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MÁSTER EN INGENIERÍA INDUSTRIAL

TRABAJO FIN DE MÁSTER

Quantification of Costs and Benefits of Power System Flexibility Provision from Distributed Energy Resources (DER) for Balancing and Congestion Management in Europe

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August 2024

Declaro, bajo mi responsabilidad, que el Proyecto presentado con el título

"Quantification of Costs and Benefits of Power System Flexibility Provision from Distributed Energy Resources (DER) for Balancing and Congestion Management in Europe"

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Autorizada la entrega del proyecto

EL DIRECTOR DEL PROYECTO

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Fdo.: José Pablo Cháves Ávila Fecha: 25/ 08/ 2024

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Acknowledgements

I would like to thank my directors José Pablo Cháves Ávila, Luis Olmos Camacho, David Ulrich Ziegler.

Moreover, I also want to show my gratitude to my friends for all help they have provided to me during my university years.

Lastly, I want to thank my parents and sister for their unwavering support. I would not have made it without them.

QUANTIFICATION OF COSTS AND BENEFITS OF POWER SYSTEM FLEXIBILITY PROVISION FROM DISTRIBUTED ENERGY RESOURCES (DER) FOR BALANCING AND CONGESTION MANAGEMENT IN EUROPE

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RESUMEN DEL PROYECTO

1. Introducción

El presente trabajo pretende avanzar en el análisis de los costes y beneficios de proporcionar flexibilidad en los sistemas de energía que utilizan Recursos Energéticos Distribuidos (DER por sus siglas en inglés – Distributed Energy Resources) en el entorno europeo, con un enfoque particular en los servicios de balance y la gestión de la congestión. La flexibilidad es esencial en las redes eléctricas modernas para adaptarse a la variabilidad de las fuentes de energía renovable (FER) como la eólica y la solar, al tiempo que se garantiza la estabilidad de la red.

2. Contexto:

- El cambio hacia la descarbonización, impulsado por la preocupación por el cambio climático y eventos geopolíticos como la guerra en Ucrania, enfatiza la necesidad de diversificación energética y resiliencia.
- Europa tiene como objetivo aumentar la integración de las energías renovables (hasta un 60-70% de la demanda eléctrica para 2040), estos objetivos son aún mayores para España, lo que requiere el uso de servicios de flexibilidad como la respuesta a la demanda, el almacenamiento de energía y la generación flexible para gestionar la demanda de la red y evitar la congestión.

3. Objetivos:

- Objetivo 1: Identificar los servicios de flexibilidad que pueden ofrecerse en los mercados de electricidad y analizar la viabilidad de la integración de estos servicios en el mercado.

- Objetivo 2: Estimar el volumen potencial de flexibilidad y cuantificar los correspondientes costes y beneficios asociados en los distintos mercados de electricidad.

- Objetivo 3: Investigar cómo se distribuirá la flexibilidad entre los diferentes servicios de los sistemas comparables (UE27+países adyacentes). Esto implica analizar la asignación de flexibilidad en diferentes aplicaciones, como el mercado mayorista, los servicios de equilibrio, la adecuación y la gestión local de la red. El objetivo es comprender cómo se utilizará y priorizará la flexibilidad entre los diferentes servicios identificados.

- Objetivo 4: Examinar los ahorros potenciales que podrían obtenerse utilizando servicios de flexibilidad en cada uno de los sistemas comparables analizados. Se trataría de evaluar los beneficios económicos que se pueden lograr a través del despliegue de soluciones de flexibilidad.

4. Situación actual:

- El marco legislativo de la Unión Europea, en particular el paquete de medidas «Energía limpia para todos los europeos», promueve la flexibilidad en los mercados de la electricidad. Las regulaciones clave fomentan la integración de las energías renovables y los servicios de flexibilidad a través de precios dinámicos, flexibilidad del lado de la demanda y acceso al mercado para el almacenamiento de energía.

- Los proyectos piloto y las plataformas operativas, como GOPACS y Piclo Flex, demuestran la viabilidad de los mercados de flexibilidad, pero la escala de la flexibilidad comercializable sigue siendo pequeña en comparación con la generación convencional.

5. Metodología

El objetivo final es cuantificar el impacto potencial de la flexibilidad en todos los servicios de la UE-27+Reino Unido+6 en el horizonte 2030. El análisis tiene como objetivo recopilar algunas muestras y casos para argumentar a favor de la implementación de soluciones de flexibilidad para los servicios del sistema a través de mecanismos de mercado.

Para ello, aplicamos la metodología que se muestra a continuación

- El análisis implica la definición de servicios de flexibilidad, la identificación de fuentes de datos de alta calidad, el análisis de estas fuentes y el análisis de los resultados para cuantificar los beneficios de la implementación de la flexibilidad.

- Un análisis cuantitativo detallado incluye modelos de red, suposiciones sobre la capacidad de generación y la demanda, y los beneficios potenciales de la flexibilidad en el balance, el redespacho y el ahorro de costes.

6. **Aspectos detectados:**

- La flexibilidad puede ofrecer beneficios que podrían ser significativos en la reducción de los costes asociados con la congestión de la red, los servicios de balance y los mercados mayoristas de electricidad.

- El estudio destaca que las barreras regulatorias son un obstáculo importante para la adopción de servicios de flexibilidad.

7. **Conclusión:**

La tesis concluye que, si bien la flexibilidad es técnicamente factible y beneficiosa, el desarrollo regulatorio es crucial para que se convierta en un modelo de negocio generalizado y viable en el mercado energético europeo. La investigación proporciona una hoja de ruta para aprovechar la flexibilidad como parte de la transición energética de Europa. La tesis se llevó a cabo en el contexto del proyecto OneNet del programa Horizonte 2020, destinado a crear una red eléctrica unificada e interoperable en Europa.

8. Referencias

[1] European Commission. Directorate General for Energy. and Artelys., *Mainstreaming RES: flexibility portfolios : design of flexibility portfolios at Member State level to facilitate a cost efficient integration of high shares of renewables.* LU: Publications Office, 2019. Accessed: Nov. 30, 2023. [Online]. Available: https://data.europa.eu/doi/10.2833/97595

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EXECUTIVE SUMMARY

1. Introduction

The present master thesis investigates the costs and benefits of providing flexibility in power systems using Distributed Energy Resources (DER) across Europe, with a particular focus on balancing and congestion management. Flexibility is essential in modern electricity grids to accommodate the variability of renewable energy sources (RES) like wind and solar while ensuring grid stability.

2. Context and Motivation:

- The shift towards decarbonization, driven by climate change concerns and geopolitical events like the war in Ukraine, emphasizes the need for energy diversification and resilience.

- Europe aims to increase RES integration (up to 60-70% by 2040), or even more ambitious for the Spanish context which necessitates the use of flexibility services such as demand response, energy storage, and flexible generation to manage grid demand and avoid congestion.

3. Objectives:

- Objective 1: Identify flexibility services that can be provided in electricity markets and assess the feasibility of market integration for these services.

- Objective 2: Estimate the potential volume of flexibility and quantify its associated costs and benefits within various electricity markets.

- Objective 3: Investigate how flexibility will be distributed across the different services in the comparable systems (EU27+adjacent countries). This involves analyzing the allocation of flexibility across different applications, such as the wholesale market, balancing services, adequacy, and local grid management. The goal is to understand how flexibility will be utilized and prioritized among the different services identified.

- Objective 4: Examine the potential savings that could be realized by utilizing flexibility services in each analyzed comparable system. This objective aims to evaluate the economic benefits that can be achieved through the deployment of localized flexibility solutions.

4. State of the Art:

- The European Union's legislative framework, notably the Clean Energy for All Europeans Package, promotes flexibility in electricity markets. Key regulations encourage the integration of renewables and flexibility services through dynamic pricing, demand-side flexibility, and market access for energy storage.

- Pilot projects and operational platforms like GOPACS and Piclo Flex demonstrate the feasibility of flexibility markets, but the scale of traded flexibility is still small compared to conventional generation.

5. Methodology:

The ultimate objective is to quantify the potential impact of flexibility across all services in the EU27+UK+6 in the 2030 horizon. The analysis aims to collect some first-hand evidence to make a case for the implementation of flexibility solutions for system services through market mechanisms.

In order to do this, we applied the methodology shown below:

- The research involves defining flexibility services, identifying high-quality data sources, analyzing these sources, and mapping results to quantify the benefits of implementing flexibility.

- A detailed quantitative analysis includes grid modeling, assumptions about generation capacity and demand, and the potential benefits of flexibility in balancing, redispatch, and cost savings.

6. Findings:

- Flexibility can deliver significant benefits in reducing costs associated with grid congestion, balancing services, and wholesale electricity markets.

- The study highlights that regulatory barriers are a major obstacle to the wider adoption of flexibility services. Once these barriers are addressed, flexibility could compete on equal terms with traditional generation methods in electricity markets.

7. Conclusion:

The thesis concludes that while flexibility is technically feasible and beneficial, regulatory development is crucial for it to become a widespread and viable business model in the European energy market. The research provides a roadmap for leveraging flexibility as part of Europe's energy transition.

The thesis was carried out in the context of the OneNet project under the Horizon 2020 program, aimed at creating a unified, interoperable electricity grid across Europe.

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[1] European Commission. Directorate General for Energy. and Artelys., *Mainstreaming RES: flexibility portfolios : design of flexibility portfolios at Member State level to facilitate a cost efficient integration of high shares of renewables.* LU: Publications Office, 2019. Accessed: Nov. 30, 2023. [Online]. Available: https://data.europa.eu/doi/10.2833/97595

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Chapter 1 INTRODUCTION

Climate change, driven by greenhouse gas emissions (GHGs), poses a global threat. To mitigate its impact, most countries are increasingly committed to achieving net-zero emissions by 2050. Decarbonization involves shifting away from fossil fuels (coal, oil, and gas) and transitioning to renewable energy sources. This shift is essential to limit global warming. Simultaneously, the war in Ukraine disrupted energy markets, leading European utilities to stockpile coal and natural gas, and reactivate coal-fired power plants in anticipation of a possible winter energy crisis due to Russia's invasion. This crisis highlighted the vulnerability of countries to globalized oil and gas shocks, emphasizing the need for energy diversification and resilience, which in the end, resulted on a boost on decarbonization efforts to ensure security of supply.

As we shift toward cleaner energy sources through demand electrification driven by technologies like electric vehicles, heat pumps, and batteries, more intermittent renewable energy sources (RES) are introduced. These RES, such as solar and wind, can be unpredictable and variable. At the same time, the adoption of new demand types (often power intensive) places additional strain on the grid, potentially leading to congestion or high demand peaks. To address these challenges, flexibility becomes crucial. Flexibility encompasses temporal adjustments (matching supply and demand fluctuations), spatial balancing across regions, and services like demand response, energy storage, and flexible generation. Globally, there's a push toward integrating more RES in the electric systems, with Europe aiming for 60-70% RES by 2040. The EU's electricity market reform emphasizes low-carbon flexibility solutions, including demand response.

1.1. FLEXIBILITY SERVICES

Flexibility services are actions or adjustments made by electricity consumers, producers, or storage providers to change their normal electricity consumption or generation patterns in response to external signals such as price incentives, grid constraints, or market conditions.

These services help balance supply and demand in the electricity grid, particularly as the integration of renewable energy sources increases. Flexibility services can include activities like demand response, where consumers reduce or shift their electricity usage, or the use of energy storage systems to store and release power as needed.

The use of flexibility is crucial for maintaining grid stability, deferring the need for new infrastructure investments, and enabling the transition to a more decentralized and renewable-based energy system.

The flexibility that must be provided to the system must be activated according to the needs of the transmission or distribution grid. One of the main objectives of this Master's Thesis is to identify the different services that flexibility can provide.

Additionally, it is deemed important to assess if those flexibility services can be provided through markets. Those markets could either be already existing markets that can be adapted for the provision of flexibility, or new markets created ad-hoc where only flexibility can participate.

1.2. STATE OF THE ART

The approval of the Clean Energy for All Europeans Package, which comprises Regulation (EU) 2019/943 on the internal market for electricity and Directive (EU) 2019/944 on common rules for the internal market for electricity, set the cornerstone for the implementation of flexibility in the European power systems. The package aimed to create a more competitive, decarbonized, and flexible electricity market to support the integration of renewable energy and to improve overall system efficiency and security, by the following means:

- Promoting demand-side flexibility and consumer participation through dynamic pricing, access to aggregators, and demand response.
- Enhancing the role of energy storage in providing flexibility services and ensuring market access.

- Ensuring that balancing markets are open to all resources, including renewables, demand response, and storage.
- Facilitating cross-border trading and shorter market timeframes to improve real-time balancing of supply and demand.
- Empowering DSOs and TSOs to procure flexibility services to manage grid operations more effectively, with a focus on market-based solutions.

The initiatives following the Clean Energy Package, such as the European Green Deal, Fit for 55, REPowerEU, have further developed the regulatory framework of flexibility and made efforts for wide-scale adoptions of related technologies.

As per ACER's mandate in 2022, following article 59 of Regulation (EU) 2019/943, ENTSO-E and the DSO Entity submitted their joint proposal for the Network Code on Demand Response in May 2024.

Article 59 of Regulation (EU) 2019/943 stated that this network code must specify the rules for participation on demand response, including rules on aggregation, and the market rules that allow demand response to participate on equal footing with generation in all electricity markets, including balancing, ancillary services, and capacity markets.

Lastly, the European Electricity Market Design (EMD) Reform (Regulation (EU) 2024/1747 & Directive (EU) 2024/1711), included key provisions for enhancing flexibility within the European electricity system, driven by the need to integrate more renewable energy sources and ensure grid stability:

- Non-Fossil Flexibility Support Schemes: The regulation promotes support schemes specifically for non-fossil fuel flexibility. These include payments for available capacity from flexible resources that do not rely on fossil fuels. This encourages the development and integration of resources like battery storage, demand response, and other clean flexibility options.
- Peak-Shaving Products: To manage demand fluctuations, the regulation encourages the use of peak-shaving products. These products help reduce electricity demand during

peak hours, improving overall system flexibility and preventing over-reliance on fossil fuel-based generation during high-demand periods.

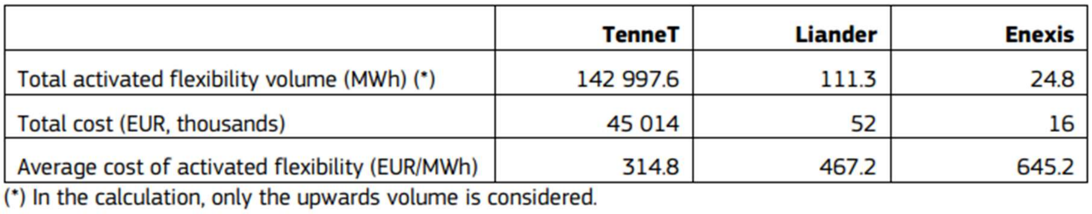
- Adaptation of Intraday Markets: The regulation mandates adapting intraday markets to facilitate the participation of renewable energy technologies. By making markets more accessible to renewables, the regulation supports real-time adjustments and enhances the overall flexibility of the electricity grid.

As seen above, regulation is of utmost importance for flexibility, as it requires that many regulatory barriers are removed so that flexibility can compete on equal footing with traditional services and become an attractive business for potential providers. In this regard, we can see how most of the initiatives for the provision of flexibility services through markets are either pilot tests or small-scale markets that aim to assess the technical and economic feasibility of flexibility. In 2021, in their study titled "Analysis of New Flexibility Market Models in Europe" [6], Valarezo, O., Gómez, T., Chaves-Avila, J.P., Lind, L., Correa, M., Ulrich Ziegler, D., and Escobar, R. examined emerging models for flexibility markets across Europe. They identified 13 market platforms for flexibility, out of which 11 were pilot tests, and there were only 2 platforms that were not pilot tests: GOPACS & Piclo Flex.

In this regard, the two non-pilot platforms currently in operation showcase the feasibility of the use of flexibility, but the traded flexibility in those platforms is still far from the volumes traded in conventional generation:

In 2021, according to JRC [7], GOPACS activated 143 GWh of flexibility, which represents less than 1% of the total generation in the Netherlands in that year (118.000 GWh).

Table 1: Flexibility dispatcher & provision costs in 2021 in GOPACS



	TenneT	Liander	Enexis
Total activated flexibility volume (MWh) (*)	142 997.6	111.3	24.8
Total cost (EUR, thousands)	45 014	52	16
Average cost of activated flexibility (EUR/MWh)	314.8	467.2	645.2

(*) In the calculation, only the upwards volume is considered.

Table extracted from [7]

In conclusion, flexibility would be already feasible from a technical standpoint, and what is missing is the development of the regulatory framework in order to remove regulatory barriers so that flexibility becomes a more attractive business model for potential providers. That way, wide scale adoption of flexibility would happen, and flexibility would compete on equal footing with the rest of assets and technologies in the different electricity markets.

1.3. MOTIVATION

In recent years, there has been significant technological progress in the development of smart grids and digitalization devices, such as smart meters. Simultaneously, demand electrification has steadily increased by means of an augment in the use of heat pumps, batteries, and electric vehicles, alongside the rise of distributed generation, driven by the growing adoption of self-consumption. The combination of these circumstances enables and motivates the use of flexibility to balance generation and demand at all times.

This master's thesis was carried out in the context of the OneNet[1] project, which is a Horizon 2020 project that aims to create a unified, integrated approach to electricity grid operations across Europe. It seeks to build an interoperable electricity grid that supports the transition to a low-carbon energy system. It brings together Transmission System operators distribution system operators (DSOs), energy providers, and technology companies.

The objectives of OneNet are:

1. Development of a Unified Market Design for Europe: This involves establishing standardized products and key parameters for grid services to facilitate coordination among all stakeholders, from grid operators to consumers.

2. Creation of a Common IT Architecture and Interfaces: Instead of building a single IT platform for all products, OneNet aims to develop an open architecture that allows for

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[1] https://www.onenet-project.eu/

seamless interaction between multiple platforms. This ensures that participants can access and engage with various markets across Europe.

3. Implementation of Large-Scale Demonstrators: The project includes extensive demonstrators to apply and showcase the scalable solutions developed. These demonstrators are organized into four clusters that encompass countries from every European region, testing innovative use cases that have not been previously validated.

As part of the Business model, the motivation for this Master's Thesis is to assess and quantify the potential of flexibility within different electricity markets, as well as to analyze the associated costs. By doing so, it seeks to provide valuable insights that will drive wide scale adoption of flexibility and support the ongoing energy transition and decarbonization efforts.

1.4. OBJECTIVES

The main objectives of this Master's Thesis are:

- Objective 1: Identify the services that can be provided through flexibility, and, if those services can be provided through a market, the key markets where flexibility services can play a significant role. This translates into determining the primary markets where flexibility can be integrated, as well as outlining the types of services that flexibility can provide.
- Objective 2: Estimate the potential volume of flexibility across comparable systems. .The focus will be on quantifying the projected volume of flexibility resources across the EU27 and adjacent countries. As we will see later, it includes an assessment of factors such as demand response, energy storage, and other flexibility mechanisms that could contribute to meeting energy and grid needs in the future.
- Objective 3: Investigate how flexibility will be distributed across the different services in the comparable systems (EU27+adjacent countries). This involves analyzing the allocation of flexibility across different applications, such as the wholesale market, balancing services, adequacy, and local grid management. The goal is to understand how flexibility will be utilized and prioritized among the different services identified.

- Objective 4: Examine the potential savings that could be realized by utilizing flexibility services in each analyzed comparable system. This objective aims to evaluate the economic benefits that can be achieved through the deployment of localized flexibility solutions.

1.5. SUSTAINABLE DEVELOPMENT GOALS

Flexibility services, and therefore, this master's thesis, contribute to the achievement of the Sustainable Development Goals[2] (SDGs) set by the United Nations. Here's the objectives to which they contribute, and how they contribute to said objectives:

- Affordable and Clean Energy (SDG 7): By managing energy flows and motivating changes in energy supply and demand, flexibility markets support the integration of renewable energy resources. This, in turn, promotes the use of affordable and clean energy, which usually is cheaper than fossil fuel sourced energies.
- Industry, Innovation, and Infrastructure (SDG 9): Flexibility markets foster innovation by integrating smart meters, smart appliances, and energy-efficient resources. They also contribute to building resilient infrastructure. Additionally, industries can benefit from cheap, clean energy, which directly reduces production costs for most products.
- Sustainable Cities and Communities (SDG 11): Flexibility services can help manage energy consumption in cities, enabling the large-scale penetration of self-consumption, heat pumps and electric vehicles, making them more sustainable.
- Climate Action (SDG 13): Flexibility services help integrate renewable energy sources into the energy system. This aids in reducing greenhouse gas emissions and combating climate change.

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[2] https://sdgs.un.org/goals

- Partnerships for the Goals (SDG 17): Flexibility markets involve various stakeholders, including distribution system operators and third-party service providers. This encourages partnerships and cooperation.

Figure 1 Sustainable Development Goals defined by the UN

Chapter 2 METHODOLOGY

The ultimate objective is to quantify the potential impact of flexibility across all services in the EU27+UK+6 in the 2030 horizon.

The analysis aims to collect some first-hand evidence to make a case for the implementation of flexibility solutions for system services through market mechanisms.

In order to do this, we applied the methodology shown below Figure 2

Figure 2: Methodology for Business Model Quantification

In sections 2.2 to 2.5 we will deep dive in each of the steps of the methodology.

The analysis considers the information on costs and benefits of flexibility solutions as used in OneNet for each study analyzed, as well as additional information on flexibility solutions from previous studies conducted.

The value created by the implementation of the OneNet business models in the context of the European Union was quantified. This value is mainly related to the delivery of DER-based flexibility when providing the services targeted within the Business Use Cases (BUCs) the BMs are associated with. To provide the best possible quantification of the market potential in the European Union, for the business models identified in OneNet, the methodology shown in Figure 2 is applied. The methodology, as well as the results of the first steps, are described in the following. Initially, the goal was to set the analysis in this chapter in relation to the KPIs for which values have been determined by the OneNet demos. Though unfortunately, this was not possible for the following reasons. First, almost none of the OneNet demonstrators provided the KPI on cost-effectiveness. Second, those that computed a value for that KPI argue that assessing this value for the KPI does not allow to draw conclusions as, in some cases, the bid price for flexibility services was agreed bilaterally between the DSOs and FSPs. Therefore, unfortunately assessing the few provided KPI values in relation to the findings of this analysis would not provide relevant insights. However, the quantitative estimates gathered when taking the last step of the methodology just outlined are discussed in relation to the OneNet business models.

2.1. DEFINING THE MAIN FLEXIBILITY SERVICES

The first step of the methodology is defining the main flexibility services within the power system potentially affected by DER flexibility.

In this step, we identify the relevant flexibility services to later analyze them. Some of these services are congestion management, power system balancing and electricity wholesale services.

This step is crucial to efficiently and reliably identify high-quality publications that will provide relevant quantitative data that will be used in the next steps.

The geographical scope of the analysis will be Europe (EU+UK+6), due to the technological and regulatory similarities among the systems in the region. Furthermore, Europe is the region of study of the OneNet project.

We identified the following services as relevant for further analysis:

- **Congestion management**: problems related to congestion management in power system operation and planning.

- **Power system balancing**: problems related to power system balancing related to frequency control services and related capacities/volumes, as well as trends and existing and emerging new agents (such as DER(s)).
- **Electricity wholesale services**: effects of flexibility from DER on electricity wholesale markets, capacities/volumes and trends.

When possible, we will consider savings and costs from delivering the flexibility services mentioned above.

The focus shall be laid upon the savings achieved through the mobilization of power system flexibility provided by DER.

Overall savings and costs will also include relevant impact derived from flexibility services, such as indirect savings (e.g. CO2 savings).

2.2. IDENTIFYING AND MAPPING HIGH QUALITY SOURCES

The second step of the methodology is “2.2 Identifying and mapping high quality sources”.

In this step, we undertake an extensive literature review to identify **relevant publications**. The result is a list of 20 relevant and recent publications, both from private actors and governmental entities, shown in Table 2.

Table 2: Identified Sources

Author	Title	Pub. Date	Period	Geo. scope	Quant. Results (2.3)
SmartEn	Demand-side flexibility in the EU: Quantification of benefits in 2030	09.2022	2023 - 2030	EU27	X

Eurelectric	Connecting the dots	01.2021	2020-2030	EU27	X
ENTSO-E	Mid-term Adequacy Forecast 2019	2019	2019-2021-2025	ENTSO-E area	X
EC: DG ENER	Assessing the role and magnitude of different flexibility measures and assets in distribution and transmission grids: METIS 2: study S1	2023	2018-2030	EU27+UK+6	X
EC: DG ENER	Mainstreaming RES: flexibility portfolios: design of flexibility portfolios at Member State level to facilitate a cost-efficient integration of high shares of renewables	2017	2030	EU28 +6	X
EC: DG ENER	The role and need of flexibility in 2030 focus on energy storage: study S07	2019	2030	AU, GER, UK	X
EC: DG ENER	Optimal flexibility portfolios for a high-RES 2050 scenario: METIS Studies: study S1	2018	2030	EU28+6	X

ENTSO-E	TYNDP 2022 - scenario report 2022	04.2022	2025-30-40-50	EU27	NONE
ACER	ACER Decision 23-2020 on VOLL CONE RS - Annex I	10.2023	n.a.	EU27	NONE
EC: DG JRC	Flexibility requirements and the role of storage in future European power systems	2023	2030, 2050	EU27	X
Linares and Rey	The costs of electricity interruptions in Spain. Are we sending the right signals?	10.2013	n.a.	Spain	X
Scheidler et al. 2018	DER Integration Study for the German State of Hesse - Methodology and Results for the Medium- and Low-Voltage Level	10.2018	2034	Hesse (DE)	X
ENTSO-E	Assessment of Future Flexibility Needs	09.2021	n.a.	ENTSO-E area	NONE
EC: DG ENER	ETIP SNET - Flexibility for Resilience How can flexibility support power grids resilience?	03.2022	n.a.	n.a.	NONE

Elia Adequacy	Flexibility study 2022-2023 (Belgium)	07.2021	2022-2032	Belgium	X
Scottish & Southern	Evaluating Flexibility as Alternative To Traditional Network Reinforcement	07.2020	2022	UK	X
SP Energy Networks	Procurement Statement for SP Distribution PLC and SP Manweb PLC	04.2023	2022	UK	X
UKPN	Flexibility Post Tender Reports	2018-2022	2022	UK	X
Heggarty et al.	Quantifying power system flexibility provision	2020	n.a.	n.a.	NONE
ISGAN	Flexibility needs in the future power system	02.2019	n.a.	n.a.	NONE

2.3. ANALYSING THE SOURCES COLLECTED

The third step of the methodology is “2.3 Analyzing the sources collected”.

In this step, we analyze the relevant literature identified in the previous step more closely, with the aim to identify quantitative information related to the business models defined and analyzed in OneNet so that we can assess the potential of those business models.

The quantitative information that we looked for is the following:

- Balancing and congestion management problems for which DER-based flexibility can be valuable.
- The quantitative aspects of these balancing and congestion management problems (cost, size, forecasts)
- The quantitative aspects of DER-based solutions (cost, size, forecasts)
- The quantitative aspects of non-DER-based solutions (cost, size, forecasts)

After having analyzed the 20 relevant sources presented in Table 2, 14 (70%) have shown to contain relevant quantitative information (see Table 2).

As the number of publications containing quantitative results is too large for the project scope, and both the time horizon as well as geographical scope vary significantly, we have further reduced the scope of our analysis. We will consider the publications whose geographical scope is roughly the EU27 and where the time horizon targeted is the year 2030, reducing the set of relevant publications to five shown in Table 3.

Table 3: Comparable Sources utilized for analysis

Nr.	Author	Title	Pub. Date	Period	Geo. scope	Quant. results
1	SmartEn	Demand-side flexibility in the EU: Quantification of benefits in 2030	09.2022	2023 - 2030	EU27	X
2	Eurelectric	Connecting the dots	01.2021	2020-2030	EU27	X
3	EC: DG ENER	Assessing the role and magnitude of different flexibility measures and assets in	2023	2018-2030	EU27+UK+6	X

		distribution and transmission grids: METIS 2: study S1				
4	EC: DG ENER	Mainstreaming RES: flexibility portfolios: design of flexibility portfolios at Member State level to facilitate a cost-efficient integration of high shares of renewables	2017	2030	EU27 + UK	X
5	EC: DG ENER	Optimal flexibility portfolios for a high-RES 2050 scenario: METIS Studies: study S1	2018	2030-2050	EU28+6	X

We will further analyze the five publications in the Table 4 in the next step of the methodology.

2.4. MAPPING THE RESULTS

The fourth and second to last step of the methodology is “2.4 Mapping the results”

In this step we focus on specific categories of quantitative information, and we benchmark the information available for each of the five sources short-listed in step 2.3.

Below is a general overview of the categories used to classify the information.

We first identified three main categories corresponding to the savings achieved when delivering the specific relevant services mentioned before:

- Congestion management/redispatch savings
- Balancing market savings
- Electricity markets benefits

The impact of the savings achieved for these services can be classified, or decomposed, into other categories that are related to several relevant system cost components that can be potentially affected by the delivery of flexibility. The subcategories are the following:

- Investment savings
- Variable production cost savings
- Curtailment reduction savings
- Carbon emissions saving
- Energy not served savings

After analyzing the five short-listed relevant sources, the results are shown in Table 4, where the presence of relevant quantitative information in the respective source is indicated.

We can see that quantitative information for the different services and costs components, or aggregated benefits across services or cost components, is sparsely present across the different studies. This is mostly due to the different nature and the limited scope of the studies.

Table 4: Services and benefits by components

Publication	Service benefits			Benefits per cost components				
	Redispatch savings	Balancing savings	Electricity market benefits	Investment savings (Adequacy)	Variable production cost savings	Curtailment reduction	Carbon emissions	Energy not served
SmartEn	X	X	X	X	X	X	X	X
Eurelectric	NONE	NONE	NONE	NONE	NONE	NONE	X	NONE
METIS 2 S1	X	NONE	NONE	NONE	NONE	X	NONE	X
METIS 1 Mainstreaming RES	NONE	NONE	X	X	X	NONE	X	X
METIS 1 S1	NONE	NONE	NONE	X	NONE	NONE	NONE	NONE

2.5. *QUANTIFICATION*

The last step of the methodology is “2.5 Quantification”.

In this step, we will determine the quantitative range for each savings category based on the information gathered in the previous steps. We will also include an outlook into the future, if the respective quantitative information is available.

The saving ranges will also consider the size of the problem that a service is tackling, providing a kind of “market potential”.

The analysis is provided in Chapter 3.1 “Background and assumptions” provides the background and assumptions for the studies, helping to understand the quantitative information provided and discussed afterwards, in subsection 3.2. as only one source covers all the services and cost component categories presented in subsection 2.4, the related study (SmartEn [2]) is used as the base case.

Chapter 3 QUANTITATIVE ANALYSIS OF THE IMPLEMENTATION OF FLEXIBILITY SERVICES

Here we provide the main quantitative estimates of the benefits and costs involved in the implementation of different solutions for system services including those concerning the implementation of local markets for SO services. As explained above in Section 2.4, the information collected is incomplete and based on that published in previous works.

3.1. BACKGROUND AND ASSUMPTIONS

As mentioned in section **¡Error! No se encuentra el origen de la referencia.**, the selected publications differ significantly, both in the aim and the depth of the studies as well as in the quantification methodology applied. Therefore, to be able to draw conclusions based on the quantitative information each of them presents, it is important to understand the context of each of them.

This section discusses the context and underlying assumptions of the analyses performed in each of the publications to obtain the quantitative information, which we will present in the next section.

The assumptions made are categorised as follows:

- Modelling approach (type of simulation)
- Grid modelling approach
- Flexibility-related assumptions
- Generation mix capacity
- Demand scenarios (DSF vs no-DSF)
- Comparison of scenarios considered

3.1.1. MODELLING APPROACH (TYPE OF SIMULATION)

In this section, the characteristics of the simulations applied in the models used for each study are presented and compared.

- METIS 1: Mainstreaming RES [1] uses multiple time series for RES generation and demand for each country, for up to 50 weather scenarios. These time series are then used to perform a stochastic simulation of the wholesale and balancing markets, and to assess that the adequacy requirements are met. The characteristics of the simulation in the METIS model are obtained from METIS technical note T6 [8].
- The Smarten study [2] uses a deterministic market model to calculate the outputs of the wholesale and balancing markets, and to check whether the adequacy requirements are met in the different scenarios defined in said study. The study adds a disclaimer stating that the use of a deterministic model for adequacy is not the most accurate, and a stochastic model would be more suitable for that purpose.
- METIS 2: Study S1 [3] analyzes the use of flexibility for transmission and distribution congestion management, and it utilizes a different approach for each one. Whereas in transmission a robust approach considering six different scenarios (maximum residual demand, minimum residual demand, maximum residual demand in summer, minimum residual demand in winter and average day) is used, in distribution, a stochastic simulation is used to assess the annual reduction in generation curtailment and load shedding.

Table 5 summarizes the characteristics of each model regarding the type of simulation:

Table 5: Simulation characteristics applied in each study.

Service/Study		METIS 1: Mainstreaming res	Smarten	METIS 2: Study S1
	Adequacy	Stochastic (for RES generation and demand by country, for up-to 50 weather scenarios, RES generation and demand forecasts by country, Imbalances and Reserve sizing)	Deterministic	-
	Wholesale			-
	Balancing			-
Congestion	Transmission	-	-	Robust (calculated for the most favorable/unfavorable/average scenarios)
	Distribution	-	-	Stochastic

3.1.2. GRID MODELS

Each Study utilizes a different approach for grid modelling.

- METIS 1: Mainstreaming RES [1] considers the Net Transfer Capacity (NTC) of the interconnections at a cluster level as the sole constrain for the grid. The grid at the country level would then be modelled following a "copper plate" approach.
- SMARTEN [2] considers the cross border NTC between countries for the wholesale market model, whereas the grid at a country level is modelled following a "copper plate" approach. Any curtailment on RES generation can only stem from lack of cross border capacity. For the balancing services, SMARTEN considers that the interconnection is enough so that EU 27 can be considered as a single system for balancing purposes.
- METIS 2: Study S1 [3] is the only one that considers transmission and distribution networks in its model. It first performs the zonal market model simulation to determine the cross-border load flows, and then uses that data as inputs to calculate the DC load flows in the transmission and distribution network levels. In the distribution network level, it also imposes constraints on the voltage deviations.

Table 6 below summarizes the different grid models

Table 6: Grid modelling for each service in each study considered.

Service/Study		METIS 1: Mainstreaming res	Smarten	METIS 2: Study S1
Adequacy		Cluster level, NTC (interconnections) based power flow	Only NTC are considered (interconnections)	-
Wholesale				-
Balancing			Grid is not considered (enough NTC is assumed), so there is a single, european level balancing market	-
Congestion	Transmission	-	-	1st. Zonal market model determines flows through interconnections. 2nd. Nodal DCLF is performed to calculate the base load flows and identify the congestion. 3rd. Flexibility measures are dispatched to optimize the DCLF (DCOPF)
	Distribution	-	-	After the Zonal market model simulation, the resulting market dispatch is projected onto the archetypes of the distribution core models (DCM) for each distribution grid. Each DCM is then optimized

3.1.3. FLEXIBILITY ASSUMPTIONS

Here we discuss the background and assumptions regarding flexibility provision made in the analyses discussed in each publication (e.g. EV performing V2G, interconnections between systems…).

3.1.3.1. Base case: SmartEn

The study is taken as the base case since it is the most comprehensive (it includes most of the services defined in 2.1, savings and their cost components). The geographic scope is EU27.

The study [2] is focused on analysing the impact of demand side flexibility (DSF) on the provisions of the different associated services (balancing services, adequacy, and wholesale markets). Additionally, it breaks down the savings from these services into different cost components.

As mentioned above, the type of flexibility whose impact is assessed in this study is flexibility mobilized by demand, also known as Demand Side Flexibility (DSF). The study compares two scenarios to analyse the impact of DSF: one in which DSF is used, and other in which DSF is not used.

However, the study makes a disclaimer on the unfeasibility of the no DSF scenario, since DSF is already in use to some extent in EU member states and removing it from the system is not realistic. Additionally, some of the technologies present in said study are, by nature, flexible, (mostly Front of the Meter BESS and H_2) even if only for arbitrage purposes, so trying to exclude them from operation for the no-DSF scenario would provide unfeasible results.

The assumptions for each scenario are provided in Table 7.

Table 7: SmartEn – DSF and no DSF scenario implementation

Resource	DSF Scenario	No-DSF Scenario
Industrial DSR	Price-responsive	Fixed traditional load
BESS - Behind the Meter	Provides flexibility	Does not feed-in or off-take electricity
Smart Charging	Optimized against prices	Fixed hourly profile
V2G	Provides flexibility	No V2G
Residential Electric Heating	Optimized against prices	Fixed hourly profile
Industrial Electric Heating - CHP	Flexible generation	Fixed generation profile
District Heating - CHP	Flexible generation	Fixed generation profile
BESS - Front of the Meter	Provides flexibility	Provides flexibility
Electrolysers	Price-responsive	Price-responsive

Table extracted from [2]

The assessment of the correlation between DSF power and investment savings is not calculated using grid model simulations. Instead, it is extracted from two different studies that provide the necessary data required to calculate it.

The model is an energy only model. It considers marginal costs to calculate the different savings, in line with the way the market currently works, instead of using a different approach for estimating costs, such as Levelized Cost of Energy (LCOE). Investment costs are then not considered for either balancing and wholesale markets, but they are looked at for adequacy purposes.

Capital expenditure in generation assets, batteries, electrolysers, and DSF is overlooked, except when quantifying the security of supply benefits (for adequacy purposes). Additionally, the study takes into account the fact that, theoretically, the investments in DSF are significatively lower than in the rest of technologies. However, there is some uncertainty on the level of DSF costs, since it is not possible to know how the DSF technologies will develop: if on their own, or if they will need some regulatory incentives, as it appears to be the case with batteries, electrolysers, and RES.

Savings in TSO redispatch and DSO grid reinforcement costs are not considered, and neither are the efficiency savings obtained from the activation of DSF.

The impact of the provision of each service is not directly associated to its cost components. Similarly, the impact in each cost component cannot be traced back to each of the provision services, only overall numbers are given.

Benefits stemming from the provision of each service in this study (wholesale, balance) are discussed separately. The outcome of this is that the total DSF benefits are lower than the sum of the benefits per segment, due to the close interaction of the segments.

Lastly, it is worth considering that the model assumes lower natural gas prices than the levels registered in 2022, and that the model assumes that regulatory barriers hindering the deployment of DSF are entirely removed.

3.1.3.2. Comparison case: METIS 2 S1

This study delves into the use of different sources of flexibility, at the transmission and distribution levels, to analyse the main benefits in terms of reduction in congestion management costs, through energy not served and RES curtailment reductions.

The study considers METIS-EUCO3232.5 [3] as the baseline scenario for which it provides the installed capacity, the baseline demand, and the available flexibility based on the different technologies that are expected to be present by the year 2030. The study covers 34 zones corresponding to the EU27+UK (scope of PRIMES scenario) and is complemented with data for 6 additional countries (referred to as EU27+UK+6), which enables a better representation of power exchanges within Europe.

The identification of the flexibility solutions analysed includes the analysis of the various technologies that are included in the EUCO3232.5 scenario, followed by an assessment of their capability to offer flexibility on different timescales and their characteristics, based on the following assumptions:

- Thermal power plants (CCGT/OCGT/Nuclear/Coal/Biomass/Waste) can provide both upwards and downwards flexibility, by means of ramping down/up production.
- Renewable energy sources (onshore and offshore wind, hydro run-of-the-river (RoR), Tidal) can only provide upwards flexibility by means of curtailing production.
- BESS, PHS and EVs can provide both upwards and downwards flexibility by means of modifying the charging/discharging times, sometimes imposing the constraint that charging not taking place at a certain time must take place at another point in time later.
- Heat Pumps and DHW can provide flexibility by shifting their load both upwards and downwards. Even though the METIS 2 model allows for V2G procurement, it has not been applied for this study.

Certain technologies can provide flexibility at the transmission level, the distribution level, or both. In this regard:

- Wind onshore, solar, waste, biomass, and BESS can provide flexibility at both transmission and distribution levels.
- The rest of thermal power plants, wind offshore, and reservoir hydro/PHS can only provide flexibility at transmission level.
- Heat pumps and EVs can only provide flexibility at the distribution level.The redispatch of interconnections/HVDC/Phase shifting transformers is also contemplated in the study as a source of flexibility at the transmission level.

Lastly, one key difference between SmartEn [2] and this study is that in METIS 2 S1 [3], the hydrogen fleet (electricity generation hydrogen turbines), electrolysis and methanation (production of electrolytic hydrogen and potential subsequent methanation) are not considered, as they are considered either absent or insignificant.

Methodology for congestion management at distribution level

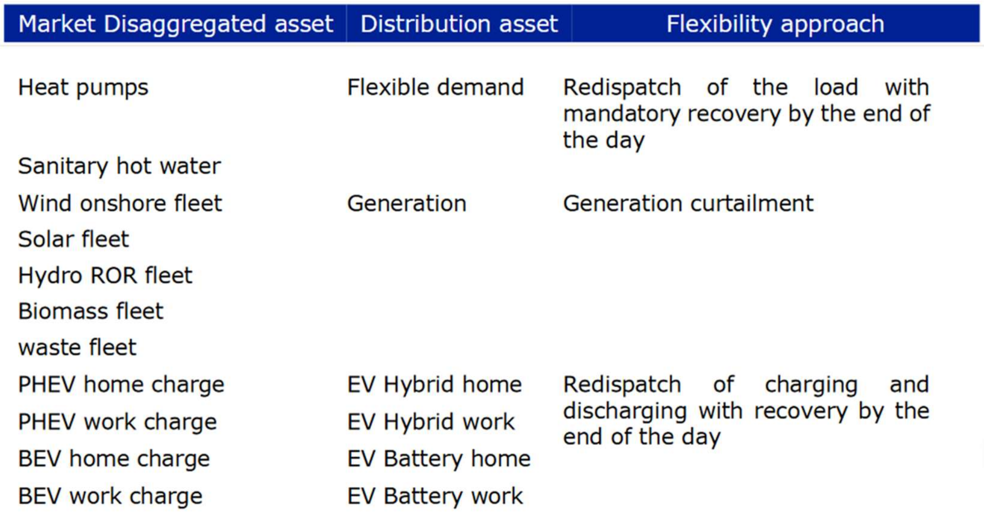
The distribution networks within the EU27+UK+6 countries are represented through 288 archetypes, capturing the topology and technical attributes of European distribution networks. These archetypes are tailored to specific countries, climatic zones, and types of loads (rural, urban, semiurban). The study facilitates drawing conclusions about the operation of the

European grid within the framework of the EUCO3232.5 scenario, particularly focusing on congestion issues and examining how certain types of flexibilities can effectively address them at the distribution level.

The distribution model encompasses the following generic assets:

- Demand: just one demand assets profile, split in two subcategories:
    - Flexible Demand: This category includes Heat-pumps and Sanitary Hot Water assets. The demand from these sources can be adjusted through load-shifting actions.
    - Non-flexible Demand: This category comprises market assets such as Air Conditioning, Thermosensitive Remainder, Non-thermosensitive Remainder, and Hybrid and Battery immediate-charging Electric Vehicles (EVs). The demand from these assets is considered fixed and cannot be modified by either the market or the distribution model.
- Generation: One unified generation profile that includes Wind Onshore, Solar, Hydro Run-of-River (RoR), Biomass, and Waste market assets. These assets are treated as curtailable.
- Electrical Vehicles: Electrical vehicles that can be charged either in vehicle-to-grid or smart charging mode are considered. Four types are distinguished, based on their technical characteristics and driving patterns: hybrid and pure electric EVs both at home and at work.
- Batteries: distribution-level electrical storage units, which are batteries directly connected at the consumer's location. In the reference situation outlined by the EUCO3232.5 scenario, only a minor storage capacity in Portugal is taken into account. Consequently, this particular asset was excluded from the disaggregation process for all the countries examined.

Table 8: Summary of flexibility assets and the flexibility approach for different technologies at distribution level – METIS 2 S1



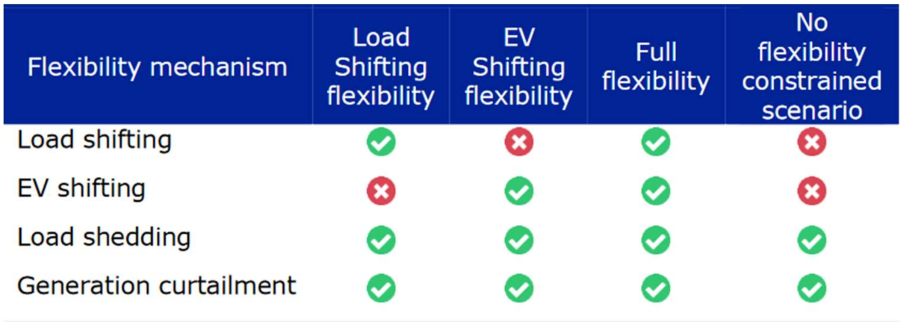
Market Disaggregated asset	Distribution asset	Flexibility approach
Heat pumps	Flexible demand	Redispatch of the load with mandatory recovery by the end of the day
Sanitary hot water		
Wind onshore fleet	Generation	Generation curtailment
Solar fleet		
Hydro ROR fleet		
Biomass fleet		
waste fleet		
PHEV home charge	EV Hybrid home	Redispatch of charging and discharging with recovery by the end of the day
PHEV work charge	EV Hybrid work	
BEV home charge	EV Battery home	
BEV work charge	EV Battery work	

Table extracted from [3]

Then, three different scenarios depending on the type of flexibility employed are compared to the base scenario where no flexibility is considered. The available solutions for flexibility in distribution consist of:

- Load shifting mechanisms: Redispatch of the flexible load profile with mandatory recovery of the displaced energy during the day. No limitations in terms of maximum/minimum power or energy are considered.
- EV shifting: EVs charging profiles whose redispatch follows the same rules as load shifting.

Table 9: Flexibility deployed for each scenario at the distribution level



Flexibility mechanism	Load Shifting flexibility	EV Shifting flexibility	Full flexibility	No flexibility constrained scenario
Load shifting	✓	✗	✓	✗
EV shifting	✗	✓	✓	✗
Load shedding	✓	✓	✓	✓
Generation curtailment	✓	✓	✓	✓

Table extracted from [3]

The resulting scenarios can either be just load shifting, or EV load shifting, or both.

3.1.3.3. Comparison case: METIS 1 Mainstreaming RES & Metis 1 S1

Both METIS 1 Mainstreaming RES [1] and METIS 1 S1 [4] consider the same flexibility methodology and assumptions. These studies focus on looking at what the flexibility needs will be in the EU by the year 2030, and on that basis, calculate the optimal flexibility portfolio for different scenarios.

The methodology used to determine the flexibility needs and optimizing the flexibility mix is as follows:

The first step in the methodology involves determining the required level of system flexibility to accommodate the presence of a significant proportion of RES-e. This is necessary to manage fluctuations in both demand and generation. Various factors create the flexibility needs across different timeframes:

- At the hourly and sub-hourly levels, the surge in flexibility needs is primarily driven by the necessity to address imbalances resulting from forecasting errors in RES-e.
- At the daily level, flexibility needs on a daily basis are predominantly influenced by the daily demand pattern and the solar generation cycle.
- At the weekly level, flexibility needs are mainly shaped by wind regimes and the structure of weekday/weekend demand profiles.

- Lastly, at the annual level flexibility needs are primarily determined by a combination of solar, wind, and demand patterns. Solar production peaks during summertime, while wind generation exhibits contrasting behaviour. Another factor impacting annual flexibility needs is the sensitivity of load to temperature, which can vary significantly among Member States based on the mix of heating and cooling technologies.

Subsequently, daily, weekly, and annual flexibility needs are defined by analysing the dynamics of the residual load[3] across various timescales. This approach ensures the consideration of all underlying phenomena driving the demand for flexibility.

Daily, weekly, and annual flexibility needs are calculated using the following procedure:

- The residual load is calculated throughout the year by subtracting variable Renewable Energy Sources for electricity (RES-e) generation and must-run generation from the demand, at an hourly/daily/monthly resolution for the daily/weekly/annual levels respectively.
- Then, the daily/weekly/annual average of the residual load is calculated. Afterwards, depending on the level, the procedure varies:
  - For the daily/weekly flexibility needs calculation, the aggregate positive difference between the hourly/daily average load and its daily/weekly average is computed. The result is expressed as a volume of energy per day/week. Then, the sum of the results obtained over the 365 days/52weeks are summed up, and the result is expressed as a volume of energy per year in both cases.

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[3] Residual load is defined as the load that has to be served by dispatchable technologies (thermal, hydro, storage, demand-response, interconnectors, etc.). It is computed by subtracting the wind, solar and must-run generation from the demand.

Flexibility is defined as the ability of the power system to cope with the variability of the residual load curve at all times. Hence, flexibility needs can be characterised by analysing the residual load curve.

- For the annual level, the difference between the monthly residual load and its annual average is calculated. The result is presented as an amount of energy per year.

Secondly, after quantifying the flexibility needs, the possible flexibility sources are identified and analysed for each member state, considering that the characteristics of each flexibility solution are different for each member state (investment costs, operating costs, availability…). The flexibility sources identified are the following:

- Flexible generation technologies. Includes traditional thermal units, such as coal, OCGT and CCGT, considering either new power plants or retrofitting existing ones.
- Storage. It includes PHS, battery storage, and compressed air storage.
- DR. It considers industrial peak shaving and load shifting.
- Interconnections. It extracts the interconnection capacity for the year 2030 from ENSTO-E TYNDP 2016.
- System-friendly RES. It mostly considers “system friendly” wind turbines, which are basically new-generation wind turbines, and offshore wind, which has a higher power yield for the majority of the time (For example, VESTAS V110)

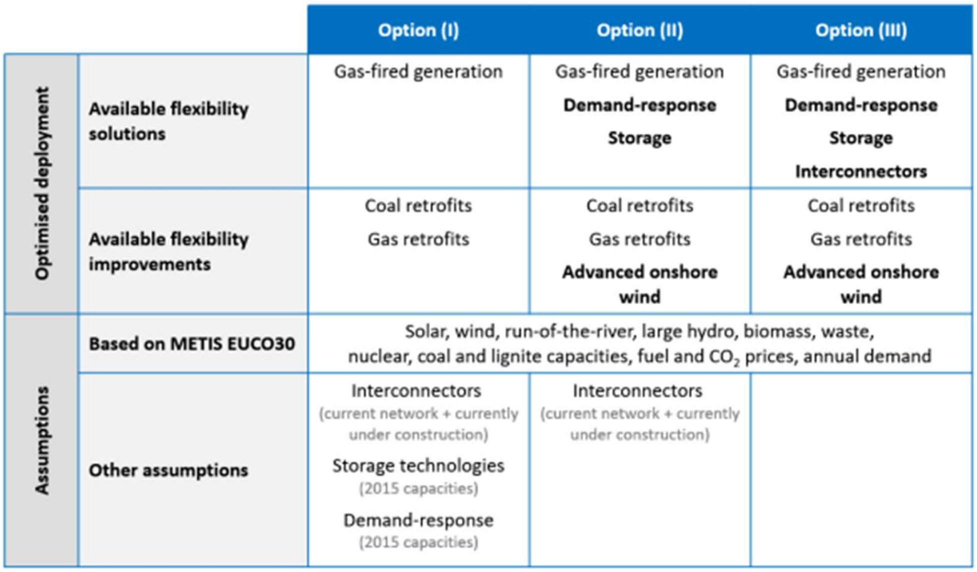
When all of the flexibility needs have been quantified and possible sources have been identified, a model is used to optimize the portfolio of flexibility solutions. From this, three different scenarios emerge from the constraints that are chosen:

- Option (I) – In the first option, the model is only allowed to invest in flexible thermal generation (including retrofitting). This option can reflect situations in which the regulatory framework does not allow other technologies such as demand-response, storage or interconnectors to participate in the provision of flexibility.
- Option (II) – In the second option, the model has access to more flexibility options: storage, demand-response and system-friendly RES.
- Option (III) – the same constraints as in Option (II) apply, and additionally interconnectors are considered as a way to increase the flexibility of the European power system. This scenario serves to highlight the role of an increased level of cooperation between Member States.

METIS 1 Mainstreaming RES & METIS 1 S1

Next, the scenarios METIS 1 Mainstreaming RES [1] & METIS 1 S1 [4] are described.

Table 10: Options for flexibility deployment and assumptions considered in the METIS 1 Mainstreaming RES & METIS 1 S1 cases



		Option (I)	**Option (II)**	**Option (III)**
Optimised deployment	**Available flexibility solutions**	Gas-fired generation	Gas-fired generation **Demand-response** **Storage**	Gas-fired generation **Demand-response** **Storage** **Interconnectors**
	Available flexibility improvements	Coal retrofits Gas retrofits	Coal retrofits Gas retrofits **Advanced onshore wind**	Coal retrofits Gas retrofits **Advanced onshore wind**
Assumptions	**Based on METIS EUCO30**	Solar, wind, run-of-the-river, large hydro, biomass, waste, nuclear, coal and lignite capacities, fuel and CO_2 prices, annual demand		
	Other assumptions	Interconnectors (current network + currently under construction) Storage technologies (2015 capacities) Demand-response (2015 capacities)	Interconnectors (current network + currently under construction)	

Table extracted from [1]

The expected results for this study are:

- Installed capacities (MW) and associated power generation (MWh) - These indicators show the capacity of the selected flexibility solutions and their annual electricity generation.
- Investment costs – They provide the cost of the optimal flexibility portfolio, expressing it as annuities, and measuring it in M€ (they do not include operational costs)
- Production costs - They correspond to the production and running costs associated with power generation and reserve procurement.
- Social welfare –It indicates the socio-economic welfare achieved. To obtain it, the sum of the producer surplus, consumer surplus and congestion rents is calculated.

- Provision of flexibility - This indicator shows the impact of each technology on the flexibility needs. The provision of flexibility by any given technology is obtained by comparing the flexibility needs based on the residual load to residual flexibility needs. The latter are computed as the residual load less the corresponding technology generation profile.

3.1.4. GENERATION CAPACITY MIX

In this section, the assumptions made regarding the mix of generation capacity for the various studies are discussed.

3.1.4.1. Generation Capacity mix: METIS 2 S1

Regarding capacity, the EUCO3232.5 scenario encompasses a total installed power production capacity of 1.400 GW (Figure 3), with Germany, France, Great Britain, Spain, and Italy emerging as the leading countries in terms of installed capacities. The scenario demonstrates a notable level of renewable energy sources (RES) penetration. The primary technologies in place include Solar (300 GW) and Wind onshore (270 GW), collectively constituting 41% of the European energy mix. This is followed by CCGT (Combined Cycle Gas Turbine) at 160 GW, Hydro at 140 GW, and Nuclear at 110 GW.

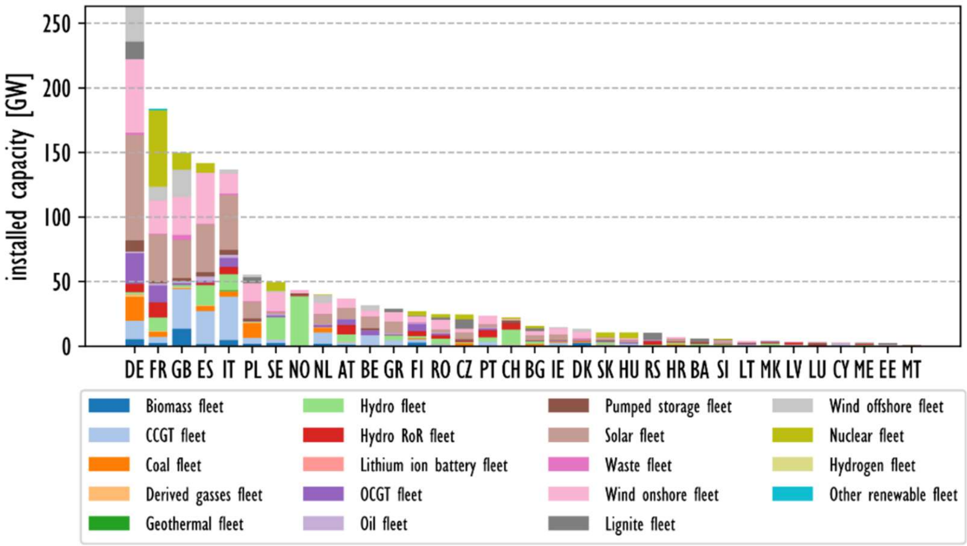


Figure 3: Installed capacity in EU27+UK+6 METIS 2 S1

Figure extracted from [3].

The overall capacity installed in the EU27+UK+6 in this study is shown in the table below:

Table 11: Overall capacity per technology in the EU27+UK+6 METIS 2 S1 study

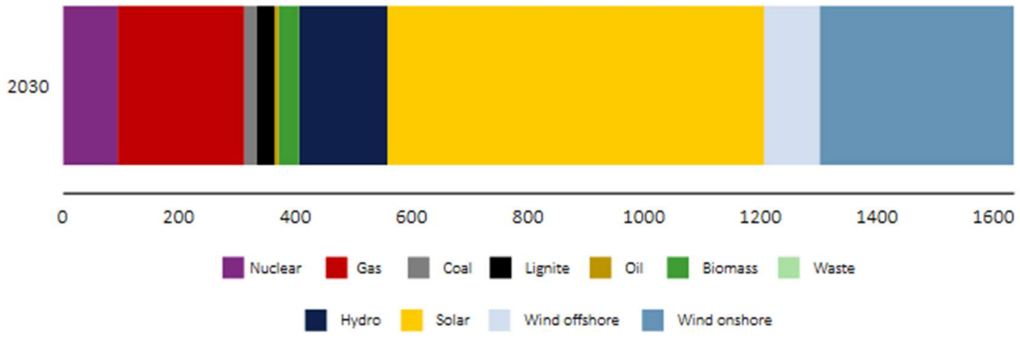
Generation mix			
Conventional generation		RES	
Technology	Installed capacity (GW)	Technology	Installed capacity (GW)
Nuclear	110	Hydro	140
CCGT	160	PV	300
Others	350	Wind offshore	70
		Wind onshore	270
Subtotal	620	780	
Total	1.400		

Data in this table have been extracted from [3].

3.1.4.2. Generation Capacity mix: SmartEn

In this study, for the EU 27 Member States, the generation capacity mix in 2030 is characterized by a substantial emphasis on renewables, constituting 75% of the total installed capacity. Thermal installed capacity is notably reduced, comprising less than 25% of the overall generation portfolio. Gas-fired generation emerges as the primary thermal source, with significant reductions in coal and lignite generation. Specifically, the installed solar photovoltaic (PV) capacity, encompassing both front and behind-the-meter installations, is projected to reach 600 GW across the EU 27 by 2030 as outlined in the REPowerEU Plan. Furthermore, capacities for offshore wind in the North Sea are expanded in line with the latest targets established by Belgium, Denmark, Germany, and the Netherlands, reaching 65 GW by 2030 according to [33].

Table 12: Generation Capacity mix in SmartEn



Generation mix in SmartEn			
Conventional generation		RES	
Technology	Capacity installed (GW)	Technology	Capacity installed (GW)
Nuclear	92	Hydro	149
Gas	212	PV	634
Coal	21	Wind offshore	97

Lignite	32	Wind onshore	328
Oil	8		
Biomass	36		
Waste	<1%		
Subtotal	402	1.208	

Total	1.610

Graphic and data in this table have been extracted from [2].

3.1.4.3. Generation Capacity Mix METIS 1 Mainstreaming RES & METIS 1 S1

The generation capacity installed in the year 2030 in both METIS 1 studies [1] is shown in Table 13, for the three different scenarios considered and used for comparison: no flexibility (Option (I)), flexibility without additional interconnection capacity (Option (II)), and full flexibility with increased interconnection capacity (Option (III)).

Table 13: Installed Capacity in the year 2030 for METIS 1: Mainstreaming RES & S1 [1]

Technologies [GW]		Option (I)	Option (II)	Option (III)
Variable RES-e	Solar	238	238	238
	Wind	331	228	228
	Run-of-the-river	50	50	50
Hydro storage	Lake + Mixed PHS	138	138	138
	Pure PHS	31	37	37

Lignite		47	47	47
Waste		12	12	12
Biomass		42	42	42
Coal	Legacy	44	46	46
	Retrofit	2	0	0
	State-of-the-art	16	16	16
Nuclear		110	110	110
CCGT	Legacy	104	110	110
	Retrofit	9	3	4
	State-of-the-art	87	78	77
OCGT	Legacy	27	27	27
	State-of-the-art	34	26	18
Total installed capacities		1.322	1.208	1.200

Table extracted from [1].

3.1.4.4. Generation Capacity Mix Eurelectric

Eurelectric [5] considers necessary to install additional 510 GW of vRES by the year 2030, totalling at 940 GW of cumulative capacity. No information is provided on the mix of conventional generation.

3.1.4.5. Generation capacity mix comparison

Table 14: Generation mix comparison among studies.

	Technologies [GW]		METIS 1: Mainstreaming RES			Smarten	METIS 2
			Option (I)	Option (II)	Option (III)		
Variable RES-e		Solar	238	238	238	634	300
	Wind	Wind Onshore	331	228	228	328	270
		Wind Offshore				97	70
Dispatchable RES	Hydro	Run-of-the-river	50	50	50	149	140
		Lake + Mixed PHS	138	138	138		
		Pure PHS	31	37	37		
Non-RES		Nuclear	110	110	110	92	110
	CCGT	Legacy	104	110	110	212	160
		Retrofit	9	3	4		
		State-of-the-art	87	78	77		
	OCGT	Legacy	27	27	27		40
		State-of-the-art	34	26	18		
	Coal	Legacy	44	46	46	21	310
		Retrofit	2	0	0		
		State-of-the-art	16	16	16		
		Biomass	42	42	42	36	
		Lignite	47	47	47	32	
		Waste	12	12	12	1	
		Oil	-	-	-	8	
Total installed capacities			1322	1208	1200	1610	1400

The comparison of the generation capacity mix comparison between the different studies presents similar capacity values for non-RES technologies, but it presents very different values for installed capacity in variable RES. This is due to the fact that most of these studies are based on different EUs decarbonisation scenarios, and as time has passed, the decarbonisation goals have become ever more ambitious.

In the METIS 1 Mainstreaming RES [1] study conducted in 2017, the aim was to evaluate the flexibility requirements across the EU+UK+6 countries. This assessment was intended to assist the relevant authorities in drafting their initial National Energy and Climate Plans (NECPs).

METIS 2: Study S1 [3], was conducted right before the Fit for 55 scenario, and that is why there is a higher share of RES when compared to METIS 1: Mainstreaming RES.

Lastly, the Smarten study [2] was conducted after both Fit for 55 and REPowerEU, and that is why this study assumes the highest volume of RES capacity out of the three.

3.1.5. DEMAND & INSTALLED FLEXIBILITY

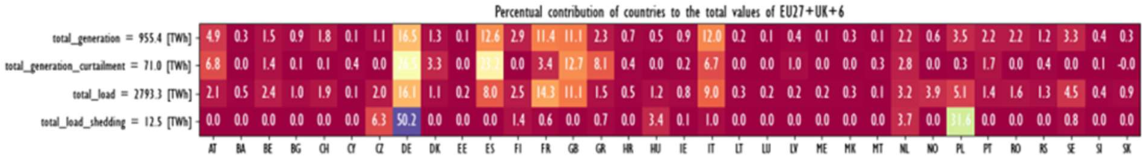
This section gathers all the available information on the electricity demand contemplated in each study. Additionally, it contains information on the types of flexibility utilized, and the installed flexibility power, whenever stated in the study.

3.1.5.1. Demand & flexibility: METIS 2 S1

METIS 2 S1 considers a total demand value of 3.731 TWh/year in 2030. However, the scope of this study is to quantify the potential of flexibility for congestion management and voltage control by means of redispatch at both levels (transmission & distribution). As stated in 3.1.1 Modelling approach, the modelling approach for transmission follows a robust approach, in which only 6 snapshots concerning residual demand are evaluated. For that reason, it is not possible to quantify the savings thanks to redispatch at the transmission level, and thus, the demand at the transmission level will be overlooked.

The main features of the generation and demand at the distribution level for the quantification of congestion savings in the METIS 2: S1 [3] are shown in Table 15.

Table 15: Annual generation & demand at the distribution level per EU member in the year 2030 in METIS 2 S1



Percentual contribution of countries to the total values of EU27+UK+6

	AT	BA	BE	BG	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GR	HR	HU	IE	IT	LT	LU	LV	ME	MK	MT	NL	NO	PL	PT	RO	RS	SE	SI	SK
total_generation = 955.4 [TWh]	4.9	0.3	1.5	0.9	1.8	0.1	1.1	16.5	1.3	0.1	12.6	2.9	11.4	11.1	2.3	0.7	0.5	0.9	12.0	0.2	0.1	0.4	0.1	0.3	0.1	2.2	0.6	3.5	2.2	2.2	1.2	3.3	0.4	0.3
total_generation_curtailment = 71.0 [TWh]	6.8	0.0	1.4	0.1	0.1	0.4	0.0	26.5	3.3	0.0	23.2	0.0	3.4	12.7	8.1	0.4	0.0	0.2	6.7	0.0	0.0	1.0	0.0	0.0	0.3	2.8	0.0	0.3	1.7	0.0	0.4	0.0	0.1	-0.0
total_load = 2793.3 [TWh]	2.1	0.5	2.4	1.0	1.9	0.1	2.0	16.1	1.1	0.2	8.0	2.5	14.3	11.1	1.5	0.5	1.2	0.8	9.0	0.3	0.2	0.2	0.2	0.3	0.1	3.2	3.9	5.1	1.4	1.6	1.3	4.5	0.4	0.9
total_load_shedding = 12.5 [TWh]	0.0	0.0	0.0	0.0	0.0	0.0	6.3	50.2	0.0	0.0	0.0	1.4	0.6	0.0	0.7	0.0	3.4	0.1	1.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7	0.0	31.6	0.0	0.0	0.0	0.8	0.0	0.0

Table extracted from [3].

The total demand at the distribution level in the base case with no flexibility is 2.793,3 TWh. Heat pumps do not include large-scale heat pumps for district heating. The information on the installed flexibility in this study has been estimated using information contained in the METIS 1 & 2 Technical notes, as well as ENTSO-E's TYNDP 2018.

The interconnection capacity was also estimated using ENTSO-E's TYNDP 2018[4]

Additionally, the METIS 2 model assumes that in 2030, only 30% of heat pumps and EVs can procure flexibility through load shifting, and even though the model allows for V2G, in this study it is not used.

Table 16: Flexibility and interconnection capacity available in METIS 2: study S1

Technologies [GW]		METIS 2 S1
Batteries		-
Load Shedding	Industrial DSR	-
Load Shifting	Smart charging	18
	Residential electric heating (Heat pumps)	29
	DHW	44
	Industrial electric heating	-
	Industrial heating - CHP	-
	District Heating - CHP	-
	V2G	-

Total	91

Interconnectors	258

3.1.5.2. Demand & flexibility: SmartEn

- Traditional demand is comprised of household, commercial and industrial power demand. This segment of demand reaches 2.858 TWh across EU 27 Member States in 2030.

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[4] Input Data for TYNDP 2018:
https://www.entsoe.eu/Documents/TYNDP%20documents/TYNDP2018/Scenarios%20Data%20Sets/Input%20Data.xlsx
Data for EVs and Heat Pumps extracted from:
https://energy.ec.europa.eu/publications/metis-1-scripts-and-data_en

- Electric vehicles. Technological and infrastructure development results in an electricity demand of 151 TWh in 2030.
- Electrification of heating consists of both space heating and industrial heating, that amount to 510 TWh by 2030.
- Power-to-hydrogen. The electrolysers' demand increases significantly in 2030 to reach the targeted 10 Mt of renewable hydrogen production in Europe, based on the REPowerEU Communication. Therefore, according to European Commission assumptions and according to SmartEn's [2] calculations, 562 TWh of electricity consumption for hydrogen production is expected in 2030.

The components of electricity demand in SmartEn [2] are provided in Table 17

Table 17: Electricity and its composition for the SmartEn study

Electricity demand	
Type of demand	Annual consumption (TWh)
Conventional demand	2858
Electric vehicles	151
Electric heating	510
P2H	562
Total	4081

Data in this table have been extracted from [2].

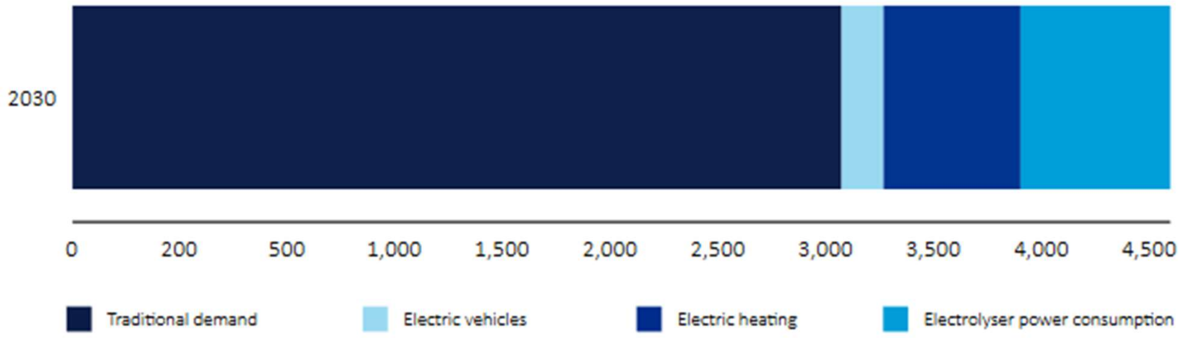

Figure 4: Electricity demand in EU27 in 2030 (TWh). Figure extracted from [2].

Various Distributed Solar Flexibility (DSF) technologies with significant potential were omitted from the flexibility sources portfolio for this study. The exclusion was attributed to insufficient data availability for assessing their presence across the EU 27 by the year 2030. Noteworthy among these technologies are district cooling, residential cooling, Joule effect electric heating, and residential electric boilers. The study authors opted to exclude them from consideration to avoid the risk of overestimating the total DSF capacities accessible to the power system in 2030.

The flexibility sources and amounts in distribution networks considered in SmartEn [2] comprise the following:

1. Smart charging – 60 million EVs by 2030 are included for the 27 Member States.
2. Vehicle-to-grid capabilities
3. Behind-the-meter (BTM) batteries – A capacity of 10,9 GW of BTM batteries in the EU 27.
4. Industrial demand-side response (DSR) – A capacity of 21,7 GW
5. Residential space electric heating – An energy capacity of 449 TWh by 2030.
6. Industrial electric heating – A capacity of 7 GW.
7. District heating – A capacity of 56 GW of combined heat and power (CHP).
8. Industrial heating – A capacity of 19 GW (CHP).
9. Grid-connected storage – A capacity of 15,5 GW of front-of-the meter batteries in EU 27

10. Electrolysers – A capacity of 149 GW in total for all Member States by 2030 at cost of 86,2 €/MWh.

3.1.5.3. Demand & flexibility: METIS 1 – Mainstreaming RES & METIS 1 S1

In these studies [1], the conventional demand in 2030 amounts to 2650TWh, as per EUCO30. The installed flexible power capacity is shown in Table 18, for the several scenarios considered (No flexibility, flexibility without additional interconnection capacity, and full flexibility).

Table 18: installed flexibility in METIS 1: Mainstreaming RES

Technologies [GW]		Option (I)	Option (II)	Option (III)
Batteries	1-hour discharge time	-	2	2
DR	Load shedding	-	4	4
	Load shifting[5]	-	8	8
Interconnectors	Import capacity	181	181	205

Table extracted from [1].

3.1.5.4. Demand: Eurelectric

According to the Eurelectric study [5], the demand in EU27+UK in the year 2030 is ~3.530TWh. The flexibility portfolio in this study comprises the following components:

- Heat pumps: 40-50 million units.
- Electric vehicles: 50-70 million
- P2X: additional industrial demand and P2X totalling at 335TWh.

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[5] Includes EVs & Heat pumps

3.1.5.5. Comparison of installed flexibility between studies

Table 19: Comparison of installed flexibility between studies

Technologies [GW]		METIS 1: Mainstreaming RES			SMARTEN		METIS 2 S1
		Option (I) (No flex)	Option (II) Flex + current interconnections	Option (III) Flex + increased interconnections	Upwards	Downwards	
Batteries	(1h discharge time)		2	2	-		-
	3h discharge time				11	11	-
Load Shedding	Industrial DSR		4	4	22		-
Load Shifting	Smart charging		8	8	49	16	18
	Residential electric heating (Heat pumps)				33	26	29
	DHW				-	-	44
	Industrial electric heating				7	73	-
	Industrial heating - CHP				6	-	-
	District Heating - CHP				11	0	-
	V2G				26	4	-
	Total	0	14	14	164	131	91
	Interconnectors	181	181	205	269	269	258

The demand in SmartEn [2] is significantly higher than that in METIS 2 S1 [3], which does not consider electrolysers (4081 vs 3.667 TWh). Furthermore, the total demand in METIS 2 S1 [3] is similar to the traditional demand in SmartEn [2]. If we only consider the common technologies, the demand in SmartEn [2] is 2858 + 151 + 510 = 3519.

The model used for the Smarten model does take into account behind-the-meter solar PV for generation; however, it is not represented as a controllable asset but rather as non-curtailable PV generation. In the METIS 2: Study S1 [3], biomass, wind and ROR hydro is considered to be curtailable generation in distribution, but no direct mention is made to PV behind the meter.

It is worth noting that in terms of flexibility capacities, the Smarten study [2] has 20 times as much flexibility capacity than METIS 1: mainstreaming RES [1], and 3 times as much as METIS 2: Study S1 [3].

Lastly, the interconnection capacity for the Smarten study was estimated to be the available capacity in 2020 plus the increase in capacity forecasted in ENTSOE's 2020 TYNDP [9].

3.2. QUANTITATIVE FLEXIBILITY BENEFITS

In order to provide the best possible quantification of the costs and benefits associated with the mobilization of flexibility in the European Union according to the business model solutions identified in OneNet, a large body of relevant publications has been reviewed. The condensed, most relevant publications to be used in this chapter for quantitative analysis are shown in the Table 20.

Table 20: Names of publications to be reviewed by grouped categories of quantitative information

	Service benefits			Benefits per cost components				
Publication	Redispatch savings	Balancing savings	Elec. market benefits	Investment savings	Variable production cost savings	Curtailment reduction	Carbon emissions	Energy not served
SMARTEN: Demand-side flexibility in the EU: Quantification of benefits in 2030	X	X	X	X	X	X	X	X
EURELECTRIC: Connecting the dots	NONE	NONE	NONE	NONE	NONE	NONE	X	NONE
DG ENER: Assessing the role and magnitude of different flexibility measures and assets in distribution and transmission grids: METIS 2: study S1	X	NONE	NONE	NONE	NONE	X	NONE	X

DG ENER: Mainstreaming RES: flexibility portfolios: design of flexibility portfolios at Member State level to facilitate a cost-efficient integration of high shares of renewables	NONE	X	X	X	X	NONE	X	NONE
DG ENER: Optimal flexibility portfolios for a high-RES 2050 scenario: METIS Studies: study S1	NONE	NONE	NONE	X	NONE	NONE	NONE	NONE
DG JRC: Flexibility requirements and the role of storage in future European power systems	NONE	NONE	NONE	X	NONE	NONE	NONE	NONE

For each of the categories introduced in the following subsections of this chapter, the quantified benefits are discussed in relation to OneNet business models.

3.3. SERVICES BENEFITS

DER-based flexibility business models provide various services that result in savings and benefits. The following subsections will shed light on the prospective benefits to be obtained by mobilizing this flexibility when providing through markets the redispatch (congestion management, and voltage control), balancing and wholesale energy services.

Because each study focuses on different aspects of service provision under different assumptions, and the methodology applied varies from one case to another, the results are not easily comparable. For this reason, a discussion of where the savings for each service and cost component originate from each of the studies consulted is also included in the following.

SmartEn [2] – For the most part, this study provides the total savings achieved when providing each service (redispatch savings in the wholesale markets, balancing savings). Besides, this study also computes the savings for some selected cost components (CO2 emissions, investment costs, curtailment costs, costs related to energy not served) without necessarily breaking down these into the specific services that these savings are attributable to.

METIS 2 S1 [3]– This document only analyses congestion management as a service, and it considers that savings obtained from this service can be broken down into reduced load shedding and reduced curtailment. Generation costs are considered for the optimal dispatch, but the savings in generation costs are not presented in this study. We can, however, assume that savings in generation costs will be achieved, as a reduction in curtailment ought to provide savings in inframarginal productions.

METIS 1 Mainstreaming RES [1] – This study analyses the deployment of the potential flexibility portfolio for the year 2030. It does not break down the savings into those attributable to each specific service. It provides the overall operational savings achieved thanks to the use of flexibility. Because the operational savings are not attributable to any service in particular, but rather, to the two contemplated services (wholesale & balance) the results will be presented in the following section. The estimates here provided correspond to a single study, the METIS 1 Mainstreaming RES one [1]. Several scenarios for the mobilization of flexibility are considered in this study.

- For the first flexibility scenario, in which the flexibility solutions considered do not include the flexible use of interconnections, the operational savings achieved amount to €1,2Billion compared to the scenario without flexibility mobilization and no interconnections.
- For the second flexibility scenario, in which all the flexibility solutions, or sources, are considered, including the use of interconnection capacity for this, the overall savings achieved amount to €1,9 Billion.

The authors state that the benefits thanks to the simultaneous provision of flexibility in the wholesale and balance markets generate positive synergies. Namely, the use of flexibility for balancing services enable baseload and mid merit power plants to produce energy at a higher load rate, because they will have lower reserve requirements. This also reduces operational costs for those technologies.

Furthermore, the METIS 1 Mainstreaming RES [1] study also analyses the savings achieved in investment costs and CO2 emissions for each scenario, when comparing it to the base case, in which no demand side flexibility, nor increased interconnection capacity is considered. Lastly, it also delves into determining the volume of new flexibility deployed for balancing services.

3.3.1. REDISPATCH SAVINGS

This section reports on the redispatch savings quantified in the SmartEn [2] and the METIS 2 S1 studies [3], that largely stem from congestion management and voltage control.

3.3.1.1. Redispatch savings: SmartEn

Redispatch is considered from the perspective of achieving savings in generation costs, and reduction of the

Additionally, the scenario for which redispatch savings have been calculated in SmartEn [2] considers that there is enough generation to cover all the demand when DSF is mobilized, and so, energy not served is zero, whereas without DSF NSE would amount to 2.054 TWh. (€9 billion estimated in the paper as savings obtained by avoiding all the lost load. The VoLL has been deemed to be 3.500 €/MWh in the study).

Savings in generation costs alone make up for €4,6 billion, which represent 5% of production costs in the scenario where no DSF is applied.

Furthermore, renewable energy curtailment is reduced by 61% thanks to the activation of these flexibility mechanisms, which translates into 15,5 TWh.

3.3.1.2. Redispatch savings - DG Ener METIS 2 S1

In METIS 2 S1 [3], redispatch is looked at from a network standpoint, and congestion seems to be alleviated through it. Quantitative estimates of redispatch savings are provided for the reduction of both energy not served and curtailment. Redispatch savings are provided both at transmission and distribution levels, although for transmission, these savings are only estimated for three critical time steps identified. In this section, we will only focus on the distribution redispatch savings, as these are the ones comparable to the estimates produced within SmartEn [2]. In this case, redispatch savings (for congestion management) at the distribution level comprise those for reduced load shedding, and reduced generation curtailment.

Table 21: Summary of the three flexibility configurations and their network problems alleviation outcome, for EU27+UK+6

Flexibility Mechanism	Generation Curtailment (TWh)	Load Shedding (TWh)	Load Shifting (TWh)	EV Shifting (TWh)
No flexibility	71.0	12.5	-	-
Load shifting	69.1 (-3%)	10.5 (-15%)	3.5	-
EV load shifting	69.9 (-2%)	11.8 (-5%)	-	1.7
Full	68.3 (-4%)	10.1 (-19%)	3.0	1.6

Table extracted from [3].

In the scenario where all kinds of load shifting are used at the same time, generation curtailment is reduced by 2,7 TWh (4%) and load shedding is reduced by 2,4 TWh (19%), as shown in Table 21.

3.3.1.3. Redispatch savings: Conclusions

Load shedding is reduced similarly in both studies consulted (2,56 TWh in SmartEn [2] compared to 2,4 in the METIS 2 S1 study [3]), whereas curtailment reduction is significantly lower in the METIS 2 S1 study [3] compared to those estimated in SmartEn [2] (2,7 TWh in METIS 2 S1 study [3] compared to 15,5 TWh in SmartEn). This can be attributed to the fact that, while generation capacity in SmartEn [2] is assumed to be 1.600 GW and in METIS 2 S1 [3] it is 1.400 GW, the overall annual demand in SmartEn [2] is significantly higher than in METIS 2 S1 [3] (4.800 TWh in SmartEn compared to 2.800 TWh in METIS 2 S1 [3]).

3.3.2. BALANCING SAVINGS

This section reports on the savings achieved when delivering the balancing service including the mobilization of flexibility. The studies focusing on these savings are also the SmartEn [2] and the METIS 1 Mainstreaming RES [1] ones.

3.3.2.1. Balancing savings - SmartEn

The SmartEn study [2] assumes that the required volume of energy for balance needs in EU27 remains the same as in 2021, as can be seen in Table 22

Table 22: Balance needs in EU27 in 2030 according to SMARTEN [2]

	Reserve	Volumes 2021 (GWh)
aFRR	aFRR down	-7735.64
	aFRR up	8504.27
mFRR	mFRR down	-10746.07
	mFRR up	8504.27
RR	RR down	-17689.66
	RR up	13344.83

The mobilization of demand-side flexibility reveals quantifiable balancing cost savings. It determines that the total potential cost savings from mobilizing flexibility in the provision of balancing services range between €0,3 billion for the pessimistic (low) and €0,7 billion for the more optimistic case (high) as shown in Table 22, which may seem relatively low due to the smaller size of the balancing market compared to the wholesale market. In relative terms, these savings amount approximately to between 0,7 € and 1,6 € per consumer in the EU27 area. That represents between 43 % and 66 % savings in the DSF scenario, underlining the substantial economic advantages of implementing DSF in balancing markets.

Under the assumption that the provided DSF technologies meet the technical requirements, a three-step analysis based on the technology's marginal costs is conducted in this study. In a first step, they collect data on the market size in terms of reserve volumes and range for aFRR, mFRR and RR, as well as technology data in terms of marginal cost and balance service eligibility. In a second step, the technology merit order is built both for a DSF and a no-DSF scenario, showing, among other things, that "all aFRR upward capacity can be provided by hydro energy in the no-DSF scenario (at around 6 €/MWh) and by residential DSF in the DSF scenario (at around 3 €/MWh).“ [2]. The third step involves calculating the balancing costs for the researched market size in both scenarios. The difference between both of them represents the benefits broken down by technology and category.

Table 23: SmartEn - DSF power system balancing benefits per category in million €

Reserve	DSF balancing benefits (million €)	
	Low	High
aFRR down	53,1	53,1
aFRR up	23,6	23,6
mFRR down	127	127
mFRR up	58,4	486,6
RR down	0	0
RR up	0	0
TOTAL	262	690,2

Table extracted from [2].

3.3.2.2. Balancing savings - METIS 1 Mainstreaming RES

The study METIS 1 Mainstreaming RES [1] considers that upwards synchronized reserves (FCR and aFRR) are mainly covered by hourly flexibility solutions, that is, by 7,7 GW of short-term demand-response and 2,1 GW of batteries at the EU28 level, whereas in the no-DSF scenario (Option I), this reserves are provided through Hydro (mostly PHS) and thermal units. The related cost saving are not provided in the METIS 1 Mainstreaming RES study [1]. However, the reserve needs are presented:

Table 24: FCR and Frequency restoration reserve needs in the year 2030 in METIS 1: Mainstreaming RES [1]

FCR Needs (GW)	
FCR	6,3

Frequency restoration reserve needs (GW)		
Frequency restoration reserve needs GW	2015	2030
aFRR Upwards	9,9	10,5
aFRR Downwards	8,8	10
mFRR Upwards	15,1	17,4
mFRR Downwards	11,7	15,6
Total	44,2	53,5
Increase		21%

Table extracted from [8]

3.3.3. ELECTRICITY WHOLESALE ENERGY MARKET SAVINGS

Savings corresponding to the reduction of the cost of the wholesale energy market dispatch are provided here. These have been only drawn from the SmartEn study [2].

Wholesale savings- SmartEn

The results from the SmartEn study [2] show that, in the year 2030, the activation of 397 TWh of upward DSF and 340,5 TWh of downward DSF will have the following effects.

- It will reduce the aggregated expenditure of all the consumers in the wholesale market by 48%. That is €301,5 billion less than in the no-DSF scenario. Costs to generate energy will be €4,6 billion (5%) lower than in a no-DSF system. It is worth noticing that consumer savings are much higher than savings in energy production, which means that under SmartEn [2] forecasted energy mix, most of the energy produced will be RES based, and thus, its marginal cost will be zero. The system can serve all demand throughout the year when mobilizing DSF, whereas the no-DSF system leaves 2.054 GWh of load unserved in 2030. Therefore, the DSF system saves €9 billion on value of lost load.
- The savings in what the sum of all market consumers spend on the wholesale market are significantly higher than the rest of identified savings. This highlights the considerable impact that load curtailment and load shifting have on the market price at certain times. DSF avoids the creation of high price spikes where very expensive (and price setting) generators are needed. DSF also absorbs the excess energy in the case of a generation surplus and relatively low prices. Therefore, it can be observed that even if the generator costs are only 5% less, the lower utilization of expensive generators makes a tremendous impact on the final cost to load (nearly 50%).

Electricity wholesale savings – METIS 1: Mainstreaming RES

METIS 1: Mainstreaming RES [1], does not calculate the wholesale savings per se, but rather, the increase in social welfare associated to the provision of flexibility in the wholesale market.

The study defines the social welfare as the sum of the producers' surplus, the consumers' surplus and congestion rents in the interconnections.

The provision of flexibility by 2,1 GW of 1h batteries, 7,7 GW of short-term demand response, and 4 GW of industrial DSR achieves an increase of 1,6 billion euros in social welfare (Option (II)) over the no-DSF scenario, whereas the same flexibility and an increase of 24 GW in interconnection capacity between EU countries achieves 2,6 billion euros in increased social welfare (Option (III)).

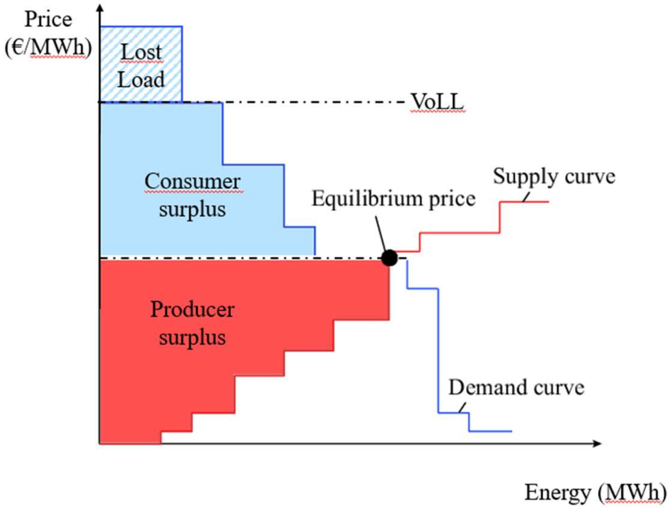

Figure 5: Illustration of consumer and producer surplus.

Unfortunately, the study does not provide the breakdown on how flexibility contributes to each of these terms (consumer and producer surplus), so the possible causes for the increase in consumer & producer surplus thanks to flexibility are listed hereafter:

For consumers:

- Provision of downwards flexibility (increasing demand) can result in increased surplus at times of high share of electricity generation compared to demand before the dispatch of flexibility, as it reduces curtailment and enables a higher consumption at the same price.

- Alternatively, provision of upwards flexibility at times of peak demand to avoid the dispatch of peaker plants would result in lower hourly price (in €/MWh) for all consumers. If baseload and mid-merit generators represented a high share of the generation that would result if no flexibility was dispatched (as should be in a high RES scenario), the reduction in price outweighs the reduction in demand that is not satisfied.

For producers:

- Provision by consumers of downwards flexibility (increasing demand) results in increased surplus at times of high share of electricity generation compared to demand before the dispatch of flexibility, as it reduces curtailment and enables a higher consumption at the same price (in €/MWh). As curtailment is reduced, and larger volumes of energy are traded in those hours, the benefits for inframarginal producers increase.
- At times of high prices, the provision of upwards flexibility by producers (storage or Hydro) allows to cover the demand with technologies that have lower production costs. This result in increased surplus for producers, while the producers' surplus increases.

Regarding interconnections, they increase the net social welfare, as they allow for a reduction in curtailment in inframarginal RES production across all countries, so they increase the overall social welfare by increasing the producers' surplus in the exporting countries and the consumer's surplus in the importing countries, while reducing the producers' surplus in the importing countries and the consumer's surplus in the exporting countries, as can be seen in the following charts:

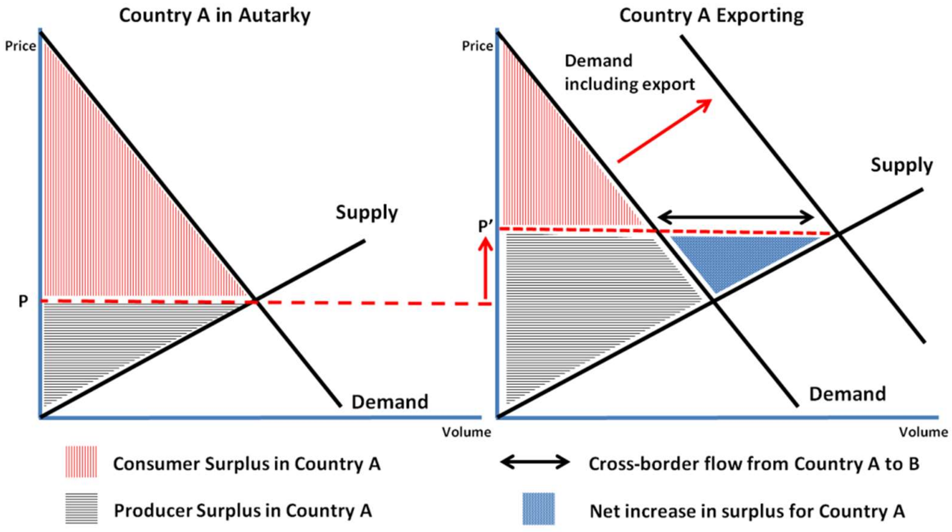

Figure 6: Effect of interconnections on the social welfare in exporting countries. [11]

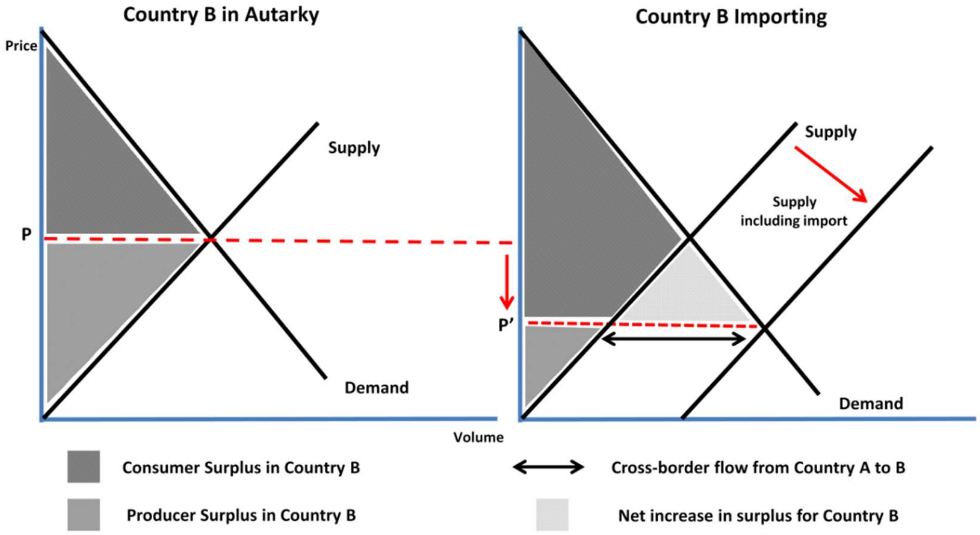

Figure 7: effect of interconnections on the social welfare in importing countries. [11]

3.3.4. BENEFITS PER COST COMPONENT

Resulting from the provision of services mobilizing flexibility, there are a multitude of types of benefits to be achieved, related to different system cost components. In the following sections, benefits on investment, curtailment, carbon emissions and energy not served cost savings are discussed.

3.3.4.1. Investment savings

The following sections quantify results in terms of possible investment savings. The publications quantified investments in generation that can be avoided or minimized thanks to the use of DER-based flexibility.

Even though adequacy is not one of OneNet's business models, it was deemed as a valuable insight.

Investment savings - SmartEn

The SmartEn study [2] provides evidence of the potential economic advantages associated with the adoption of Demand-Side Flexibility (DSF) as a replacement for traditional methods. At this point, it is important to remind the reader about the main limitation of the SmartEn study [2]. This concerns the fact that investment savings are upper bound estimates derived from data from two distinct sources. In their comprehensive cost analysis, the authors of the study make the following findings.

Gas Peaker plants, as a conventional energy source, were estimated to have a significant annual cost of 45.500 €/MW per year. In contrast, DSF was found to be an exceptionally cost-effective alternative, with a remarkably lower cost of only 120 €/MW per year. Therefore, the following savings in generation capacity can be found in Table 25.

Table 25: SmartEn - capital expenditure for investment in gas peaker plants and DSF capacity

Year 2030 – EU 27	Cost [€/MW/year]	Total cost [million €]
Gas peaker CAPEX (annualised)	45,500 (LAZARD, 2020)	2,730
DSF CAPEX	120 (European Commission DG Energy, 2016)	7.2

Table extracted from [2].

Moreover, the Smarten study went further to project the potential annual grid investment savings. These savings did not stem from the model used for the study, but rather estimated the savings in distribution networks from the figures for total required investments provided in the "Connecting the Dots" study from Eurelectric [5]. From those inputs, it estimated yearly savings ranging between €11,1 billion and €29,1 billion. This range represents a substantial portion of the forecasted grid expenses, accounting for 27 % to 80 % of the total expected costs. When projected over the span of today to 2030, these savings accumulate to make a significant total of €77,6 billion to €203,6 billion. These figures are contingent upon the assumption that no grid restrictions impede the implementation of DSF, underlining the economic benefits that DSF can bring within the EU27.

Investment savings – METIS 1: Mainstreaming RES

METIS 1: Mainstreaming RES estimated the investment cost savings thanks to the use of flexibility in EU 28+6 in 2030. Looking at the annualized CAPEX alone, the investment savings amount to 168 M€/year in Option (II) (Only flexibility), whereas in Option (III) (Flexibility+Increased interconnection capacity), the savings increase up to 209 M€/year.

Table 26: Investment costs savings in generation & interconnections in METIS 1: Mainstreaming RES (M€/year)

Annual Cost difference compared to no-DSF scenario (M€/year)	METIS 1: Mainstreaming RES	
	Option (II)	Option (III)
Interconnections		466
Batteries	107	107
Peak Shaving	83	76
Load Shifting	297	297
PHS	270	270
OCGT	-345	-734
CCGT	-559	-669
Retrofitting	-21	-21
Total savings	-168	-209

Table values estimated from the information contained in [1]

Table 27: Annualized CAPEX (€/MW/year) for selected technologies.

Annualized CAPEX €/MW/year		METIS 1: Mainstreaming RES
Peaker Plants	OCGT	49.113
	CCGT	68.362
	Retrofitting	3.000
DSF	Peak shaving	20.400
	Load shifting	38.513
Dispatchable RES	Pumped hydro	45.000
	Batteries	50.903
	Interconnections	19.397

Values extracted from information contained in [1]

Comparison between investment savings in Smarten & METIS 1: Mainstreaming RES

The figures provided in each study differ greatly, for several reasons:

- Even though the assumed cost for CAPEX for peaker plants in METIS 1: Mainstreaming RES [1] is similar to the one in the Smarten study [2], the Smarten study assumes investment savings of 2.300 million euros in peaker plants, compared to the

900-1.400 million euros in METIS 1: Mainstreaming RES. This is most likely due to the higher flexibility volumes in Smarten.

- The estimated CAPEX for DSF in Smarten is significantly lower, by a factor of hundreds, compared to METIS 1: Study S1. This may account for the much larger volume of flexibility observed in Smarten compared to other studies.
- Lastly, in Smarten, the interconnection capacities are a given, and the investment costs in interconnections are not internalized by the market, which reduces severely the investment requirements, while enabling larger energy exchanges between countries. In particular, the Smarten Study would assume 64 more GW of interconnection capacity, based on ENTSO-E’s 2020 TYNDP [9], which would be the reference for interconnection capacity used by Smarten.

3.3.4.2. Production costs savings

This section presents the reduction in production costs thanks to the activation of flexibility services.

Production costs reduction SmartEn

In SmartEn [2], production costs savings are only presented for the wholesale market, where the activation of DSF allows to cut peak demand, avoiding the dispatch of marginal technologies such as CCGT, and reducing production costs by 5%, which represents €4,6 billion a year.

Production costs reduction - METIS 1 Mainstreaming RES

Two scenarios for the mobilization of flexibility are considered in this study. These savings are not service specific, so they belong to all the services that can be provided by activation of flexibility.

- For the first flexibility scenario, in which the flexibility solutions considered do not include the increased capacity and use of interconnections, the operational savings achieved amount to close to €1,2 Billion compared to the no-DSF Scenario.

- For the second flexibility scenario, in which all the flexibility solutions, or sources, are considered, including the increased interconnection capacity, the overall savings achieved amount to €1,9 Billion.

Table 28: Production costs reduction - METIS 1 Mainstreaming RES

Difference in production costs, compared to no-DSF scenario (M€)			METIS 1: Mainstreaming RES	
			Option (II) Flex + current interconnections	Option (III) Flex + increased interconnections
DSF	Batteries	BESS Behind the meter	53	37
	Load Shifting	Smart charging	184	184
		V2G		
		Residential electric heating		
		Industrial electric heating		
		Industrial heating - CHP		
		District heating - CHP		
	Load Shedding	Industrial DSR	-	-
Baseload & mid merit technologies	Nuclear		58	105
	Lignite		147	184
	Coal		832	1.447
Peaker fuel plants	CCGT		-2.132	-3.511
	OCGT		-79	-116
	Biomass & fuel		-184	-211
Total			-1.121	-1.879

Values in the table inferred from the information contained in [1].

Production cost savings in this study are less than half in absolute terms than in the SmartEn study [2]. This is most likely due to the fact that demand, generation capacity and flexibility in METIS 1 Mainstreaming RES [1] are smaller than in SmartEn [2].

3.3.4.3. RES curtailment reduction

Within this section, the reductions in the amount of curtailments incurred that are reported in several studies are discussed, though these are not monetized.

RES curtailment reduction - SmartEn

Savings in curtailment reduction thanks to redispatch make up for 15,5 TWh which represents a reduction in curtailment of 65% over the scenario where no DSF is applied.

RES curtailment reduction - METIS 2 study S1

In the scenario in which all types of load shifting are used at the same time [3], generation curtailment is reduced by 2,7 TWh, which represents a 4% reduction compared to the base scenario.

3.3.4.4. Carbon emission savings

Here, savings in the costs of emissions due to the mobilization of flexibility are discussed.

Carbon emission savings - SmartEn

The Smarten study [2] examines the carbon savings attributed to DSF. In this analysis, the total carbon emissions for the year 2030 were determined as a direct outcome of the model used, considering the carbon emissions generated by the utilization of carbon-based fuels and biomass by dispatched generators. Furthermore, the results consider the impact of carbon capture and storage measures. These emissions were then assessed against the established 2030 power system emissions target, which aligns with the 55% reduction objective. This emission target for the power sector is derived from DNV's energy transition outlook model used in the SmartEn study [2] and is set to 410 million equivalent CO2 tons. This is shown in Table 29.

Table 29: Carbon emissions savings for study SmartEn

Category	Potential Savings	% Relative to No-DSF	Potential Savings per Capita	Savings in M€
Emissions	37.5 Mt	-8%	83.8 kg	1982,2

Table extracted from [2].

In comparison to the scenarios that do not incorporate demand-side flexibility, the study reveals a reduction of 37,5 million metric tons of CO2 equivalent emissions achieved through flexibility mobilization, representing an 8% decrease with respect to the reference scenario. Notably, these emissions savings correspond to approximately 84 kilograms per capita within the European Union's 27 member states. In this study, the CO_2 emissions are valued at 53€/tCO_2, so the savings in CO_2 emissions would amount to 1.982 million euros, to be split between wholesale and balancing markets, although for the most part they would be associated to the wholesale market.

Carbon emission savings - Eurelectric

The Eurelectric study [5] estimates a range of 566-733 million metric tons (MT) of CO2 savings resulting from all DSO investments made between 2020 and 2030. While it is important to note that these figures encompass a variety of factors and are not exclusively attributable to DSF, the study does emphasize a compelling case for leveraging flexibility in the context of electric vehicle (EV) charging. Specifically, the study considers the scenario in which 75% of the EV fleet is charged during off-peak hours.

At a rate of €30 per ton of CO2, these savings correspond to an estimated range of 17-22 billion euros in average annual cost savings associated with reduced CO_2 emissions. This financial estimation is pivotal in facilitating a 50-55% reduction in greenhouse gas (GHG) emissions compared to the 1990 levels.

Carbon emission savings - METIS 1 Mainstreaming RES

This study [1] makes the assumption that carbon price remains constant regardless of the amount of CO2 emissions. The result of this is that, even if there is a big increase in RES capacity, the overall CO2 emissions increase by 0,7% or 0,9% by the year 2030, depending on the scenario (if interconnections are considered or not), because there is an increase in coal/lignite production at the expense of natural gas power plants, as those fuels are cheaper under the assumptions made. However, the authors of said study acknowledged that this could be solved applying higher costs for carbon emissions.

Table 30: Increase in CO2 emissions in METIS 1: Mainstreaming RES

		Difference in production compared to no-DSF option (TWh)		Difference in production compared to no DSF option (MtCO2)	
Fuel	CO2 emissions (tCO2/MWh GCV)	Option (II)	Option (III)	Option (II)	Option (III)
Coal	0,32	17	27	5,44	8,64
Lignite	0,34	3	4	1,02	1,36
Oil	0,25	-	-		
Gas	0,19	-28	-48	-5,32	-9,12
			Total	1,14	0,88

Values in the table extracted from [1] &[12]

The METIS 1 model assumes that the CO_2 emissions are valued at 27 €/tCO_2[6], so the increase of costs in CO_2 emissions would amount to 30,8 million euros in option (II), where only flexibility is considered, and 23,6 million euros in option (III), where both flexibility and increased interconnection capacity are considered.

The increase in CO_2 emissions ought to be split between wholesale and balancing markets.

3.3.4.5. Savings in energy not served

Here, savings related to the reduction in energy not served that are achieved through flexibility mobilization are discussed.

Savings energy not served - SmartEn

The scenario for which redispatch savings have been calculated in SmartEn [2] assumes that there is enough generation to cover fall the demand when DSF is mobilized. Then, the energy not served is zero in this case. On the other hand, without DSF, NSE would amount to 2,56 TWh, which amount to €9 billion of costs when considering a VLL of 3.500 €/MWh, as in the study.

Savings energy not served - METIS 2: Study S1

In the scenario where all kinds of load shifting are used at the same time, load shedding is reduced by 2,4 TWh [3]. The METIS 2 model assumes a VoLL of 20.000 €/MWh [10], which would result in savings of lost load equivalent to €48 billion.

If on the other hand, we assume the unit value of lost load to be at 3.500 €/MWh, as in the SmartEn study [2] discussed in the previous paragraph, this would translate into cost savings of €8,4 billion.

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[6] As stated in METIS Technical note T7: METIS Gas Module Documentation

Chapter 4 CONCLUSIONS AND FUTURE WORK

Conclusions and recommendations are divided into those of a qualitative, or conceptual, nature and the quantitative ones.

4.1. MAIN RESULTS OF THE QUANTITATIVE ANALYSES CONDUCTED

Regarding the quantitative analyses conducted to make an informed guess of the potential of the BMs analysed, our literature review has quantified the multifaceted benefits derived from DERs (DER) based flexibility services. We have classified these benefits according to two dimensions:

- service benefits, i.e. having the benefits classified by service where they are achieved, encompassing re-dispatch, balancing, and electricity wholesale. And
- secondly, benefits classified according to the associated cost component affected, encompassing investment savings, reduction in renewable energy curtailment, carbon emission savings, savings due to the reduction of energy not served, and variable production cost savings.

In summary, the service benefits of DER based flexibility services are undeniably profound, as our comprehensive literature review has revealed. Firstly, the savings related to balancing services alone, added up to a range between €0,3 and €0,7 billion, according to the Smarten study [2]. Supplementarily, in the Mainstreaming RES study carried with METIS [1] 7,7 GW of DSF and an additional 2,1 GW of batteries being mobilized for this purpose within the European Union cover for the reserve needs that otherwise would be covered by Hydro (PHS mostly), and thermal units.

Secondly, the findings for re-dispatch savings suggested that load shedding is decreased to a similar extent in both referenced studies due to flexibility mobilization (2,05 TWh in SmartEn [2] compared to 2,4 TWh in the METIS 2 S1 study [3]). In relative terms, the reduction of lost load in Smarten is higher than in METIS 2 S1 study, as Smarten achieves a 100% reduction in load shedding, compared to 19% in METIS 2 S1. However, it is worth noticing that Smarten considers the transmission and distribution grids in each country as a copper plate, whereas METIS 2 S1 accounts for grid congestion and losses. This also explains why the shedding in the no-DSF scenario is lower in the Smarten Study, even though the energy consumption is higher (4.081 TWh in Smarten compared to 3.667 TWh in METIS 2 S1)

However, the reduction in curtailment is notably less in the METIS 2 S1 study [3] when compared to the estimates in SmartEn [2] (2,7 TWh in METIS 2 S1 study [3] compared to 15,5 TWh in SmartEn). This is also most likely because Smarten does not account for congestion and losses in the grid, other than at the interconnections which reduces curtailment greatly even if we account for the fact that the Smarten study assumes 420 GW (+65%) of additional RES capacity compared to METIS 2 S1.

Thirdly, as the SmartEn study [2] states, there are substantial savings to be achieved due to the mobilization of flexibility in the wholesale market. Activating 397 TWh upward and 340,5 TWh downward DSF reduces wholesale market consumer expenditure by 48% (€301,5 billion less than no-DSF). Energy generation costs are €4,6 billion lower (5%) due to the fact that deploying flexibility allows to integrate mostly additional amounts of renewable energy with zero marginal production costs. The DSF system ensures year-round demand fulfilment, saving €9 billion on lost load compared to a no-DSF system. Reducing energy not served through conventional investments in additional capacity, instead of using DSF, is contemplated in some studies from a CAPEX standpoint, but the analysis of the impact of this on generation costs is not carried out. Load curtailment and shifting significantly impact market dynamics, preventing high price spikes from occurring. Thus, while a modest 5% reduction in generation costs is achieved in the Smarten study [2], the final cost of electricity to load nearly halves.

Stemming from these service benefits, the findings on the benefits per cost components, starting with the investment savings, were the following.

Regarding investment cost savings in generation plants, the conservative estimates where between 168 and 209 million euros per year in the METIS 1: Mainstreaming RES study [1], whereas in the Smarten study [2], they amounted to 2.700 million euros in savings per year. The difference would be due to the low CAPEX for flexibility assumed by Smarten, which is hundreds of times lower than in METIS 1: Mainstreaming RES, and thus, it would incentivize much more the adoption of flexibility than its counterpart. These annual investment savings only consider CAPEX. OPEX is to be considered separately

Our analysis concerning RES curtailment in SmartEn [2] concluded that DSF results in renewable energy curtailment being reduced by 61%, which amounts to a 15,5 TWh reduction. In the scenario considering all types of load shifting available in the METIS 2 S1 study [3] (traditional load shifting and EV load shifting) simultaneously, generation curtailment is reduced by DSF in 2,7 TWh.

Furthermore, we have discussed the carbon emission savings achieved by DER flexibility implementation. Three studies include quantitative information on these emission savings.

The Eurelectric study [5] provides a annual savings in CO_2 emissions between 1,7 & 2,2 billion euros per year, whereas the Smarten study [2]. provides an estimation in between those two values, at 1,9 billion euros per year. On the other hand, the METIS 1: Mainstreaming RES uses a lower cost of CO_2 emissions than the other two studies (27€/tCO_2 vs 30€/tCO_2 in Eurelectric and 53€/tCO_2 in Smarten), which makes the production costs of mid merit technologies such as lignite and coal lower than those of gas, resulting in an increase of CO_2 emissions, with associated costs between 23 and 30 million €.

Finally, additional savings that can be achieved by reducing the amount of energy not served. In the SmartEn study [2], all the non-served energy is avoided in the DSF scenario, while in the Reference scenario the cost of non-served energy amounts to €9 billion approximately (the cost of VLL in this study is 3.500 €/MWh). In the METIS 2 S1 study [3], using all types of load shifting simultaneously results in a load shedding reduction of 2,4 TWh with a cost of load shedding of 20.000€/MWh [10], which translates into 48 billion € in savings. If the same cost of non-served energy as in SmartEn [2] is used, the savings in energy not served achieved in METIS 2 S1 [3] would amount to €8,4 billion, which is 6% less than in SmartEn [2].

As shown above, the business model potential for OneNet flexibility solutions is enormous. Even though the studies quantitative findings are not directly comparable, and the aggregated benefits related to individual services cannot simply be summed up, the ranges of savings provided give a good indication of the large potential for cost reduction that flexibility from DER has. Future research could provide significant added value by analysing the quantitative flexibility benefits in a more comprehensive way. This involves, for example, studying the value of flexibility mobilized for different services individually as well as overall, considering a range of realistic scenarios that appropriately represent the related uncertainties.

4.2. WAY FORWARD

The quantitative analyses here conducted are only providing information produced in previous works. The benefits and costs of the implementation of flexibility solutions through markets for SO services should be properly estimated in the context relevant for this study. Not only this, the allocation of benefits and costs to the main stakeholders involved in the implementation of these solutions should also be investigated to derive a proper reallocation of benefits and costs if needed to engage these stakeholders.

Future works could improve upon several aspects:

- To effectively optimize the use of flexibility across Europe's energy systems, it is essential to develop detailed and representative models of both transmission and distribution networks. These models must accurately reflect the physical constraints and operational realities of the grid, such as line capacities, regional generation patterns, and load distribution. By incorporating these complexities, we can move beyond simplified assumptions and provide more realistic solutions for optimizing grid flexibility. Accounting for the transmission and distribution networks is the only way to accurately quantify the potential cost savings that can be achieved through the use of flexibility in congestion management, and voltage control. Without an in-depth understanding of these networks, the benefits of flexibility cannot be fully realized or measured.

- In addition, it is crucial to gather and incorporate more granular data on the nature and characteristics of demand-side flexibility. This includes specific details such as the temperature ranges for climate control systems, capacity values, charge power and detailed charge profiles of electric vehicle fleets, etc. Unfortunately, some of the analyzed studies lacked specificity in these areas, leading to a gap in understanding how demand-side measures can be effectively utilized to enhance grid flexibility. By addressing these gaps, we can create more robust and actionable strategies for managing Europe's evolving energy landscape.
- Lastly, a comprehensive study that implemented all the identified services simultaneously (use of flexibility for congestion management, balancing services and wholesale markets), would provide more insightful results:
    - As acknowledged in some of the studies, significant synergies emerge when flexibility is utilized across various services. These synergies can amplify overall savings and efficiencies. For instance, utilizing flexibility for balancing services reduces the need for reserve power from dispatchable generation plants, which can lead to lower operational costs and reduced greenhouse gas emissions. At the same time, the use of flexibility for congestion management can reduce the need for curtailment of renewable energy, allowing more clean energy to be integrated into the grid without the need for costly grid upgrades or additional infrastructure.

- Additionally, the more services that can be provided by flexibility, the more flexibility will be used. This increased utilization will directly translate to greater economic benefits for flexibility providers, as their assets can participate in multiple markets and services, thereby increasing their revenue streams.

By exploring these interactions and synergies in a holistic manner, the study would offer valuable insights into the full potential of flexibility in transforming the energy landscape. It would also provide practical recommendations for policy makers, grid operators, and market participants on how to design and implement systems that fully leverage the benefits of flexibility across the board.

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