impression that a system has become overly complex.

or less strong. Indeed, while in France, one DSO has most of the market share, in Germany many DSOs share the market. This is partly linked to the political functioning of this country. In Germany, in most cases, the distribution network is owned by the local collectivity (usually the city); however, private corporations might enter into agreements to oversee the network's management as a concession. As a result, DSOs are direct competitors, if not on a daily basis, at least, at the time of the renewal of the concession contract (Schmid *et al*, 2019). It is difficult to assess whether having a unique entity responsible for the distribution or transmission of electricity is an aspect easing or hindering the development of DR in the MS. Indeed, in a perfect liberalized market with several actors and a resilient business model, competition would probably bring most of the actor to engage into the development of DR services as it would be an opening for new business revenues. However, according to the current previously described technical, institutional and market context, this could also lead to no one taking the risk of developing this 'usine à gaz' as they would have to ensure that this new flexibility will not distort the market or endanger the proper operation of the grid[29]. On the other hand, when a large company has the monopoly two things could happen: (1) the player considers that the cost-benefit is not worth it, and the development of DR is then properly blocked (2) the player engages in developing DR and its commitment is a catalyst for the development of the latter.
Expert B adds another important aspect related to the centralization of the operation of the grid. Indeed, in France, congestion management is taken care of by regional dispatchers but broad DR actions such as the activation of the interruptibility contracts are dealt with at the national level. The decentralization of some DR tools is a factor that could impact the frequency of their use, as the process to trigger the mechanism would be local.

The aspects mentioned by the Experts as catalysing or hindering the development of DR are summarized in Table 2.

[29] DR might be seen as a responsibility that the entity creating it must bear.

Category	Factors easing the expansion of DR	Expert mentioning
Institutional	Explicit definition of DR	A/C
	Low propension to protect the 'room for manoeuvre' from actors	A/C
	Clear regulatory framework at the EU level	C
	Understanding of the technical issues at the EU institutional level	C
	The principle of subsidiarity and proportionality understood extensively at the EU level	C
Economic	DR is seen as a tool for the energy transition	A
	No discrimination in the tools for DR	A
	Transparency of the market	C
	Aggregation models allowing the integration of DR	C
	Easy access to the market for smallholders	C
	Liquid market	C
Technical	MS views the development of DR as having favourable cost-benefit ratios	A
	A developed and reliable grid infrastructure	C
Historic and culture	Good repartition of the roles and tasks/liberalization	A
	Decentralization of the command of the flexibility	B
	DR is seen as a response to the energy crisis	C

Table 2. Factors easing the expansion of DR

Chapter 2 – Quantitative Analysis

I. General approach

This part aims at proving the correlation between some factors presented by the Experts and described in the previous Section and the expansion of DR in MS. This Chapter is seeking confirmation of the relevancy of the factors. However, mixed results shall in no case make the consideration of the factors in Chapter 3 irrelevant. Indeed, the panel of Experts is considered robust enough to reasonably consider every factor they mentioned as impacting DR, in the rest of the thesis. The quantitative analysis shall be considered as a confirmation of the correlation using statistics.

Further studies could be conducted on all the factors to assess the exhaustivity of the list and the repartition of the influence of the factors. Because of time limitations and data access constraints, the study only considers certain factors and attempts to prove the correlation between them and the performance of MS in the implementation of DR.

As all the interviewees gave special importance to the design of the market and the operation of the power system in the expansion of DR, priority is given to the factors in categories addressing Economic and Technical aspects. However, some of the factors identified are not easy to measure and rely heavily on interpretation. This is, for instance, the case of the perception of DR by the stakeholders. This type of factors are thus set aside for this analysis. The chosen model is linear[30]; the tests are conducted to attempt to prove the relevancy and correctness of a multilinear regression with:

$x_{i,j}$ *the value of the factors considered per MS*

y_i *the potential of DR*

a_j *the weighting of the factors*

$0 \leq i \leq n_{MS}$ *the number of MS broadcasting the indicator*

$0 \leq j \leq n_f$ the *number of factors considered*

[30] Indeed, the data set do not seem to be robust enough to justify the elaboration of a quadratic model.

The objective is then to prove that the factors and the potential of DR are linked through the following equation:

$$a_0 + a_1 x_{i,1} + a_2 x_{i,2} + \cdots + a_{nf} x_{i,nf} = y_i$$

The indicators were chosen to cover all the MS, so, $n_{MS} = 27$[31].
The study is not considered accurate enough for the coefficients a_j to be taken at face value. Their sign might be analyzed if the correlation is proven unarguable enough, but it is not the first purpose of this quantitative analysis.

II. Methodology of the implementation

The model is implemented and coded with the language R using the Integrated Development Environment Rstudio (R core team, 2018). This programming language is statistics-friendly and allows a quick and easy approach of multilinear models.
To ensure the relevancy and coherence of the model that is used, the following steps will be followed[32]:

Step.a.: A visualization of the link between the different indicators will be coded first and foremost. This allows to identify without further testing the indicators that are correlated with each other by spotting a strong linear tendency. Indeed, one of the first prerequisites when doing a multilinear regression is to make sure the sets of data are not dependent on each other[33]. For this purpose, a graphic visualization of a linear regression of each pair of sets of data will be done. This graphical methodology allows to make a first rejection of inappropriate indicators (Purdue University, *no date*).

Step.b.: As a quantitative verification of Step.a., a test of chi2 will be conducted. It allows to prove through a strict computation the independence of the indicators between

[31] In reality, hypotheses have been made for some MS when building one indicator because introducing a flaw in one indicator has been considered more relevant than restricting the entire analysis to a smaller number of MS.
[32] The theory for the implementation of the model is mainly drawn from an open-source seminar from the University of California, Los Angeles (UCLA) dedicated to the 'Introduction to Regression in R' from the Office of Advanced Research Computing (OARC), Statistical Methods and Data Analytics (OARC, 2022).
[33] For clarification purposes, each data set, from $x_{i,1}$ to x_{i,n_f}, are called 'indicators' in the rest of the analysis.

themselves. It justifies not conducting the independence test of the Ordinary Least Squared (OLS) (See Step.d. below) method as the chi2 test is more thorough than the OLS one (OARC, 2022).

Step.c.: The construction of the model will be done thanks to certain functions building directly the multilinear regression model.

Step.d.: To ensure that the results of the model are reliable and that the linear model found is the best-fitted one, the OLS method will be used (OARC, 2022). The following tests will be conducted:

> ***Step.d.1.:*** Homogeneity of variance (homoscedasticity): the error variance should be constant. A graphical methodology is considered enough and the dispersion of the errors around zero will be shown on a scatter plot.
> ***Step.d.2.:*** Linearity: the relationships between the predictors and the outcome variable should be linear[34]. A graphical methodology will be used.
> ***Step.d.3.:*** Normality: the errors should be normally distributed. For a large set of data, this step is not necessary but as this analysis is conducted on a restricted number of indicators, it has been considered safer to check this parameter.

Step.e.: Analysis of the results: Once the preliminary tests are done – and their results considered good enough to believe the model relevant – the characteristics of the model can be analyzed. For this purpose, two elements will be looked at: the probability associated with each correlation coefficient and the adjusted r-squared coefficient. The former shows the likeliness of the correlation between the indicator, and thus, by association the factor, and the potential of DR in MS. The commonly used significance threshold for determining whether a variable is correlated to the outcome variable is 5%. The r-squared coefficient is an adaptation for multilinear regression of the correlation factor r used for simple linear regression. It depicts the proportion of potential explained by the indicators. As the list of indicators included in this quantitative analysis is not exhaustive, the r-squared coefficient is expected to be low.

[34] Here, the predictors are the values of the indicators for each MS, meaning $x_{i,j}$. The outcome variables are the values of y_i.

III. Data collection

A. The selection criteria

The factors considered are chosen according to four criteria:

- The importance given to the factor during the interviews: this includes both the general emphasis by the interviewees and the mention of the same criterion by more than one of the three experts.

- The accessibility of the data: the data used are collected from reliable sources – whether they are academic or from public institutions. The choice of a data set depends on its date of release, its estimated correlation with the factor considered, the reliability of its source and the robustness of its construction. Sometimes the indicator characterizes only a fraction of what the factor implies (See Table 3.)[35]. This is why, for some factors, several indicators are aggregated to take into account their complexity[36]. Exceptionally, the factor "A developed and reliable grid infrastructure at the MS level" will be characterized by two indicators as two very relevant sets of data have been found and as the aggregation between the two would be highly irrelevant.

- The presence of the data for every MS: This criterion implies either the abandonment of an indicator or major assumptions to be made for the missing values. The latter is preferred, as it has been decided to prioritize the presence of all the MS in the study.

- The assessment of whether the factors considered are used in the study from SmartEn: Indeed, as detailed below, the outcome variable y_i is taken from the report 'European Market Monitor for Demand Side Flexibility' (Mazzaferro and Murley, 2021), a study from the association SmartEn. It is vital to ensure that it is not designed with the same indicators that we are trying to demonstrate the

[35] The construction of a very accurate and robust database for this analysis would necessitate more time and a better knowledge of the specificity of the different MS.
[36] However, this aggregation is done cautiously as the aggregation also brings some uncertainty due to the weighting of the sub-indicators in the building of the general one. The difficulty is here to find a compromise between the oversimplification of a factor and the introduction of an important uncertainty with the construction of a complex indicator.

correlation to, or else the entire analysis would be rendered worthless.

The factors where a relevant set of data has been found or created are the ones displayed in Table 3.

Category	Indicator per MS	Factors	Code name
Economic – Market Design, regulation	Access to the market for Aggregators (adimensional)	MS's Aggregation model allows DR to be a systematic tool	E_aggreg_acc
Technical - operation of power system	Amount of investment in the Smart grids (€)	A developed and reliable grid infrastructure at the MS level	T_invest
	Share of the distribution grid delivery point that is equipped with smart meters (%)		T_smrt_mtr
Historic and culture	Number of registered TSO and Number of registered DSO	Repartition of the roles and tasks, the concentration of tasks is not in the hands of a single TSO/DSO at the MS level	H_mon
	The average size of the Bidding zone (km^2)	Decentralization of the command of the flexibility at the MS level	H_biddz

Table 3. The factors considered and their indicators.

B. The building of the indicator

Following the selection criteria mentioned previously, the following criteria have been chosen:

1. Access to the market for aggregators (E_aggreg_acc)

As the aggregation model has been highly emphasized by two of the Experts it was crucial to find proper indicator of it. However, a classification of the aggregation model of the different MS is difficult to characterize, and not in every stakeholder's interest to do. Thus, it is not possible to find nor build an indicator that classifies MS according to their aggregator's model. The indicator of the aggregators' access to the market is used instead. This indicator is extracted from a map (See Figure 6.) built by the European Consumer

Organisation (BEUC, 2018), and shows three levels of performance in giving access to the market to aggregators: commercially active, partially opening, preliminary development, closed, not assessed. This qualitative indicator is transformed into a quantitative one by creating a scale of 0 to 4[37].

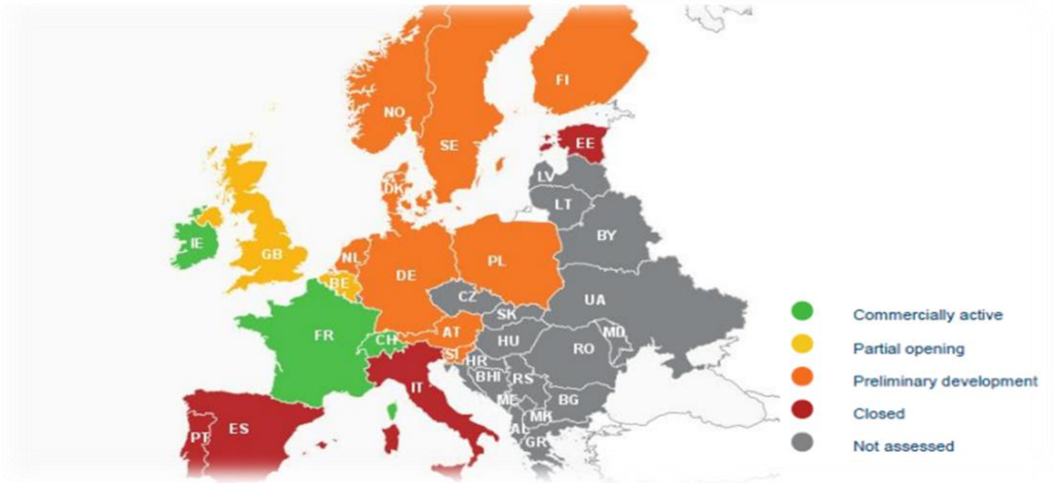


Figure 6. Level of access to the market for aggregators per MS (BEUC, 2018)

2. **Investment in the Smart grids (T_invest) and Share of the distribution grid delivery point equipped with smart meters (T_smrt_mtr)**

Estimating the level of development of the grid gives an idea of the level of electrification and advancement in terms of ancillary services of the MS. Therefore, if a MS has not dedicated an important part of its investment in the development of smart grids or does not have a broad implementation of smart meters, the integration of DR tools such as storage parcs or Virtual Power Plant should be low. The quality and reliability of the grid are aspects difficult to characterize. Indeed, one of the best ways is to quantify the number of HVDC (High Voltage Direct Current) lines – they are to electricity what highways are to road mobility – compared to the number of consumers for each country. However, even though ENTSO-E broadcast a map of the HVDC lines on its website (See Figure 7.), the original data is not open source (ENTSO-E, 2019). Other indicators have to be found.

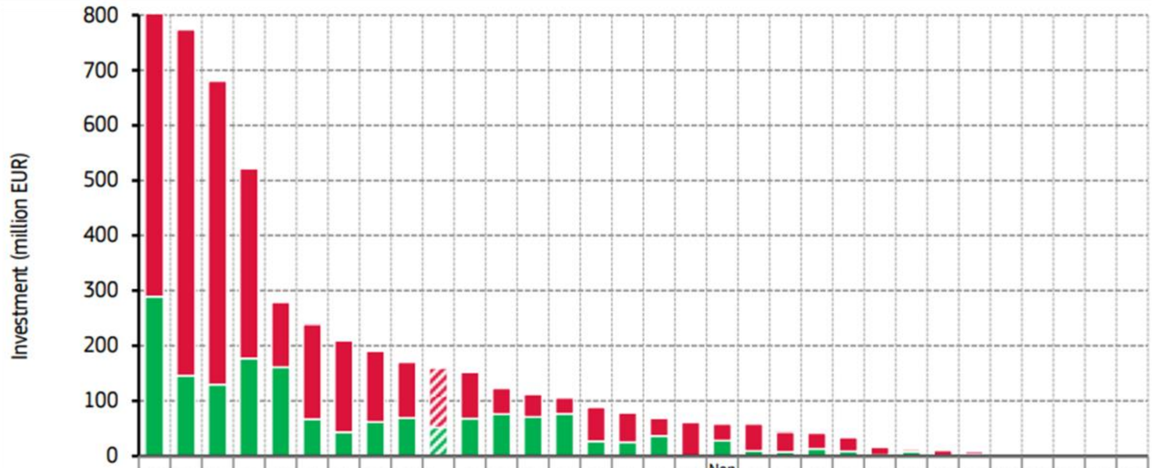
[37] The countries where the indicator is not assessed are allocated the lowest grade: The assumption is made that a country where the indicator could not be assessed does not have an innovative openness and transparent approach to the integration of aggregator which implies a poor performance in the matter. This hypothesis implies an important flaw in the study and is analyzed in the results.

Figure 7. Map of the HVDC lines in the electricity grid (ENTSO-E, 2019).

The first one regards the level of implementation of smart meters in the MS. This indicator is supposed to be relevant enough to characterize a 'developed' grid. Indeed, it is one of the most common – albeit one of the most fundamental – advancements to make a 'regular' grid evolve into a smart grid. More precisely, the indicator characterizes the share of the distribution grid delivery point that is equipped with smart meters (Kochanski *et al*, 2020)

The second indicator regards the total investment per country in millions of euros for the transition of their grid into smart grids (*Covrig et al*, 2017). This data set is based on the number of projects in which the MS are investing[38]. This indicator represents the average between the investment in Demonstration and R&D. This aggregation of the two variables might distort the data. Indeed, as shown in Figure 8., the observations of countries regarding the sum of their investment, the investment in demonstrations or the investment in R&D gives different rankings. Considering the advantages and disadvantages, aggregation makes sense.

[38] The choice to not use the normalized data set is justified by two aspects: (i) the accurate number are not given and the study would lose some of its accuracy (ii) the desire to keep harmonized indicators meaning to prevent the study from having normalized indicators while other are not.



	DE	UK	FR	ES	DK	IT	NL	BE	SE	Avg	AT	CH	NO	FI	PT	EL	PL	LU	Non -EU	RO	CZ	SI	IE	HU	SK	LT	BG	LV	HR	CY	EE	MT
Demonstration	520	628	550	344	117	172	166	128	102	108	84	47	41	29	62	53	32	61	30	49	36	28	25	14	3.7	8.9	5.1	3.5	2.4	1	2.3	1.2
R&D	289	146	130	177	161	67	43	62	69	52	68	76	71	77	27	25	36	0	28	9.1	7.1	13	8.8	1.8	8.2	1.2	2.9	4.2	3.8	3.7	1	1

Figure 8. Level of investment of MS in smart grids (Covrig et al, 2017)

3. Number of registered TSO and DSO (H_mon)

This indicator is built from two sets of data. One is the number of TSOs registered as members of ENTSO-E per MS (ENTSO-E, no date). The second is the number of DSOs registered at EU DSO Entity per MS (EU DSO Entity, 2023). As the ultimate goal is to build an indicator providing the information on whether the power to invest in DR is centralized in the hand of a monopolistic power or not, the weighting between the monopoly of the DSO and the monopoly of the TSO are considered equal. To use the ratio of the annual revenue from the DSOs and the annual revenue from the TSOs of each MS has been considered. However, it would mean that the repartition of power between the TSOs and the DSOs is strictly linked and characterized by their revenues which is an assumption too hazardous to be made. An arbitrary ratio of 50/50 is chosen due to the lack of other findings, the flaw that this assumption brings is taken into account while analyzing the results.

4. The average size of the Bidding zone (H_biddz)

This indicator represents the average area of a bidding zone in a country. It has been built from the map provided by the Florence School of Regulation (Florence School of

Regulation, 2020) and the area of regions from Wikipedia.

5. Potential market size of flexibility (y_i)

To ensure the relevancy of the study, it is necessary to make sure that the chosen indicator of the potential of DR per MS, is not made of the exact same factors that have been identified in Chapter 1 (See Chapter 2, Section I.). The study from SmartEn (Mazzaferro and Murley, 2021) displays 4 indicators of DR: Potential market size of flexibility, Demand side flexibility regulatory progress, Local flexibility, and future of flexibility. The former is the one that is being considered as "y_i *the potential of DR*", it comprises:

- Volume of ancillary services procured and activated.
- Price paid for reservation and activation of ancillary services (the lower this price, the higher the potential market size will be considered).

These criteria can relate to one of the indicators chosen for the multilinear regression: a link could be drawn with the indicator 'aggregator's access to the market'. However, the criteria used by SmartEn do not explicitly involve the aggregator but rather directly the supplier of ancillary services. Therefore, while a connection could be done between the indicators, the correlation is not direct and is considered not conspicuous enough to be hindering the relevancy of the study.

Another important aspect to verify would be the correspondence of this thesis' definition of DR and the definition that SmartEn gives to flexibility: "Flexibility is the ability of electrical generators and consumers to alter their output or consumption on demand. This includes both large front-of-meter assets and DSF assets." (Mazzaferro and Murley, 2021). This definition englobes more aspects than this thesis' definition of DR but every aspect of it. The assumption is made that as flexibility includes DR, the study of flexibility gives a good enough idea of the state of play for DR.

6. Summary of the indicators and their characteristics

To give a clear picture of the relevancy of the indicators chosen, a scoring has been developed regarding the reliability of the source, the robustness of the indicator's construction, the correlation between the indicator and the factor that it represents and the date of the set of data's publication.

Regarding the reliability of the sources, all of them are considered highly reliable. However, as no studies were conducted to investigate their affiliation or if they have a specific interest in the subject of DR, precaution dictates to consider them as bringing a small flaw. The only indicator that is bringing a bigger flaw regarding its source is the one regarding the area of the bidding zones (H_biddz) as it uses some data from Wikipedia.

The robustness of the building of the indicator is one of the weakest points of the data collection. Indeed, as soon as some data must be aggregated, the weighting factor of the aggregation has a crucial impact on the outcome. Thus, every time an aggregation or an interpretation of the data set is made, the uncertainty is considered as important enough to be remembered in the analysis.

The correlation between the indicator and the factor relates to the full coverage of the latter by the former or whether the relation between both is direct. For instance, H_biddz is supposed to characterize the 'Decentralization of the command of the flexibility at the MS level'. Even if one can say that the size of bidding zones is directly linked to the decentralization of some schemes, one cannot ensure that smaller bidding zones will necessarily imply the triggering of DR actions at the bidding zone level. Thus, it is considered to bring a flaw.

In conclusion, the factors are characterized as follows (See Table 4.):

Code name	Reliability of the source	Robustness of the building of the indicator	Correlation between the indicator and the factor	Date
E_aggreg_acc	++	+	+++	2018
T_invest	++	+	++	2017
T_smrt_mtr	++	++	++	2020
H_mon	++	+	+	2023
H_biddz	+	+	+	2020
y_i	++	+++	++	2021

Legend:
+++: does not bring any flaw in the analysis
++: this element brings a small flaw that is considered negligible
+: this element brings a small flaw that is important enough to be considered an important hypothesis and should be remembered when conducting the analysis of the results.

Table 4. Summary of the indicators and their characteristics

IV. Implementation

A. Validity tests and hypotheses

The detail of the code implemented in Rstudio is part of the Annexes (See Annexe 2.). The first step of the implementation is the importation of the indicators that composes the global data set. The library ‘ggpubr’ and ‘car’ – respectively used for data visualization and regression model – along with some specific packages (Kassambara, 2023; Weisberg, 2019) will be imported.

1. Step.a. Visualization of the Matrix of scatter plot

The visualization of the matrix of scatter plots aims at determining if a strong correlation emerges from the plotting of one of the indicators as a function of the other. This is a graphical method used to detect indicators that are not relevant to the study before even conducting the chi2 test. A scatterplot of the correlation between each pairwise combination of factors is shown in each of the boxes in Figure 9.[39]

[39] For instance, the box in the top right corner diplays the scatter plot of H_biddz as a function of T_invest.

Main function	pairs()
Description	“A matrix of scatter plots is produced” (R Core Team, 2023)

Results

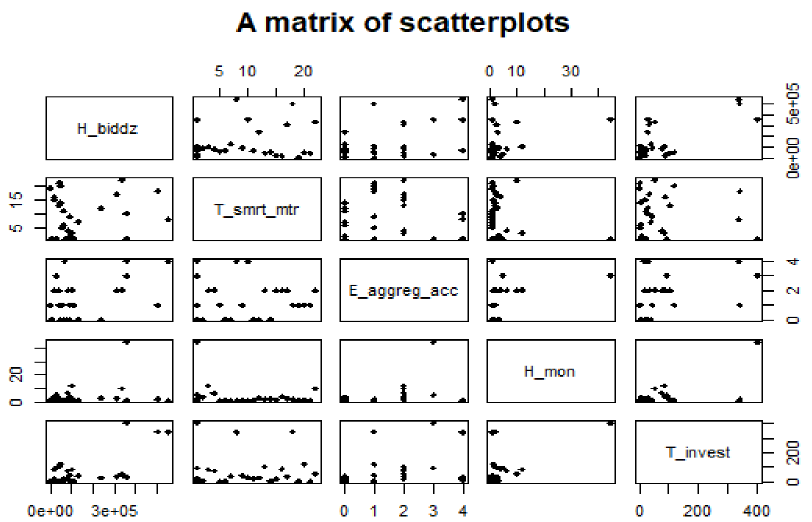


Figure 9. Graphical method assessing the independence of the indicators

Analysis	The matrix of scatter plots does not show a strong linear connection between a pair of indicators.

2. Step.b. The chi2 test

The first test that must be completed is the chi2 test. It must be conducted between every indicator to ensure they are not correlated. To this purpose, the function chisq.test, part of the basic functions from RStudio is used. The threshold to consider the variables as independent is $p > 0.05$, this value is the one usually used when a chi2 test for independence is conducted.

Because the amount of information comprises in the data set is restricted, the Monte Carlo simulation is applied to expand the data set and assess under better conditions the correlation between indicators (R Core Team, 2023).

To visualize the computation of the value of the chi2 test for all pairs of indicators, a matrix containing all the p values for each pair is built (See Figure 10.). The diagonal values should not be considered[40].

<table>
<tr><th>Main function</th><th>chisq.test()</th></tr>
<tr><td>Description</td><td>"chisq.test performs chi-squared contingency table tests and goodness-of-fit tests" (R Core Team, 2023).</td></tr>
<tr><td>Results</td><td>The function chisq.test returns different values, but the analysis is restrained to the value of p.
<table>
<tr><th></th><th>H_biddz</th><th>T_smrt_mtr</th><th>E_aggreg_acc</th><th>H_mon</th><th>T_invest</th></tr>
<tr><td>H_biddz</td><td>0.004497751</td><td>0.4062968516</td><td>1.0000000000</td><td>0.7356321839</td><td>1</td></tr>
<tr><td>T_smrt_mtr</td><td>0.400799600</td><td>0.0004997501</td><td>0.9880059970</td><td>0.6496751624</td><td>1</td></tr>
<tr><td>E_aggreg_acc</td><td>1.000000000</td><td>0.9865067466</td><td>0.0004997501</td><td>0.1004497751</td><td>1</td></tr>
<tr><td>H_mon</td><td>0.720139930</td><td>0.6541729135</td><td>0.1029485257</td><td>0.0004997501</td><td>1</td></tr>
<tr><td>T_invest</td><td>1.000000000</td><td>1.0000000000</td><td>1.0000000000</td><td>1.0000000000</td><td>1</td></tr>
</table>
Figure 10. Numerical method assessing the independence of the indicators</td></tr>
<tr><td>Analysis</td><td>The values of the p-value of the chi2 test are all superior to 0.05. Thus, all indicators are considered to be independent from one another.</td></tr>
</table>

3. Step.c. Building of the model

To build the linear model, the function lm() is used.

Main function	lm()
Description	"Lm is used to fit linear models, including multivariate ones. It can be used to carry out regression, single stratum analysis of variance and analysis of covariance" (R Core Team, 2023).

[40] It might appear surprising at first that the values in the diagonal, meaning the chi2 test between a indicator and itself, is not equal to zero. Indeed, as a representation of the dependence between a variable and itself, the value should be equal to 0, showing that the indicator is perfectly dependent to itself. However, while using the Montecarlo simulation allows having operable tests for the other chi2 tests, the simulation introduces a small error in the equality between a variable and itself, leading to the value of 4.5e-3 appearing in the diagonal.

The results and analysis will be conducted in the following section.

4. Step.d. OLS method

Step.d.1. Homogeneity of variance (homoscedasticity)

The homogeneity of the residuals' variance is the key presumptions for the ordinary least squares regression. If the model is relevant, the residuals plotted against the fitted values should not display any trend (See Figure.11). This is a graphical method.

Main function	-

Results

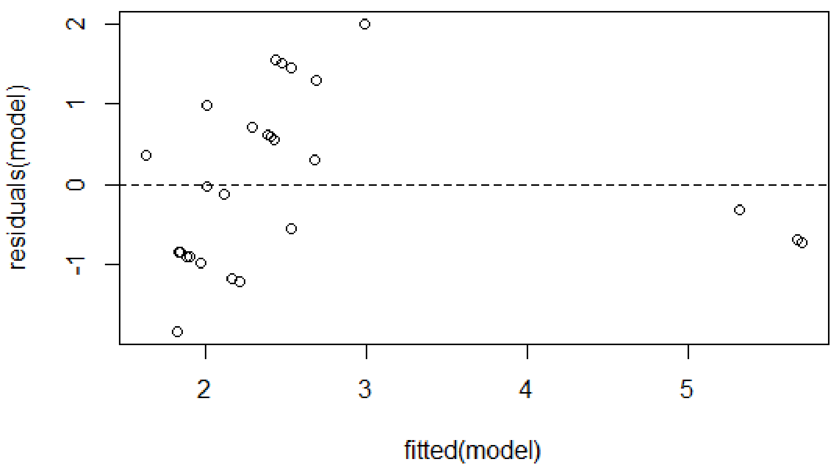


Figure 11. Graphical method assessing the Homoscedasticity

Analysis	The residuals of the model do not show any trend when plotted as a function of the fitted values. They are homogeneously scattered around zero.

Step.d.2. Linearity

The test of linearity allows to anticipate if the implementation of a quadratic model would give better results. Residuals are plotted against the fit as well as other predictors. If any of these graphs display systematic forms, it may have been preferable to include some nonlinear elements, as the linear model might not be the best fitted one.

Main function	residualPlots()
Description	"Draws a plot or plots of residuals versus one or more term in a mean function and/or versus fitted values. For linear models curvature tests are computed for each of the plots by adding a quadratic term to the regression function and testing the quadratic to be zero" (R Core Team, 2023).

Results

```
               Test stat Pr(>|Test stat|)
H_biddz          -4.2222        0.0004185 ***
T_smrt_mtr       -0.0605        0.9523190
E_aggreg_acc     -0.9294        0.3637749
H_mon            -2.3110        0.0316170 *
T_invest         -4.8080        0.0001070 ***
Tukey test       -4.5909        4.413e-06 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 12. Graphical method assessing the linearity

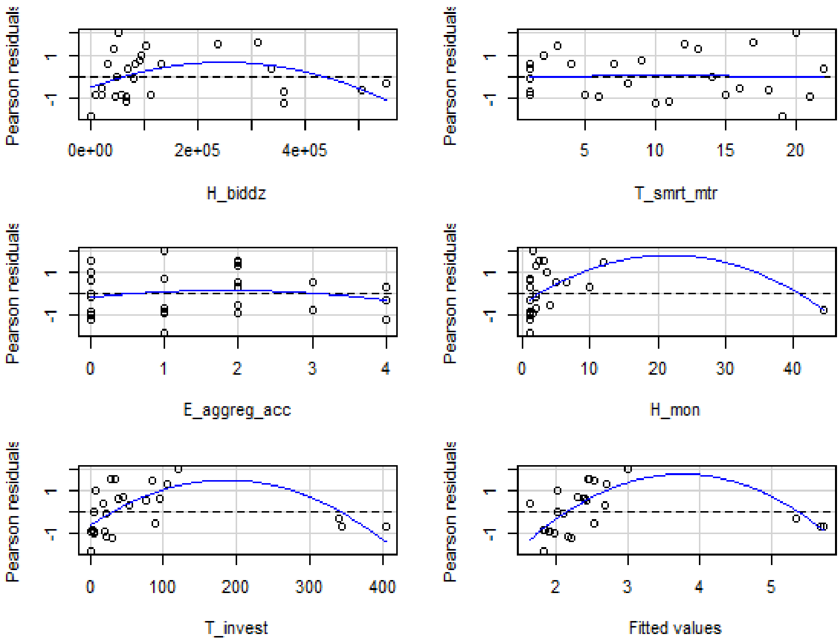


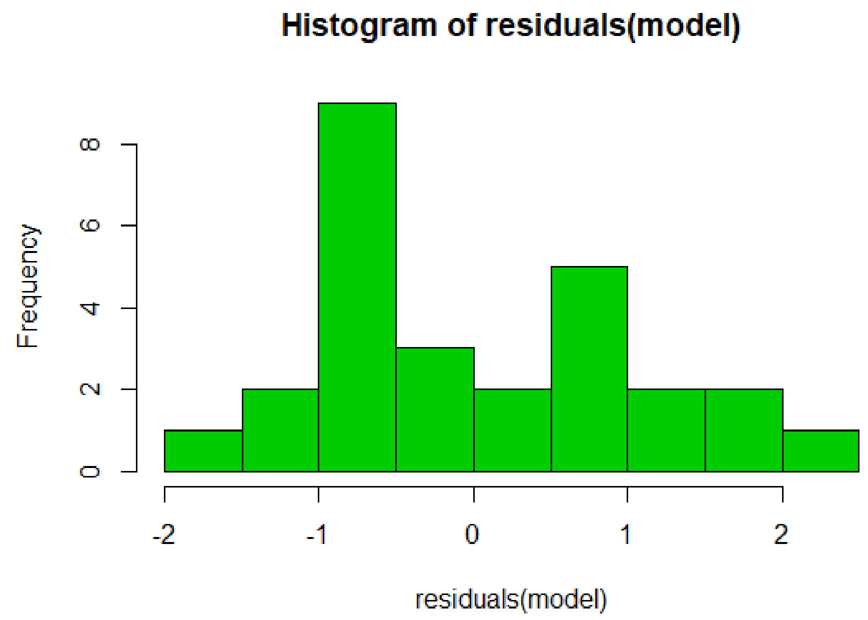
Figure 13. Numerical method assessing the linearity

Analysis

The results show that the linear is not the best model that could have been used. Introducing quadratic elements could have given better results. However, as explained in Chapter 2, Section I. the data set is not considered robust enough to try finding quadratic terms and engage in precise determination of hypothetic correlation. The results considered are the ones looking relevant, even if the model is not the best fitted.

Step.d.3. Normality

The normality of the predictors is not required for a multilinear regression. However, the normality of the residuals must be checked when the data set is small (OACR, 2022). It is considered to be the case in this analysis. To ensure the normality, a graphical method is used: a histogram of the residual is plotted and for the test to be considered passed, the observation of the distribution of the residuals should be the closest possible to a normal distribution.

Main function	**None**
Results	 *Figure 14. Graphical method to assess the normality of the residuals.*
Analysis	As displayed in the graph, the normality of the residuals is highly arguable. Indeed, the normal law would be highly rightly skewed. This test is not seen as passed, implying that the multilinear regression model is not the best-fitted model but does not exclude drawing any conclusions.

B. The results and analyses

1. The characteristics of the model

Even if the preliminary tests do not indicate that the chosen model is the best to apply, an analysis of the model will still be conducted.

<table>
<tr><th>Main function</th><th>summary()</th></tr>
<tr><td>Description</td><td>“summary is a generic function used to produce result summaries of the results of various model fitting functions” (R Core Team, 2023).</td></tr>
<tr><td>Results</td><td><pre>
Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) 1.804e+00 4.810e-01   3.751 0.00118 **
H_biddz   1.371e-06 2.155e-06   0.636 0.53166
T_smrt_mtr   6.455e-03 3.335e-02   0.194 0.84837
E_aggreg_acc -1.066e-01 1.948e-01 -0.547 0.58997
H_mon   5.903e-05 3.461e-02   0.002 0.99866
T_invest   9.221e-03 3.508e-03   2.628 0.01570 *

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.149 on 21 degrees of freedom
Multiple R-squared: 0.5417,   Adjusted R-squared: 0.4326
F-statistic: 4.964 on 5 and 21 DF, p-value: 0.003722
</pre>
Figure 15. Summary of the results</td></tr>
<tr><td>Analysis</td><td>As explained in Chapter 2, Section II., the only results that will be used are the probability associated with the coefficient and the adjusted R-squared. The results show that the only probabilities that allows to consider the coefficient as reliable enough are the one for T_invest and the Intercept. Indeed, the probability must be beneath 0.05 for the coefficient to be exploitable.
The Adjusted R-squared has a value of 0.4326 which means that only 43.26% of the value of Y can be explained by the indicators used.</td></tr>
</table>

2. The interpretation

The intercept is not relevant to discuss as the list of indicators is not exhaustive. This also explains the low value of the adjusted R-squared, which was expected. However, the values of the probabilities of the coefficients were expected to be higher. Even though the OLS method showed that a linear model is not the optimum model to use, a correlation between indicators, and therefore factors easing the expansion of DR, and the potential of DR for MS, was expected to be observable for most of the indicators. Some explanations can be imagined for these results:

H_biddz: The purpose of this indicator was to convey the decentralization of the control of flexibility at the MS level. The size of the bidding zone alone, can create the wrong impression because no information has been obtained on the aggregation model, the balancing of interests, or the sharing of tasks within the zones. The primary assumption of the failed attempt to establish the association between the indicator and the potential for DR is as follows: A small bidding zone's size does not necessarily indicate that the activation of the DR mechanism is at the bidding zone level. Another reason might be that this indicator merely provides a fragmentary picture of the centralization of DR. In other words, the indicator may influence decentralization, but not significantly enough to be seen.

H_mon: The background interviews indicated that the emergence of numerous parties and the deregulation of the energy market will act as a stimulant for DR. The sharing of roles and the proliferation of actors would be a catalyst for DR because the latter would be a way to differentiate oneself from one's competitor. However, as the result from the computation is not conclusive, this indicator might not be the best option. Indeed, the signal loses significance if historical players joined the DR bandwagon without having to share the market. France may be a nice illustration of this tendency. Indeed, RTE and ENEDIS are France's primary TSO and DSO, respectively. However, France has a significant potential for DR, particularly given that RTE is proactive in this regard. As a result, using the indicator H_mon to express this factor may not be the best choice.

T_smrt_mtr: This indicator has not been proven correlated to the potential of DR by the quantitative study. One can wonder why having the technical means to develop DR on a territory, thanks to a high share of installed smart meters on the grid, does not automatically lead to the political decision to engage in the promotion of such ancillary services. A hypothesis would be that the relationship between these two indicators is not linear and that only when the grid is highly equipped with smart meters, national changes in the promotion of DR will be conducted. In other words, a raise of 5% of the share of delivery points equipped with smart meters would not directly provoke the increase of the volume of ancillary procured and activated – that is part of the potential of DR according to SmartEn. One could imagine that once the share of delivery points equipped with smart meters reach a threshold, DR mechanisms are implemented.

E_aggreg_acc: This indicator is very relevant when considering its associated factor: MS's Aggregation model allows DR to be a systematic tool. However, a flaw is introduced with the adaptation of the set of data to make it complete. As previously indicated, when the values of this indicator are unknown, the poorest performance is assumed. This introduces confusion between performance and transparency which can be partially the cause of this absence of proven correlation.

The only factor whose correlation to the potential of DR – as understood by SmartEn – has been quantitively proven is T_invest, meaning the investment of MS in Smart grids.

T_invest: As mentioned before, the value of the coefficient associated with the factor is not relevant due to the limited robustness of data sets. However, as the quantitative approach shows that the correlation between T_invest and the potential of DR is relevant, looking at the sign of the coefficient would be reasonable. The coefficient is positive which indicates that the more investments there are in the development of smart grids the more potential for DR there is. This result is not surprising and confirms what the experts said about the necessity of a well-developed grid for DR to expand.
The only potential flaw of this indicator lies in the aggregation of the two sets of data respectively the level of investments in Demonstration and R&D for smart grids (See Figure 8.) and is not significant enough to make this result irrelevant.

Chapter 3 – The EU regulatory framework

I. Methodology

This Chapter evaluates whether the EU's regulatory framework addresses the primary drivers of the expansion of DR. For this purpose, this section comprises three steps.
The first part of this Chapter (Section II.) is dedicated to an overview of the policies and legislation governing energy in the EU. A general review of the important ones is presented, followed by a brief explanation of the main improvements brought by the subsequent legislative revisions.
The second step (Section III.) assesses whether the regulatory framework is covering the factors easing the expansion of DR, that were identified in Chapter 1. For each piece of legislation, a specific focus on whether DR is mentioned – and if it is how it is referred to – and their coverage of the factors easing the development of DR[41]. Even though the factors' coverage is not thoroughly explored, examples of Articles that reference the theme of the factor easing DR expansion are given. Such examples, along with details on the methodology are stated in Annexes 3 and 4. Some factors cannot be assessed when looking at the EU regulatory framework, such as the "Understanding of technical issues at the EU level". In fact, none of the components that are associated with the narrative around DR or that are hardly quantifiable are assessed in this part. A qualitative analysis of how the regulation affects the growth of DR in the EU concludes this section.

II. Overview of the legislative framework

A. The broad picture

The broad image of the EU vision for energy can be summarized by the five dimensions of the Energy Union Strategy described by a communication from the European Commission: (i) "Security, solidarity and trust" (ii) "A fully integrated internal energy market" (iii) "Energy efficiency" (iv) "Climate action, decarbonizing the economy" (v)

[41] This assessment is lenient; as long as the legislation explicitly addresses the factor's themes, the latter is deemed to be covered.

"Research, innovation and competitiveness"[42].

The CEP, Fit for 55, REPowerEU and the Reform of the Electricity Market Design mostly target the same legislations by amending, changing, or replacing them (See Figure.4). To better understand the history of these regulations and directives, six main categories are considered:

- Any pieces of legislation (or future one) targeting DR specifically: the only one that was found relevant was the Framework Guideline on Demand Response that has been asked by the European Commission, published by the ACER in December and will be revised by the ENTSO-e in the next months (ACER, 2022). This document is the basis for the future European Commission's proposal on DR.

- The legislation on the Electricity Market Design. The pieces of this legislation are of foremost interest. Both the version in force and the new proposal are considered[43] as the proposal might be subject to modifications before entering into force.

- The Regulation on the governance of the Energy Union and Climate Action[44] outlining the governance required to guarantee that the goals outlined in the other CEP directives would be reached.

- The Renewable Energy Directive (RED), and its several revisions[45] are pertinent

[42]Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank: A framework strategy for a resilient Energy Union with Forward-Looking Climate Change Policy, COM(2015) 80 final, 25.2.2015.

[43] The Electricity Market Design legislation in force comprises (1) Directive 2019/944. (2) Regulation 2019/943. (3) Regulation (EU) 2019/941 of the European Parliament and of the Council of 5 June 2019 on risk-preparedness in the electricity sector and repealing Directive 2005/89/EC; hereinafter Regulation 2019/941. The proposed Electricity Market Design comprises (1) COM(2023) 147. (2) COM(2023) 148.

[44] Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action, amending Regulations (EC) No 663/2009 and (EC) No 715/2009 of the European Parliament and of the Council, Directives 94/22/EC, 98/70/EC, 2009/31/EC, 2009/73/EC, 2010/31/EU, 2012/27/EU and 2013/30/EU of the European Parliament and of the Council, Council Directives 2009/119/EC and (EU) 2015/652 and repealing Regulation (EU) No 525/2013 of the European Parliament and of the Council; hereinafter Regulation 2018/1999.

[45] The RED includes (1) Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources; hereinafter Directive 2018/2001. (2) Proposal for a Directive of the European Parliament and of the Council amending Directive (EU) 2018/2001 of the European Parliament and of the Council, Regulation (EU) 2018/1999 of the European Parliament and of the Council and Directive 98/70/EC of the European Parliament and of the Council as regards the promotion of energy from renewable sources, and repealing Council Directive

to include in the study because, in addition to setting a target for the proportion of renewable energy that the EU should achieve, it also lays out some principles for better integrating renewable energy in the electricity mix, and more specifically the grid. This sets the stage for DR to expand or remain stagnant.

- The Energy Efficiency Directive (EED) establishes a goal for reducing the energy consumption of the EU through energy efficiency. Additionally, it establishes standards for sectors that are falling behind, and, as the directive evolves[46], the ambition and rate of energy efficiency development rise.
- The Energy Performance of Building Directive (EPBD) has the least direct relationship to the regulatory framework pertaining to DR. However, its different versions[47] should be taken into account because they have an influence on the energy market and energy management. After all, it is included in the same packages as other immediately pertinent pieces of the regulatory framework. Furthermore, households account for the second biggest share of the EU's final energy consumption (Eurostat, 2021), which makes them important to address when discussing electricity in general.

In the next Section, the broad aim of the different versions of the Directives and Regulations presented above and whether they present a frontal and clear approach to DR will be assessed. However, in order to represent the current state of the EU legislation regarding DR, only the most recent accepted version of the regulation—or, in the case of REPowerEU, the version that is about to be adopted—will be taken into consideration in the in-depth analysis[48] of Section III.

(EU) 2015/652, COM(2021)557 final, hereinafter COM(2021) 557. (3) COM(2022) 222.

[46] The EED includes (1) Directive (EU) 2018/2002 of the European Parliament and of the Council of 11 December 2018 amending Directive 2012/27/EU on energy efficiency; hereinafter Directive 2018/2002. (2) Proposal for a Directive of the European Parliament and of the Council on energy efficiency (recast), COM(2021) 558 final, hereinafter COM(2021) 558 (3) COM (2022) 222.

[47] The EPBD includes (1) Directive EU 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency; hereinafter Directive 2018/844 (2) Proposal for a Directive of the European Parliament and of the Council on the energy performance of buildings (recast), COM(2021) 808 final, hereinafter COM(2021) 808. (3) COM(2022) 222

[48] This might be a flaw since failing to take the dynamics and changes into account would mean failing to determine if the EU’s energy regulatory environment is becoming increasingly DR-friendly.

To have a clearer image of the scope of the different legislative package, Figure 16 is giving a summary of the evolution of the regulatory framework.

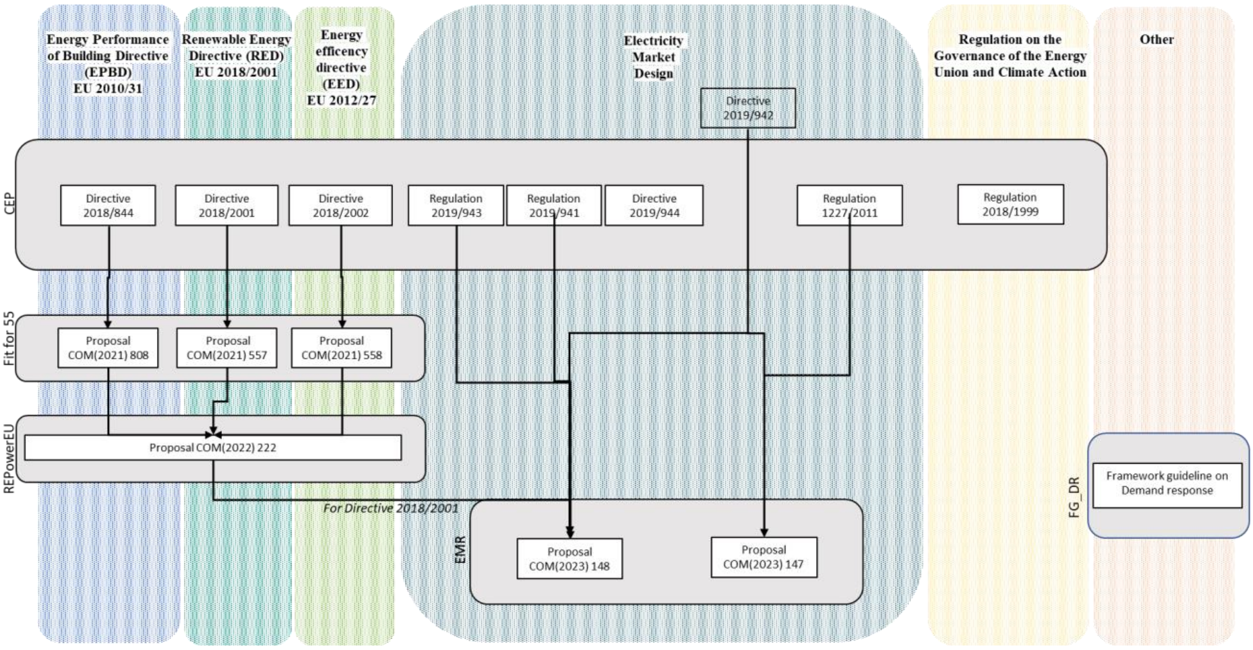


Figure 16. The evolution of the regulatory framework.

B. The content of the regulatory framework

1. The CEP

The goal of this legislative package, which was proposed in 2016 and adopted in 2019, is to bring the energy sector into compliance with the Paris Agreement (European Commission, 2019). This is the oldest of the legislative package considered here. The MS had one to two years to enact the Directives into their national legislation, and this package serves as the foundation for several revisions and modifications, therefore it is pertinent to our analysis. The CEP consists of four Directives and four Regulations: the EPBD, the RED, the EED, the Electricity Market Design Directives and Regulations, and the Regulation on the Governance of the Energy Union and Climate Action.

The CEP pieces of legislation address DR primarily in the form of general guidelines promoting flexibility in the preambles of the policies. As mentioned in Chapter 1, Section III., there should have been articles accurately focusing on DR, but since some actors – Whose names were not mentioned by Expert C – could not reach a consensus, they were removed. When DR is discussed, it is typically merely mentioned as a tool that should not be disregarded.

Directive 2018/844 is an update of the 2010 version of the EPBD. DR is only mentioned once in this piece of legislation, in Annex 1, Article 2c (Directive 2018/844). It indicates that building consumption should be viewed as a possible source of flexibility. But the only methods listed to do so are "flexibility and load shifting capacities", which remain highly vague. The main elements mandated by this Directive are the implementation by MS of financing plans for building renovations, the installation of electric vehicle charging stations as a part of "technical building systems", and the computation of an indicator of the "smartness of the building".

Directive 2018/2001 is the 2018 version of the RED that established objectives for the year 2020. DR is included in this regulation, but the main change is the new target of 32% renewable energy sources in the EU's final energy consumption by 2030. Article 24 of Directive 2018/2001 establishes that MS shall engage in actions for energy system adaptations such as the implementation of DR to facilitate the smooth integration of renewable energy into the grid.

Directive 2018/2002 revises the EED's version of 2012. The only mention of flexibility in the grid is under the form of "Demand-side response" which "compete on equal terms with generation capacity" in the recital (2) of the preamble (EU 2018/2002)[49]. This Directive foresaw the new EU objective of at least 32.5% – instead of 20% – increased energy efficiency by 2030 (compared to 2005 levels). The phrase "energy efficiency is to be treated as an energy source in its own right" is a good summary of the EED's philosophy.

Regulation 2018/1999 modifies 13 previous legislations. Called the Regulation on the Governance of the Energy Union and Climate Action, the text mentions DR 12 times. This legislation sets the means to create a governance for energy policy that will ease the reaching of the targets set in the other legislations of the CEP. The main components of this regulation are the creation of "national integrated energy and climate plans" and

[49] The fundamental purpose of this recital is to indicate that while developing a strategy to enhance the energy system or a funding plan, the development of additional generating capacity should be regarded at the same level as grid flexibility; these two components should be fair competitors.

"long-term low emission strategies" (European Parliament, 2018).

Directive 2019/944 concerns the Common Rules for the internal market for electricity and mentions not less than 35 times "demand response". This Directive is interestingly enough, mentioning that "the Union would most effectively meet its renewable energy targets through the creation of a market framework that rewards flexibility and innovation", which implies directly that DR has a role to play when it comes to the decarbonization of the power system.

Regulation 2019/943 is the Regulation on the internal market for electricity and mentions 37 times "demand response". This Regulation is strongly emphasizing the need to promote distributed generation: "Electricity from renewable sources from small power-generating facilities should be granted priority dispatch". This is significant when thinking about DR since it puts forward the idea of flexibility, even if it only refers to generational flexibility.

Regulation 2019/941 on risk-preparedness in the electricity sector does not contain any mention of DR but the overall resiliency of the electricity market is addressed, which has a direct impact on the possibility for DR to be fully integrated. This Directive is a way to put crisis prevention and management at the European level and not only at MS's level, as an interconnected European grid calls for European actions.

Regulation 1227/2011 is the Regulation on wholesale Energy Market Integrity and Transparency (REMIT) and is giving a stronger role to the ACER. The intention is to prevent market manipulation from happening. Although DR is not mentioned, this legislation stresses the function of the ACER, which supports openness and data exchange in the electricity market. The latter directly influences the growth of DR.

2. FIT for 55

The Fit for 55 package comprises proposed Directives ensuring the reaching of climate neutrality by 2050. It sets the goal of -55% of GHG emissions by 2030. The assessment of the Fit to 55 package is restricted to the pieces of legislation impacting the RED, the EPBD and the EED. Therefore, this package brings three main modifications affecting the scope considered:

The proposed Directive COM(2021) 808 is the proposal recasting the EPBD's version of the CEP (Directive 2018/844). This revision aims at aligning the EPBD's objective and roadmap to the global climate objective for 2030 and 2050 (European Parliament, 2021a). Thus, new definitions are introduced – such as 'zero emissions building' or 'nearly-zero energy building' – and a specific milestone is set: new public buildings must be zero emissions buildings by 2027 whereas private ones have until 2030. This Directive will be further amended by REPowerEU.

The proposed Directive COM(2021) 557 is a proposal for a substantive revision of the version of 2018 of the RED (European Parliament, 2021b). The target of 32% of the share of renewable energy in the final consumption of the EU by 2030 is increased to 40%. Some specific targets have been set for sectors that are slow to integrate renewable energy – such as industry, heating and cooling, and transport. This proposal also "lowers the threshold for applying sustainability criteria for small-scale RES installations to 5 MW (rather than the 20MW level set out in Directive 2018/2001)". This sets a precedent for lowering prequalifications for small providers of DR.

The proposed Directive COM(2021) 558 is a revision of the EED in the context of the EU Green Deal and more specifically in the Fit for 55 package (European Parliament, 2021c). The new targets are binding, more ambitious and more detailed: targets for reducing EU primary and final energy consumption are increased to respectively -39% and -36%. The Directive focuses on intensive energy consumer fields and aims at protecting consumers. The public sector is expected to be a model in terms of energy efficiency.

3. REPowerEU

REPowerEU was launched in May 2022 and has three pillars: save energy, produce clean energy supply and diversify this energy supply (European Commission, 2022b). At first sight, flexibility is the great absence of this plan. Indeed, Expert A highlights that it should be the fourth pillar of in REPowerEU and was critical of this absence.

The proposal of REPowerEU (COM(2022) 222) would modify the EPBD, the RED and the EED and emphasizes the need to have an energy system more independent from third countries. The new targets that REPowerEU would replace the ones planned by Fit for 55.

The main amendments are the following:

- Regarding the EED, the objective of Fit for 55 is increased, as stated in Article 1(2) of COM(2022) 222. The new goals would be of -40% for final energy consumption and -42,5% for primary energy consumption. (European Parliament, 2023a).
- The target share of renewable energy in the final consumption of the EU would go from 40% to 45%. The RED would also be modified to promote the acceleration of "permitting procedure [delivery] for new RES power plants or for adaptation of existing RES installations" (European Parliament, 2023b)
- Regarding the EPBD, REPowerEU would raise the ambition and bring forward some of the milestones. Indeed, buildings would have to be zero-emission by 2028 and be equipped with solar technologies by the same deadline. The pace of the obligation to climb the performance label would also be also heightened. The scheme to promote renovation should target the worst-performing buildings (European Parliament, 2023c).

4. Electricity market reform

The European Commission proposed two pieces of legislation that have 7 main objectives[50]: (1) "Making electricity bills less dependent on the price of fossil fuels" (2) "Limiting revenues of inframarginal generators" (3) "Improving the efficiency of short term market" (4) "Facilitate and incentivize non-fossil flexibility services for renewables integration" (5) "Towards better consumer protection and empowerment" (6) "Enhance the transparency of the energy market and protection against market manipulation" (7) "Generation and system adequacy for a decarbonized electricity system". The main way these pieces of legislation address DR is through the expression "peak shaving products". The electricity market reform consists of two proposed regulations:

[50] Commission Staff Working Document, Reform of Electricity Market Design, accompanying the documents "Proposal for a Regulation (EU) of the European Parliament and of the Council amending Regulations (EU) 2019/943 and (EU) 2019/942 as well as Directives (EU) 2018/2001 and (EU) 2019/944 to improve the Union's electricity market design" and "Proposal for a Regulation (EU) of the European Parliament and of the Council amending Regulations (EU) No 1227/2011 and (EU) 2019/942 to improve the Union's protection against market manipulation in the wholesale energy market", SWD(2023) 58 final, 14.3.2023.

The proposed regulation COM(2023) 147 aims at improving the Union's protection against market manipulation in the wholesale energy market. It amends the REMIT Regulation to widen the scope of data reporting on the electricity market, improve cooperation between energy and financial regulators, increase market transparency, and tighten up on reporting parties' oversight. It also provides a framework for the harmonization of national regulatory authority fines.

The proposed regulation COM(2023) 148 aims at improving the EU's electricity market design. It amends Regulation 2019/943, Directive 2019/942, Directive 2018/2001 and Directive 2019/944, and mentions several times DR. The goal of the proposal is to optimize the electrical market so that decarbonized and distributed power generation may be effectively integrated. It also seeks to safeguard customers by ensuring reliable, affordable electricity. Thus, the amendments address:

- The need for an undistorted market to allow a good integration of flexibility and the resilience of long-term investment which will help mitigate the volatility of the short-term market. The general approach to the improvement of intraday and day-ahead markets is provided. The need for more liquidity in forward electricity markets is also addressed by the amendments.
- The rules for TSOs to use DR as a means to smooth the load curve by shifting the peak. However, this part is not extensively developed and does not enter into detail about the technical aspects of the ancillary services that could shift the peak. These elements are described in the Framework Guideline on Demand Response (ACER, 2022) that addresses the way for actors to effectively implement DR. New rules apply also to data access from smart meters.
- The development of more long-term contracts under the form of Power Purchase Agreements and Contracts for Difference. These two schemes amplify long-term investment signals for the adoption of carbon-neutral generation while reducing risks for the parties entering into an agreement.
- The lack of transparency in the electricity market.

5. Framework Guideline on Demand Response

Following the request from the European Commission, the ACER drafted a Framework Guideline on Demand Response on December 2022 (ACER, 2022). It covers only the explicit side of DR and aims at being non-discriminatory between the technologies used for DR (ACER, 2023). The goal of the Guidelines is the framing of future binding rules regarding the integration of DR in the grid. The rules aim at allowing the consumer to be more involved whether it is with distributed generation, storage or explicit peak shaving, while integrating DR as a tool to handle congestion.
The ACER's Framework Guideline has been sent to the European Commission in December 2022. Once the commission will have given its approval, the ACER, ENTSO-E and EU DSO Entity will draft a proposal.

III. Analysis

The legislation that is considered in the in-depth analysis comprises the latest versions of the directives and regulations (except for the Electricity Market Design set of legislations as the new version is only at the early stage of the Ordinary Legislative Procedure).

Therefore, the versions considered are the following:

- **EPBD:** Proposed Directive COM(2021) 808 with proposed amendments of COM(2022) 222.
- **RED:** Proposed Directive COM(2021) 557 with proposed amendments of COM(2022) 222 and COM(2023) 148.
- **EED:** Directive 2021/0203 with proposed amendments of COM(2022) 222.
- **Electricity market design legislation in force:** Regulation 2019/943, Regulation 2019/941, Directive 2019/944, and Regulation 1227/2011.
- **Regulation on the Governance of the Energy Union and Climate Action:** Regulation 2018/1999.
- **Proposal on Electricity market design:** Proposed Regulation COM(2023) 148 and proposed Regulation COM(2023) 147.
- **Framework Guideline on Demand Response** (ACER, 2022).

The table of results (See Annexe 4) shows that all the factors easing the expansion of DR and identified in Chapter 1 are covered by the EU regulatory framework. The methodology used to build this table is detailed in Annexe 3.

The lexical field and synonyms of DR (See Chapter 1, Section I.) are present in all the pieces of legislation considered. However, most of the occurrences are in the preamble of the texts. This means that DR is mostly understood as an element of context. This is not surprising as no Directive or Regulation directly targets DR. This is why the Framework Guideline for Demand Response is a breakthrough. Indeed, if these recommendations result in the adoption of a Regulation[51], this would be the first one directly targeting DR in the EU. This element is crucial to consider. Indeed, a Regulation is binding in its entirety while a Directive is only binding as the result to be achieved, leaving flexibility to the MS for the means.

An explicit definition of DR is given in the Electricity Market Design, in Directive 2019/944 (in force), while the new proposed version only defines flexibility in a broad way. This is why, Expert C, explained during his interview that the Framework Guideline for DR aimed also at banning the word 'flexibility' which was considered too vague. Therefore, the Framework Guideline specifies that the definition of the tools for DR must be clearly defined in future legislation. The other legislations mainly give examples such as in Annex IV.2.(c) of the proposed EPBD COM(2021) 808 stating that DR in buildings can be achieved through "flexibility and load shifting capacities". This way of mentioning DR is neither technical nor accurate but is common in the pieces of legislation considered.

The rule of no discrimination, regarding non-discriminatory principles between both technologies and actors, can be found in every legislation as it is a general rule. The non-discriminatory principle for actors is directly linked to the factor "Easy Access to the market for smallholders" and is mentioned by almost every legislation. Indeed, small actors are seen as consumers to protect (for instance through securing access to affordable electricity for SMEs) but also as actors that should be able to easily access the market. The most important advancement in this regard is section 3.2 of the Framework Guideline

[51] After mandating the ACER to draft this Framework Guideline, the European Commission will have to validate it. The EU DSO Entity and ENTSO-E must then develop a proposal in accordance with the guidelines, which must be confirmed by the ACER before being submitted to the European Commission as proposed new EU rules.

for DR which is titled “Simplification of the products prequalification processes” (ACER, 2022). It indicates accurate and pragmatic ways to ease the opening of the market to smallholders.

Almost all piees of legislation make the connection between the need for DR and the energy transition, which entails a growing percentage of renewable power, whose instability might pose a danger to the security of the grid. In the proposed RED version (COM(2021) 557), Article 20a is dedicated to the integration of renewable generation sources into the grid. Although in a vague way, this article is mentioning most of the factors that could ease the expansion of DR in the EU regarding market design such as transparency of the market, no discrimination in the tools for DR, aggregation models allowing the integration of DR, easy access to the market for stakeholders, and liquidity of the market.

The transparency of the market, an element crucial for the development of DR, is a general principle is mentioned in every preamble of the pieces of legislation – except the EPBD. Transparency of markets is not limited to the electricity market and is a general value promoted by the EU. In the field of energy, the specific regulation dedicated to this topic is the Regulation on wholesale Energy Market Integrity and Transparency (REMIT) (Regulation 1227/2011).

The aggregation model is one of the hardest factors to consider. Indeed, in order to characterize whether the aggregation model allows the integration of DR, a characterization of the models of aggregation should be done. Only after, a regulation can promote the model that eases the development of DR. However, no regulation describes the model that should be prioritized by MS. Only some guidelines on certain aspects of it are given, such as in recital (51) of the preamble of the proposed Regulation COM(2023) 148 that describes how to aggregate generation sources while including active consumers.

Is DR seen as a possible answer to the energy crisis or is it a daily congestion management tool? Ideally, according to Expert A, DR is a dual tool that should be used for both. While the latest proposed EED, RED and EPBD present it as so in their explanatory memorandum, the content of REPowerEU (COM(2022) 222) – the EU answer to the energy crisis – sends conflicting signals, as it does not give a proper place to flexibility in the grid. With the proposed reform of the Electricity Market Design or the upcoming proposal on DR, the flexibility of the grid is resurfacing as a key topic.

The liquidity of the market helps its development and assures its effective operation. The regulatory framework makes frequent references to the system operating in close proximity to real-time, particularly when it comes to imbalances: “The imbalances shall be settled at a price that reflects the real-time value of energy.” Article 6 (5) (Regulation 2019/943)

Most pieces of legislation mention the need for the development of infrastructure and a grid that can support the integration of new renewable sources. One of the evolutions in this regard is the emphasis on the need to build connections with offshore power plants.

Assessing the coverage of the factor on the repartition of the roles and tasks between the actors is challenging. As the electricity market is largely liberalized, the effectiveness of this liberalization depends mostly on the historic and cultural context of the MS. Indeed, while most of the regulatory framework directly or indirectly addresses the repartition of the tasks, it is mainly into the hands of the MS and their historic actors for it to let emerge a fair competition allowing a good repartition of the roles and less asymmetrical information issues.

The centralization of the control of DR tools is difficult to evaluate. Indeed, even if the size of the bidding zone is an aspect of it, it is not the only one. The only legislation that slightly hints toward the decentralization of the market decisions is the proposal COM(2023) 148. However, details on bidding zones are mostly dealt within the Bidding Zone Review that is currently carried on by the ACER and ENTSO-E[52].

[52] A new division of Bidding Zones should be presented in 2024 (ENTSO-E, no date).

Discussion

This thesis is considering the coverage of DR by the EU Regulatory Framework.
Indeed, the two first stages of this work aim at ensuring that the last one (Chapter 3) is relevant, they are justifying the analysis of the last Chapter.
The hypotheses of every analysis conducted in the thesis are described along with the methodology and taken into account when looking at the results. They are not considered important enough to threaten the overall pertinence of the deductive chain presented in Figure 17.

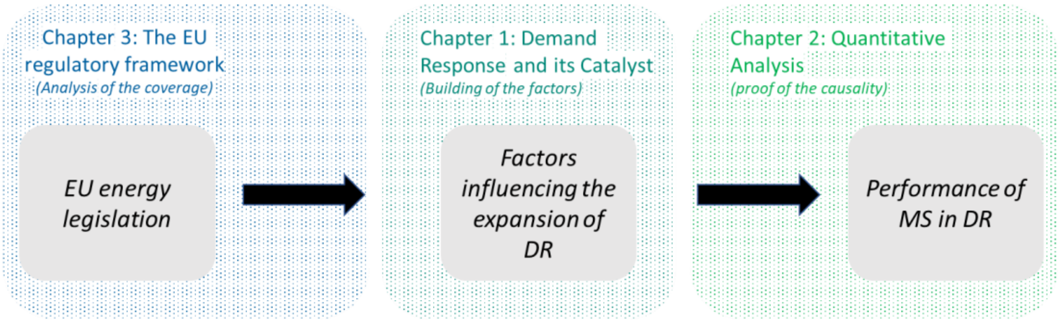


Figure 17. This thesis structure

To conclude on the relevancy of the analysis, one falls under the conclusion that the quantitative study is the one bringing the most uncertainty. However, the objective of this Chapter was to confirm the correlation with statistics. The general feeling is that a slight strengthening of the accuracy of the model would most likely end up giving immediate better results. Moreover, the aim of this Chapter was mainly to prove, with a quantitative methodology, elements found through the interviews. Therefore, the uncertainty mentioned in the qualitative study, in any case, does not imply the absence of correlation but mostly that it has not been thoroughly and without doubts proven. The factor that has been proven to affect the potential of DR is the investment in a well-developed grid.
One aspect that has not been covered when looking at the hypotheses for the broad thesis is the difference in scale in the different Chapters. Chapters 1 and 2 are looking in detail at the factors and building of associated indicators, while Chapter 3 is an overview at a more global scale of the broad coverage of the factors. Thus, further studies could be conducted to harmonize the scales of the different analyses[53]. However, the trends that

[53] The detailed analysis of the content and the extent to which the Directives and Regulation are

are emerging from this are unequivocal enough to allow strong conclusions to be made.
The general chain of deduction reveals that the EU energy regulatory framework is covering every aspect that would make the use of DR expand but is letting room for interpretation. In fact, as energy is a shared competence between the MS and the EU, it is highly logical that MS keeps some flexibility. The analysis of the national framework would most likely bring more elements to understand the differences in the performance of MS regarding DR.
If one would like to conduct a watch on the subject of DR the main development will probably come from the modifications that will be (or not) made by the new Electricity Market Design proposal and the Framework Guideline on DR specifically.
It would be enlightening to observe the evolution of the performance of MS, or even the changes in the indicators, following the entry into force of these legislations.

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impacting the different factors could be a proper thesis on its own.

Conclusion

As for the research question inquiring about the influence of the EU regulatory framework on DR, main trends have been identified.

The factors that are influencing the expansion of DR in the EU are numerous and can be found in different fields, from technical to institutional aspects. They are mostly contextual. A fertile ground for DR to develop can be summarized in four points. (1) An institutional framework that is clear and gives a specific role to each stakeholder. (2) A market that is liberalized, leaves room for ancillary services to be used both as balancing tools and congestion management elements, liquid, transparent, and close to real-time operation (3) a well-developed and smart grid whose operation is decentralized (4) A national tendency to detach from historic national grid operator monopolies and the culture of innovation and flexibility including prosumers.

When looking at the influence of this context on DR, it appears that looking precisely at the domestic context of each MS would give precious further information. The overall tendency would be that investment in Smart grids is strongly correlated to the performance of DR in MS. For other factors, a strong correlation has not been demonstrated but results indicate that further work and the elaboration of a more complex model would most likely show a causality between the other factor and the performance of MS in DR implementation. It is thus relevant to consider with reasonable probability that the factors would impact (the extent of the impact is however very much unknown as the list is not exhaustive) the expansion of DR by creating the necessary conditions.

The review of the coverage of the factors by the legislation in force or soon to be implemented shows that the policies are tending to create the right context for DR to expand. As explained in Chapter 3 and the Discussion Section, the only thing preventing the EU regulatory framework from addressing all elements that would create a perfect context, on top of the gap between theory and implementation, is the sharing of the energy competence: important aspects of the overall legislation are domestic ones. Moreover, the thorough examination of the evolution of the legislation, from the CEP to the Framework Guideline for Demand Response leads to two main conclusions: The number of legislation on energy is conspicuously increasing. Due to the invasion of Ukraine by Russia and the ambitious climate objective, the pace of revision of some Directives and

Regulations is increasing. Secondly, these legislations are more and more targeting the aspect that would ease the development of DR, when they are not directly targeting DR. One can deduce, that the results of the same thesis two years from now could give drastically different results.

To summarize, EU legislation is increasingly acting as a driver for DR. The regulatory incentives along with the necessity to invest in flexibility due to the new constraints of the grid and of energy security will most likely cause the use of DR to skyrocket in the next years.

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Annexes

Annexe 1. Interview table

	General theme	Specific questions	A	B	C
	I: Personal presentation		x	x	x
Expert presentation	Q: Expert presentation	Education, seniority, complementary professional activities, link with the international (especially with the EU)	x	x	x
Subject frame	I: Presentation of the thesis question	To what extent do EU public policies on electricity provide the required framework for the expansion of DR in the electricity grid?	x	x	x
	Q: How would you describe the link between DR and Demand-side Flexibility?	Inclusion? Complementary notions?	x		x
	Q: What is the hierarchization of the flexibility tools? Which one would you use first?	Interruptibility contract? Interconnection?		x	
	Q: What Flexibility means to you? DR? Demand-Side Flexibility? DSM?			x	
	Q: According to you, what would include DR?	Which tools? V2G? Pricing? …?	x		x
Professional Practice	Q: In your professional experience, when did you begin to hear about DR?	Year? Specific time period?	x		
	Q: Would you say that the subject is considered of strategic importance in your company/institution/field?	Compared to other smart grids tools	x	x	x
	Q: In practice how does the company's activity is linked to DR?		x		
	Q: What regions/countries are in advance on this subject?		x		
	Q: Where is the flexibility decision taken?	In the sense, do you think some regions do use it more than others?		x	
	Q: Double speed in the EU	In the EU, which countries would you cite in advance in the subject?			x
Actualities	Q: Do you see the interest in DR increasing with the awareness on climate change? Since the breakthrough of the energy crisis?	Has the explosion of the awareness of 'energy sobriety' and the fear of offloading increased the public/professional interest in the subject?	x	x	x

	Q: Which innovations are the most interesting for the expansion of DR?		x	x	x
Heart of the matter	Q: According to you, which characteristics 'boost' or prevent the development of DR?	Technical innovation? Lack of incentivization? Legislative limitations?	x	x	x
	According to you, would there be risks of 'too much' DR?		x	x	x
	Q: Do you have further knowledge of the legislative framework for these practices?		x	x	
	Q: If yes, would you say that the regulation's impetus is given more at the national or at the European level?	Monitoring of the subject at the EU level? Knowledge of the ACER?	x	x	
		Would you say the thrust for DR comes generally more from National Regulatory Agencies or the TSO/DSO?			x
	Q: Did you see important reactions in the sector to EU announcements such as REPowerEU?		x	x	
	Q: Catalysts	Would you say the hindering of DR comes mainly from technical, market, or institutional characteristics?			x
		Could the competition between tools hinder the expansion of DR (Storage v. DR?)			x
	Q: EU Regulations - general	According to you, which are the most relevant EU policies to consider regarding DR specifically?			x
		What are you expecting from the reform of the EU electricity market design in terms of DR?			x
		What do you think of the current balance of power of decisions between the EU and the MS regarding DR? Any insights on the possible evolution of this?			x
		The last Impact Assessment on energy policies that I could find is from 2021, do you know why/if there are going to be new ones?			x
		Do you forecast any specific complications or difficulties for a binding policy to be implemented?			x
	Q: EU policies – Framework Guidelines on Demand Response	Did you spot any striking/unexpected points from the public consultation?			x
		What would be, according to you, the three more disruptive points of the Framework Guideline? The one which could be the more contested?			x
		Emphasis on the sharing of data and knowledge between SOs, is it usually an issue?			x

Annexe 2. Code for the multilinear regression

```
#Clear R environment
graphics.off()

#import and visualize data
bd_2305 <- read.csv2("data_2305.csv")
fix(bd_2305) #vizualisation of the set
attach(bd_2305)

#Library used
library(ggpubr)
install.packages("ggpubr", dependencies = TRUE)
install.packages("backports")
install.packages("car")
library(car)

#Step.a matrix of scatterplot
bd_2305[,4] = as.numeric(factor(bd_2305[,4])) #correcting format in data set
pairs(
  x = bd_2305[3:7],
  main = "A matrix of scatterplots",
  pch = 18,
  bg = c("red", "green3", "blue3", "orange2"),
)


#Step.b the chi2 test
n1 <- 5 #number of rows of result's matrix
n2 <- 5 #number of columns of result's matrix
a <- matrix (rep(0, n1*n2), n1, n2) #creation of result's matrix
m1 <- 27
m2 <- 2
tableau <- matrix(rep(0,m1*m2), m1, m2) #intermediate table
for (i in 3:7){
  for (j in 3:7){
    tableau[,1] <- bd_2305[,i]
    tableau[,2] <- bd_2305[,j]
    test_chi2 = chisq.test(tableau[,1], tableau[,2],
                           simulate.p.value = TRUE, B = 2000)
    a[i-2,j-2] <- test_chi2$p.value #value of the test in the result's matrix
  }
}
x <-colnames(bd_2205[3:7]) #assigning names
rownames(a) <- x
colnames(a) <- x
print(a)

#Step.c building of the model
model <- lm(Y ~ H_biddz + T_smrt_mtr + E_aggreg_acc
            + H_mon + T_invest, data = bd_2305)

#Step.d.1 homoscedasticity
plot(fitted(model), residuals(model))#create fitted value vs residual plot
abline(h = 0, lty = 2)#add horizontal line at 0

#Step.d.2 Linearity
residualPlots(model)

#Step.d.3 Normality
hist(residuals(model), col = "green3")
```

Annexe 3. Methodology for Evaluating the Legislation's Coverage of the Factors

In order to assess the coverage of the factors by the legislation, the factors are translated into questions. If the piece of legislation answers the question, the associated factor is considered covered. This assessment is lenient; as long as the legislation explicitly addresses the factor's themes, the latter is deemed to be covered.

The summary Table (See Annexe 4.) provides some justifications for this analysis. However, the articles mentioned in the table are not exhaustive and are mostly examples/sections where the question is answered. When there is insufficient material in the texts to establish that the legislation covers the element, the cell is marked in red.

'Not relevant to consider' elements are those that cannot be addressed since their coverage is not included in the legislation.

Category	Factors easing the expansion of DR	Question to answer
Institutional	Explicit definition of DR	Does the piece of legislation set precise definitions of terms such as 'ancillary services', 'demand response', and 'flexibility'?
	Low propension to protect the 'room for manoeuvre' from actors	Is it a directive or a regulation?
	Clear legal Framework at the EU level	Not relevant to consider
	Understanding of the technical issues at the EU institutional level	Not relevant to consider
	The principle of subsidiarity and Proportionality understood extensively at the EU level	Not relevant to consider
Economic	DR is seen as a tool for the energy transition	Does the piece of legislation draw a link between the need for DR in the context of the energy transition?
	No discrimination in the tools for DR	Is the piece of legislation leaving room for every technology of DR to emerge?
	Transparency of the market	Is the piece of legislation aiming at more transparency of the market by setting obligations to prove and broadcast more data?
	Aggregation models allowing the integration of DR	Is the piece of legislation describing the aggregation models or putting some guidelines on them?

	Easy access to the market for smallholders	Is the piece of legislation easing access to the energy market to smallholders (small bidding granularity) by easing the prequalifications?
	Liquid market	Is the piece of legislation emphasizing the need to have a more agile real-time/day-ahead market?
Technical	MS views the development of DR as having favourable cost-benefit ratios	Not relevant to consider
	A developed and reliable grid infrastructure	Is the piece of legislation emphasizing the need for ancillary being a proper tool and not only for congestion management?
	Good repartition of the roles and tasks/liberalization	Is the legislation setting guidelines to develop the electricity grid?
Historic and culture	Decentralization of the command of the flexibility	Is the piece of legislation easing the liberalization?
	DR is seen as a response to the energy crisis	Is the piece of legislation acting on the size of bidding zones?
	Explicit definition of DR	Is the legislation a 'crisis measure' mentioning DR?

Annexe 4. Summary table

	EPBD *(EU 2021/0426 + amendments of 2022/0160)*	**RED** *(EU 2021/0218 + amendments of 2022/0160 and 2023/0077)*	**EED** *(EU 2021/0203 + amendments of 2022/0160)*	**Current electricity market design** *(EU 2019/943 + 2019/941 + 2019/944 + 1227/2011)*	**Regulation on the Governance of the Energy Union and Climate Action** *(EU 2018/1999)*	**Proposal of Electricity market design** *(EU 2023/0076 + 2023/0077)*	**Framework Guideline on Demand Response**
Number of mention of "Demand Response"	*2021/0426* : 1	*2021/0218* : 2	*2021/0203:* 11	*2019/943:* 36 *2019/944:* 35	12	*2023/0076* : 8 *2023/0077:* 23	32
Number of mention of "Flexibility"	*2022/0160* : 2 *2021/0426* : 6	*2022/0160* : 2 *2021/0218* : 11	*2022/0160:* 2 *2021/0203:* 9	*2019/943:* 13 *2019/944:* 18	12	*2023/0076* : 24 *2023/077:* 86	0
Number of mention of "Ancillary Services"	0	0	*2021/0203:* 2	*2019/943:* 8 *2019/944:* 22	0	*2023/0077:* 1	2
Factors easing the expansion of DR							
Explicit definition of DR	No	No	No	*2019/944:* Article 2 (20)	No	*2023/0077:* preamble recital (80)	(82)
Low propension to protect the "room for maneuver" from actors	Directive	Directive	Directive	Regulation (except for 2019/944)	Regulation	Regulation	Regulation
Clear legal Framework at the EU level	not relevant to consider						
Understanding of the technical issues at the EU institutional level	not relevant to consider						
The principle of subsidiarity and Proportionality understood extensively at the EU level	not relevant to consider						
DR is seen as a tool for the energy transition	*2021/0426* : preamble recital (37)	2021/0218: preamble recital (5)	No	*2019/943:* preamble recital (15) *2019/944:* preamble recital (41)	Article 22	Explanatory memorandum	No
No discrimination in the tools for DR	No	*2021/0218:* Article 20a	*2021/0203:* preamble recital (49)	*2019/943:* Article 6c *2019/944:* Article 7 (1)	Article 23 (1)e	'23/0077: Article 7 (	1.1 (2)
Transparency of the market	No	*2021/0218:* Article 20a	*2021/0203:* Article 9 (106)	*2019/943:* preamble recital (9) *2019/941:* preamble recital (3) *2019/944:* preamble recital (22) *1227/2011:* all regulation	preamble recital (46)	*2023/0076: preamble recital* (9), (11) and (21)	5.3
Aggregation models allowing the integration of DR	No	*2021/0218:* Article 20a	No	*2019/943:* Article 3, 6, 7 *2019/944:* Article 2 (18) and Article 12	No	*2023/0077:* preamble recital (51)	2.2
Easy acces to the market for smallholders	*2022/0160* : Article 16 (4)	*2021/0218:* Article 20a	*2021/0203* : Article 11 (6)	*2019/943:* preamble recital (67)	No	*2023/0077:* preamble recital (15)	3.2
Liquid market	No	*2021/0218:* Article 20a	No	*2019/943* : Article 6 (5) *2019/944:* preamble recital (10)	No	Explanatory Memorandum *2023/0077:* Article 9 (5)	(62)c
MS views the development of DR as having favorable cost-benefit ratios	not relevant to consider						
A developed and reliable grid infrastructure	No	*2021/0218* : Article 15 (8)	*2021/0203:* preamble recital (112)	*2019/943:* Article 13c *2019/944:* preamble recital (20)	in "Policies and measure" 3.4.3	*2023/0077: preamble recital* (41) and Article 18 (8)	2 (19)
Good repartition of the roles and tasks / liberalization	No	*2018/2021:* in "Regulatory fitness and simplification" in "Impact assessment"	*2021/0203:* preamble recital (32)	*2019/944:* preamble recital (12) and (22)	No	*2023/0076:* preamble recital (1) *2023/0077:* preamble recital (34) or Article 7 (1)	5.2 (90)
Decentralization of the command of the flexibility	No	No	No	No	No	3/0077: Article 9 1 ar	No
DR is seen as a response to energy crisis	Explanatory memorandum & "Consistency with other Union policies"	Explanatory memorandum & "Consistency with other Union policies"	Explanatory memorandum & "Consistency with other Union policies"	No	No	Explanatory memorandum	No