D9.14 Report on the Foundations for the adoption of new Network Codes 2

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Abstract
New European rules are being developed to shape electricity market design in a way that improves TSO-DSO coordination, makes efficient use of distribution-connected resources, and empowers the smallest network users. This deliverable combines findings and results from INTERRFACE research on demand-side flexibility and interoperability and data access and the INTERRFACE demonstration pilots to identify the need for new European rules and make proposals for their adoption.

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ACER: EU Agency for the Cooperation of Energy Regulators
aFRR: automatic Frequency Restoration Reserves
BESS: Battery Energy Storage System
BRP: Balancing Responsible Party
BSP: Balancing Service Provider
BUC: Business Use Case
CAPEX: Capital Expenditures
CCR: Capacity Calculation Region
CEF: Connecting Europe Facility
CEP: Clean Energy Package
CHP: Combined Heat and Power
DA: Day-ahead
DC NC: Network Code on Demand Connection
DER: Distributed Energy Resources
DG: Distributed Generation
DMM: Data Management Model
DNUT: Dynamic Network Usage Tariff
DSO: Distribution System Operator
ENTSO-E: European Network of Transmission System Operators for Electricity
ESGTF: European Smart Grids Task Force
ESPI: Energy Service Provide Interface
ESO: European Standards Organizations
EV: Electric vehicles
FCR: Frequency Containment Reserves
Fwd: forward (markets)
FWGL: Framework Guideline
FSP: Flexibility Service Provider
GDPR: General Data Protection Regulation
GL: Guideline
IA: Implementing Act
IACMS: Integrated Asset Condition Management System
ICT: Information Communication Technology
ID: intraday
IDN: Intelligent Distribution Nodes
IEGSA: Integrated Pan-European Grid Services Architecture
LEC: Local Energy Community
LL: Lower Level
mFRR: manual Frequency Restoration Reserves
MS: Member States
NC: Network Code
OPEX: Operational Expenditures
P2P: Peer-to-Peer
RCC: Regional Coordination Centre
REC: Renewable Energy Community
SGAM: Smart Grid Architecture Model
SO GL: System Operation Guideline
SP: Service Provider
SUC: System Use Case
TES: Thermal Energy Storage
TCM: Term, Conditions and Methodologies

TSO: Transmission System Operator
UL: Upper Level
VoLA: Value of Lack of Adequacy
VoLL: Value of Lost Load
WTA: Willingness-To-Accept
WTP: Willingness-To-Pay

1 Executive summary

Relevance of this report

The Third Energy Package of 2009 brought the development of detailed European energy market rules through a process of creating eight EU electricity network codes (NC) and guidelines (GL). While their implementation is still ongoing, the Clean Energy for all Europeans Package (CEP) of 2019 defined areas for the potential establishment of new network codes, i.e. a second generation of network codes. The H2020 INTERRFACE project started in January 2019, six months before the publication of Regulation (EU) 2019/943 and Directive (EU) 2019/944 in the Official Journal of the European Union on 14 June 2019. At that time it was not yet known which of the new network code areas would be given priority. The Florence Forum of 17-18 June 2019 and the official network code priority list in Commission Implementing Decision (EU) 2020/1479 brought clarity. The European Commission identified three areas as the most pertinent: demand side response (Art. 59 of Regulation (EU) 2019/943), cybersecurity (Art. 59 of Regulation (EU) 2019/943), and interoperability requirements and procedures for the data (Art. 24 of Directive (EU) 2019/944). While the former two are being developed as new network codes or guidelines, the latter is being developed as implementing acts in accordance with the advisory procedure referred to in Article 68(2) of Directive (EU) 2019/944.

The authorities' priorities provided guidance for our research priorities within the INTERRFACE project. Of the five research domains initially considered as relevant (Schittekatte et al. 2019), two were selected to be developed into fully-fledged INTERRFACE research streams as presented in this report:

- Demand-side flexibility in line with Art. 59 of Regulation (EU) 2019/943, and
- Interoperability and data access in line with Art. 24 of Directive (EU) 2019/944.

Over the past three years, the COVID-19 pandemic, the economic recovery and, especially, the invasion of the Russian Federation in Ukraine have brought turmoil to the energy sector and previously unknown excessive (extremely high) prices on energy markets. In the context of our INTERRFACE research on European rules for electricity markets, we have taken note of the shift in priorities of policymakers and regulators towards finding short-term measures to tackle the crises and long-term solutions for electricity market (re)design. This included a temporary pause of the work on amendments to existing European network codes (e.g. CACM2.0), while indeed continuing the work on developing new European rules, i.e. new European network codes and guidelines and other new acts, for example the implementing acts on interoperability and data access. Accordingly, we have focused our research within INTERRFACE on the development of new European rules.

Purpose

The purpose of this applied research on new rules for European electricity markets was twofold. First, the research aimed to lay some foundations for the adoption of new European rules in the form of network codes or implementing acts. Second, the work aimed to raise awareness among relevant stakeholders and provide valuable input to the public debate on new European rules.

Both the scope of the research and the stakeholder engagement activities were aligned with the level of maturity of the public debate on the respective research stream. The public debate on demand side flexibility had already been more advanced when the Clean Energy Package was published, which is why our contribution to the debate has focused on specific implementation issues. On the contrary, the public debate on interoperability at the time was almost non-existent, which is why we first focused on processing the topic for the wider energy audience and raising awareness of its importance, before we contributed with more detailed input to the ongoing policy and regulatory debate.

METHODOLOGY

To contribute to the discussion around new European rules on demand-side flexibility and interoperability and data access, we have used four different methods, namely desktop research, quantitative modelling, qualitative assessments, and stakeholder interactions.

The applied methods varied slightly between the research streams. Both research streams relied on desktop research, qualitative assessments and stakeholder interactions. The research stream on demand-side flexibility additionally benefited from quantitative modelling.

In our research, we covered different use cases for demand-side flexibility. The research made use of two types of research methods. First, a quantitative approach for assessing the potential of demand-side flexibility in realizing network investment savings was employed. The second approach was a qualitative one based on the INTERRFACE demonstrators' projects results which focus on other use cases for flexibility, mainly congestion management. The research aimed to contribute to the development process of the Framework Guideline (FWGL) on demand response prepared by the EU Agency for the Cooperation of Energy Regulators (ACER) (ACER, 2022b) and the subsequent development of the new network code or guideline on demand response.

The research on interoperability and data access was carried out in sequential steps. In the first step, we explored the fundamentals of interoperability and data access by focusing on two issues related to data exchange provisions in the network codes and other relevant European legislation. We also analysed high-level principles concerning access to the respective data. In the second step, we made an informed contribution to the ongoing policy and regulatory debate surrounding the EU implementing acts on interoperability and data access. In a third step, in the context of energy system integration and the digitalisation of the energy sector, we analysed interoperability frameworks, experiences from other sectors and at the national level, and governance issues and provided a number of policy recommendations. Where relevant, the results of the INTERRFACE demonstrators were considered when formulating proposals for the EU implementing acts on interoperability and data access (EC, 2022a).

Both research streams benefited from numerous stakeholder interactions throughout the course of the INTERRFACE project. The objective was to engage relevant market, academics, and the wider public by means of participating in online debates, webinars and academic conferences, and disseminate the research results through the publication of policy briefs, working papers and technical reports.

Results

DEMAND-SIDE FLEXIBILITY

This report assesses the use of demand-side flexibility for different use cases, mainly network investment deferral, congestion management and balancing services. Such use cases were enabled by the CEP provisions and are of particular relevance for the DSOs' tasks. We map the draft Framework Guideline (ACER, 2022b) based on the performed scoping exercise and we describe the use cases of the different INTERRFACE demonstrators. We then provide insights and policy recommendations for the use of demand-side flexibility from our modelling exercise and the results obtained from the demos.

We developed two bi-level optimization models to integrate demand-side flexibility in distribution network planning. Each proposed model is linked to a different scheme for contracting flexibility, mandatory and voluntary contracting of demand-side flexibility. First, a mandatory explicit demand-side flexibility model is developed with exogenous flexibility pricing, meaning that the DSO sets the flexibility volumes. Second, a model for voluntary demand-side flexibility is developed. The DSO endogenously sets the flexibility price in the upper level, and the consumers offer their flexibility in the lower level. Third, we extend the first model developed to include an enhanced endogenous setting of demand-side flexibility pricing.

A first result relevant to the context of using demand-side flexibility by residential prosumers[1] is on the cost-reflectivity of distribution network tariffs. We find that introducing explicit demand-side flexibility schemes in combination with cost-reflective capacity-based network tariffs leads to higher welfare gains than when combined with partly cost-reflective demand-side flexibility. Well-designed network tariffs incentivize prosumers to invest in PV and battery systems in order to pay lower bills, including the network charges. In turn, explicit demand-side flexibility complements the role of network tariffs on prosumers by curtailing the passive consumers that do not have the DERs to respond to the tariffs. This implies that we cannot avoid redesigning tariffs by using explicit demand-side flexibility. Explicit demand-side flexibility does not fix the imperfection of distribution network tariffs, but rather complements cost-reflective network tariffs. If tariffs are too imperfect, it can become too costly to fix the corresponding behaviour with flexibility contracts applied on passive consumers in addition to prosumers that will not react efficiently in this case.

Further on the results obtained from our modelling task, we focus on a specific type of explicit demand-side flexibility scheme modelled as demand-side connection agreement. They are constrained or non-firm connections between the system operator, TSO or DSO, and a customer, typically a DG owner or a consumer. We investigate first the level of compensation for mandatory demand-side flexibility. The different compensation levels, integrated with steps, show that exogenously setting the correct compensation level is not straightforward. For low compensation levels, passive consumers will be only partly compensated for the electricity load curtailment. However, when the compensation is set at high levels, e.g., at Value of Lost Load (VoLL), it becomes too attractive for prosumers, who initially value electricity consumption at lower levels than passive consumers. Thus, they use their batteries against the system needs to be curtailed more and earn the high compensation, making it difficult for the regulator or the DSO to set the correct level of compensation in the presence of active and passive consumers.

We also investigate voluntary demand-side connection agreement schemes with a focus on the compensation design. We compare uniform and differentiated pricing for voluntary demand-side flexibility. The results show that applying price differentiation leads to higher welfare gains than a uniform one. If applied, prosumers will receive lower compensation than the passive ones, as the DSO anticipates the fact that they can rely on their DER and offers a low differentiated compensation to limit gaming opportunities by the prosumers. Nevertheless, price differentiation can be tricky to apply among residential consumers. On the one hand, it may be difficult for DSOs to distinguish passive and active residential consumers. On the other hand, DSOs may decide on a single price for the sake of simplicity of the participation of small providers in flexibility schemes. We thus investigated the possibility to differentiate between different consumer categories, i.e. commercial and residential consumers, and found that it is opportune and more feasible to do so.

Then we compare two main schemes for contracting demand-side flexibility by the DSO at the planning stage for the resulting welfare gains: a voluntary demand-side connection agreement where consumers offer their flexibility, i.e., load reduction, to the DSO and a mandatory demand-side connection agreement where the DSO sets the flexibility levels, i.e., load curtailment, to be contracted from residential consumers. Load reductions in both schemes are considered to be non-recoverable, i.e., without a rebound effect. We find that mandatory demand-side connection agreements result in higher welfare gains compared to voluntary ones and a lower price for flexibility. Based on our results, the load reductions exerted by the DSO, represent only a tiny fraction of the consumers' annual demand and happen only during non-frequent consumption peaks. Furthermore, the demand reductions do not disrupt the consumers' consumption habits much and do not result in a complete load disconnection. The results suggest that regulators and DSOs should consider introducing a mandatory scheme for demand-side flexibility, i.e., mandatory demand-side connection agreements for their customers. However,

[1] In our research we consider that "prosumers" can invest in solar photovoltaic (PV) and battery systems. They also react to the network tariffs and to the compensation provided by the DSO for curtailing them. In more economic terms, they maximise their respective surpluses or welfare. Passive consumers are those that cannot invest in distributed energy resources, nor do they react to network tariffs or other signals.

mandatory demand-connection agreements entail different levels of flexibility contracting on consumers, creating equity or feasibility issues. They may, therefore, face low public acceptability.

We also analyse a pro-rata constrained mandatory scheme for demand-side contracting between prosumers and passive consumers. This means that when load reduction events take place, all the grid customers will be curtailed similarly. This scheme was investigated as the initial mandatory demand-side flexibility scheme, which was unconstrained, led to an unequal curtailment between the different types of consumers. The results suggest that a pro-rata mandatory demand-side flexibility scheme leads to lower welfare levels than the unconstrained one. However, it is still more beneficial than voluntary contracting and comes with a lower flexibility compensation price per kWh. Moreover, its implementation is more feasible than the unconstrained mandatory scheme due to equity and feasibility reasons.

Regarding the demos results (EMAX and ELJ, 2022; ELE, 2022; LOY and NRGLab, 2022; TUT et al., 2023; UNIVPM, 2022; UPRC, 2022; UPRC and BME, 2023), our scoping exercise shows that most of the demos focus on congestion management and balancing. We analysed the outcome of the demos and select the most relevant ones for the FWGL.

The results of the demos highlight that defining and harmonising product requirements (e.g., minimum capacity, response time etc.) is key. Due to the multitude of technologies it has been recognized that product definition is a difficult but feasible task. Flexibility products need sufficient alignment with the currently existing products, i.e., balancing products. The INTERRFACE roadmap (ENTSO-E, 2022) highlights that such alignment can be reached by adding resource information to current products and integrating them into the processes of Integrated Pan-European Grid Services Architecture (IEGSA).

The demonstrators' results also highlight the role of network and market data in handling both flexibility needs and constraints in the electricity network. Flexibility Service Providers (FSPs) need transparency regarding the flexibility needs of the system operators in order to build their flexibility portfolio in areas where flexibility needs are the highest (ENTSO-E, 2022). Also, adequate management and exchange of market data supports the efficient allocation of resources and the market-based procurement of system services by system operators. Decisions on data granularity should be carefully taken, however, data that is too granular would make the required data exchange processes heavy.

On the flexibility register[2], the results of the demos suggest the need for a proper management of resources and resources groups through the IEGSA platform. The system must be able to handle modification to the resources that are registered in the flexibility register at any point of the process, i.e. while a bid is submitted to the market, when it has already been accepted for activation, or after the activation when the bid is pending for settlement (ELE, 2022). On a larger scale, the flexibility register should be capable to handle significant number of users while ensuring efficiency and security. Moreover, the INTERRFACE roadmap by ENTSO-E (2022) highlights the need for some degree of alignment with already established flexibility registers (e.g. in Belgium). The roadmap also stresses the need for a proper design of the flexibility register with corresponding roles and responsibilities.

INTEROPERABILITY AND DATA ACCESS

The recast of the Electricity Directive (EU) 2019/944 in the Clean Energy Package entitles the European Commission to adopt implementing acts specifying interoperability requirements and non-discriminatory and transparent procedures for access to metering and consumption data as well as data required for customer switching, demand response and other services. This aims to promote competition in retail markets and to avoid excessive administrative costs for the eligible parties. The development of the first of a series of implementing acts has already started. With the publication of the Fit for 55 Package, the

[2] The Flexibility Register is one of four IEGSA components. It manages the flexibility resources and grants them access to specific market products. More information on IEGSA is provided in ENTSO-E (2022).

scope of the debate was expanded to increasingly cover cross-sectoral aspects in light of a future energy system integrated with sectors such as buildings or electromobility.

This report contributes to the debate by analysing existing interoperability experiences within and beyond the electricity sector, including in the context of the INTERRFACE demonstrators, and providing a number of policy recommendations.

To contribute to the policy and regulatory debate surrounding the implementing acts on interoperability and data access, we have analysed interoperability frameworks and existing interoperability experiences in the electricity and healthcare sectors. The key findings are:

- The EU implementing acts on interoperability and data access should be ambitious in addressing the multiple dimensions of interoperability. Different multi-dimensional interoperability frameworks exist. While they agree that full interoperability can only be achieved if all dimensions are addressed, they do not agree on either the number of dimensions or on labelling them. We identified commonalities across the frameworks that need to be addressed to achieve full interoperability of energy services within the EU. These are regulation and policy, business processes, information models, data format and communication protocols, use of standards, and interoperability testing.
- Inspiration can be drawn from existing experience with interoperability in the electricity and the healthcare sectors. The experiences of the North American Green Button initiative with utility customer data and of ENTSO-E with network code requirements for the exchange of market and network data show that different use cases can inspire different solutions. Moreover, experience with interoperability in healthcare is very advanced and can serve as an inspiration for energy, especially regarding interoperability testing and governance.
- Governance is a key issue in achieving interoperability. The existing governance mainly covers stakeholder dialogue and European standardisation. We provided ideas on how to use the EU implementing acts on interoperability and data access to step up these efforts. In addition, we think governance should be extended to include formalisation of best practices, implementation monitoring and reporting, and interoperability testing. We reflected that this governance could be taken on by a new EU entity.

To contribute to the policy and regulatory debate around cross-sectoral interoperability in the context of a future energy system integrated with sectors such as buildings and electro mobility, we have analysed experiences in different ecosystems (smart electricity metering, electromobility and buildings), different sectors (smart electricity metering, healthcare and public administration) and at the national level (The Netherlands, and the UK). The key related findings are:

- The definition of interoperability depends on the context and reflects a narrow (at the level of devices and systems) or broad (at the level of organisations) perspective. The elements included in a definition give an indication as to open interoperability issues in a specific sector or ecosystem. We recommend broadening the definition of interoperability that is used for smart electricity metering. The new definition should consider the multiple levels of interoperability and acknowledge the interoperability of devices as prerequisite for the interoperability of organisations.
- Despite differences in the specific interoperability issues a sector faces, the solutions applied at EU level are often similar across various sectors. More advanced sectors such as healthcare and public administration can serve as a basis for the further development of interoperability solutions for smart electricity metering. One example is to set up an EU monitoring and reporting scheme for national interoperability progress in the energy sector, in alignment with the activities conducted under the implementing acts. Another example is to create a scheme for different types of interoperability testing. We did not suggest adopting a copy-paste approach but carefully assessing which interoperability solutions used by existing initiatives in other sectors could be applied in a modified way also in the electricity sector. Previous research has, for example, provided the proof of concept for transferring a methodology to test interoperability from the healthcare to the electricity sector

(Gottschalk et al., 2018). It is clear that more research in this area is needed, including pilots that test adapted solutions from other sectors. We considered that the "interoperability community" created in the framework of Horizon Europe may facilitate the collaboration of relevant initiatives to test and implement interoperability solutions.[3]

- Synergies between sectors should be better exploited to avoid redundant activities and pool the relevant resources and expertise. Inspiration can be drawn from developments at the national level, especially when it comes to cross-sectoral aspects of interoperability. One example is to set up a governance framework for interoperability that covers cross-sectoral and sector-specific aspects, in line with the ongoing EU activities in the context of the Green Deal. Another example is to enhance sector convergence in standardisation to avoid duplication of efforts, for example in the areas of demand response, EV charging and smart appliances.

Some of the elements that we discussed in our research have recently been taken up in one way or another at the EU level. The draft implementing acts published by the European Commission in mid-2022 are taking account of the various interoperability layers (EC, 2022a). They also require the establishment of a common repository of national practices to collect information on national implementation and make it publicly available. It is foreseen that ENTSO-E and the EU DSO Entity take on this task as a shared responsibility and based on the existing responsibilities of the two bodies related to data management and data interoperability. The Digitalisation of Energy Action Plan (EC, 2022b) aims to strengthen stakeholder dialogue through the re-established Smart Energy Expert Group and the newly established Data for Energy Working Group.

We also analysed the results of the INTERRFACE demonstrators with regard to insights relevant for the development of the EU implementing acts on interoperability and data access. The majority of the demos focuses on the provision of services that are not of immanent relevance for the implementing act that is currently under development (i.e. congestion management, frequency and non-frequency ancillary services, network investment deferral). The first implementing act centres around the provision of validated historical and non-validated near-real time metering and consumption data in the context of data sharing services. Demand-side flexibility is likely the focus of a second implementing act on interoperability to be developed in close alignment with the new network code on demand response. However, several inputs from the demos have been identified as relevant for the overall debate on interoperability in the energy sector.

The results of the Italian pilot "DSO and Consumer Alliance" demonstrate the successful integration of multiple smart meters for the benefit of providing congestion management and balancing services to the system operators (UNIVPM, 2022). The demo also highlights the potential for smart meters beyond electricity, an area that deserves more attention in research projects as it can support the twin green and digital transition to a future integrated energy system.

The results of the Bulgarian Pilot "Intelligent Distribution Nodes" demonstrate the usage of an intelligent system including an information hub to leverage the flexibility of a multi-storey building (LOY and NRGLab, 2022). The demo provides insights as to the relevant capabilities of an innovative control system, namely data consolidation, data quality, data integration and data governance. The results of the Bulgarian demo are relevant for the integration of buildings as active participants in the energy system.

The Baltic-Nordic pilot "Single Flexibility Platform" provides insights for a future interoperability implementing act on demand-side flexibility and the implementation of interoperable flexibility market platforms (ELE, 2022). The pilot relies on the IEGSA / Single Flexibility Platform. The capabilities and governance of IEGSA are relevant for the interoperability discussion around future implementing acts on demand response as well as on a common European common data space for energy.

[3] See https://intnet-project.eu/.

2 Introduction

This Section is divided into five parts. Subsection 2.1 considers the relevance of this report in the context of ongoing EU policy and regulatory discussions around new European rules for electricity markets. Subsection 2.2 describes the purpose of the applied research carried out in this deliverable. Subsection 2.3 outlines the methodology applied. Subsection 2.4 provides an overview of the INTERRFACE tasks that were relevant for the research presented in this report. Subsection 2.5 takes account of the publications that resulted from the research as well as the numerous stakeholder interactions and dissemination activities that were carried out to receive well-informed feedback on the research results.

2.1 Relevance of this report

The Third Energy Package of 2009 brought the development of detailed European energy market rules through a process of creating EU network codes and guidelines (henceforth "network codes"). The first generation of network codes that was developed following the adoption of the third energy package included eight electricity network codes and guidelines. While their implementation is still ongoing, the Clean Energy for all Europeans Package (CEP) of 2019 initiated the development of a second generation of network codes.

Article 59 of *Regulation (EU) 2019/943 on the internal market for electricity* describes a number of areas in which binding Commission Regulations may be developed. Some of these areas had already been included in the Third Energy Package and had formed the basis of the first network code generation. Other areas are new and can be considered in a second generation of network codes. At the same time, *Directive (EU) 2019/944 on common rules for the internal market for electricity* of the CEP included a multitude of articles that guided Member States (MS) to innovate in new domains related to the electricity system. The relevant articles set out principles that define the boundaries for the implementation of national regulatory frameworks in these new domains. At the same time these new domains fall within the scope of (new) network code areas identified in the CEP. The general idea is that innovation with regulation at national level, triggered by Directive (EU) 2019/944, can in the longer term serve as inspiration for the development of new network codes at EU level or for amendments to existing ones.

The H2020 INTERRFACE project started in January 2019, six months before the publication of Regulation (EU) 2019/943 and Directive (EU) 2019/944 in the Official Journal of the European Union on 14 June 2019. At that time it was not yet known which of the new network code areas would be given priority.[4] Therefore, in Schittekatte et al. (2019) we conducted a regulatory gap analysis and identified a non-exhaustive list of five relevant research domains in which the CEP allowed for the development of national regulatory frameworks: flexibility mechanisms, consumer data management, framework for aggregators, peer-to-peer and community-based energy trade, and electro mobility.

The Florence Forum of 17-18 June 2019 brought clarity into the process of selecting the most relevant research domains for INTERRFACE.[5] The European Commission reflected on the need for new European acts based on the empowerment in the CEP and identified three areas as the most pertinent: demand side response (Art. 59 of Regulation (EU) 2019/943), cybersecurity (Art. 59 of Regulation (EU) 2019/943), and interoperability requirements and procedures for the data (Art. 24 of Directive (EU) 2019/944). The official priority list published as Commission Implementing Decision (EU) 2020/1479 confirmed this selection. It is important to note that interoperability requirements and procedures for access to data are not developed under the network code framework, but as implementing acts in accordance with the

[4] The development process for network codes foresees the establishment of a priority list by the European Commission (Meeus, 2020). The frequency of establishment changed from annually under the Third Energy Package to every three years under the Clean Energy Package.

[5] The agenda and presentations of the 2019 Florence Forum are publicly accessible at https://ec.europa.eu/info/events/european-electricity-regulatory-forum-florence-forum/meeting-european-electricity-regulatory-forum-florence-2019-jun-17_en (last accessed 15 October 2022).

advisory procedure referred to in Article 68(2) of Directive (EU) 2019/944. Their development has equally been a priority for the European Commission since the publication of the CEP.

The authorities' priorities provided guidance for our research priorities within the INTERRFACE project. Of the five research domains initially considered as relevant in Schittekatte et al. (2019), two were chosen to be developed into fully-fledged INTERRFACE research streams as presented in this report:

- Demand-side flexibility in line with Art. 59 of Regulation (EU) 2019/943, and
- Interoperability and data access in line with Art. 24 of Directive (EU) 2019/944.

Over the past three years, the COVID-19 pandemic, the economic recovery and, especially, the invasion of the Russian Federation in Ukraine have brought turmoil and previously unknown disruption to the energy sector in general and electricity markets in particular. In the context of our INTERRFACE research on European rules for electricity markets, we have taken note of the shift in priorities of policymakers and regulators towards finding short-term measures to tackle the crises and long-term solutions for electricity market (re)design. This included a temporary pause of the work on amendments to existing European network codes, while indeed continuing the work on developing new European rules.[6] Accordingly, we have focused our research within INTERRFACE on the development of new European rules.

2.2 Purpose

The purpose of this applied research on new rules for European electricity markets is twofold. First, the research aims to lay some foundations for the adoption of new European rules in the form of network codes or implementing acts. The combination of findings and results from our research on demand-side flexibility and interoperability and data access on the one hand, and the INTERRFACE demonstration pilots on the other hand, serves to identify the need for new European rules and make proposals for their adoption.

Second, the work aims to provide valuable input to the public debate on electricity network codes at the EU level based on our research and through various stakeholder interactions over the course of the INTERRFACE project. An objective is also to raise awareness among the relevant stakeholders of the challenges posed by the deep transformation of the electricity system to the current framework of European network codes.

Both the scope of the research and the stakeholder engagement activities were aligned with the level of maturity of the public debate on the respective research stream. At the time of publication of the Clean Energy Package, a majority of the actors in the energy sector were already aware of the importance of demand-side flexibility in the future energy system. Both our research and the stakeholder interactions we conducted have therefore focused on how to unlock its potential, and on a number of specific implementation issues. On the contrary, the public debate on interoperability and data access at the time was almost non-existent and discussions on the benefits and challenges of interoperability were held almost entirely among a few technical experts. This is why we first focused on processing the topic for the wider energy audience and raising awareness among the relevant stakeholders, before we contributed with more detailed input to the ongoing policy and regulatory debate.

2.3 Methodology

To contribute to the discussion around new European rules on demand-side flexibility and interoperability and data access, we have used four different methods:

- desktop research,

[6] In the Market European Stakeholders Committee of 14 September 2022, the European Commission orally announced a pause of its formal engagement in the work on the amendments of existing market-related network codes, in particular CACM2.0 and FCA 2.0, until the effects of the current crisis on the European electricity market design will have become clearer.

- quantitative modelling,
- qualitative assessments, and
- stakeholder interactions.

The methods applied vary slightly between the research streams. Both research streams relied on desktop research, qualitative assessments and stakeholder interactions. The research stream demand-side flexibility additionally benefited from quantitative modelling.

The research carried out in Section 4 of this deliverable covers the different use cases for demand-side flexibility. It makes use of two types of research methods. First, a quantitative approach for assessing the potential of demand-side flexibility in realizing network investment savings. This was done by use of optimization models with a bilevel setup where the DSO, as a leader, decides on the network investment levels, the flexibility compensation and the flexibility to be contracted, depending on the scheme. In the lower level we model consumers, that can be residential prosumers or passive consumers[7], as well as commercial ones. Both the DSO and the consumers optimization problems are linked with the cost-recovery constraints through which the DSO sets the capacity-based distribution network tariffs to recover the network investments and the demand-side flexibility costs. The second approach was a qualitative one based on the INTERRFACE demonstrators' results which focus on other use cases for flexibility, mainly congestion management. The use cases applied in the demos were assessed and the results of the most relevant ones for the development of new network codes were identified. Such results, even though established at a small-scale level, can be scalable to a wider level. The research aimed to contribute to the development process of the Framework Guideline on demand response prepared by ACER (2022b) and the subsequent development of the new network code or guideline on demand response.

The research on interoperability and data access in Section 5 of this deliverable was carried out in sequential steps. First, we explored the fundamentals of interoperability and data access by focusing on two issues related to data exchange provisions in the network codes and other relevant European legislation: the level of harmonisation of data exchange and the level of access to data. The Smart Grid Architecture Model (SGAM) served as a generic framework to discuss the level of harmonisation of data exchange processes and the related infrastructure in the European electricity sector relevant for network and market data as well as consumer data. We also analysed high-level principles concerning access to the respective data. Second, we made an informed contribution to the ongoing policy and regulatory debate surrounding the EU implementing acts for interoperability and data access. We analysed interoperability frameworks, experiences from other sectors, and governance issues and formulated recommendations. Third, we explored the topic in the context of the Energy System Integration Strategy (EC, 2021b) and the Digitalisation of Energy Action Plan (EC, 2022b). We went deeper into the analysis of interoperability experiences in other ecosystems, other sectors, and at the national level in selected European countries, and provided a number of policy recommendations. We have also assessed the INTERRFACE demonstrators' results relevant for the new implementing acts on interoperability requirements and access to the data (EC, 2022a).

Both research streams benefited from numerous stakeholder interactions throughout the course of the INTERRFACE project. The objective was to engage relevant market actors (e.g. DSOs, TSOs, aggregators, energy suppliers, power exchanges, energy cooperatives, associations of energy consumers), academics concerned with electricity markets, and the wider public by means of participating in online debates, webinars and academic conferences, and disseminate the research results through the publication of policy briefs, working papers and technical reports. Table 1 in Section 2.5 provides an overview of all relevant activities and publications.

[7] See footnote 1.

2.4 Overview of the INTERRFACE tasks relevant for this deliverable

The results presented in this deliverable stem from three interrelated INTERRFACE tasks led by EUI and have benefited from the interaction with other INTERRFACE tasks and work packages.

Figure 1 shows the interaction between Tasks 2.4, 9.2 and 9.4 led by EUI. Task 2.4. set the regulatory framework for Task 9.4 and provided input to WP3 (Schittekatte et al., 2019). For each research topic, EUI carried out various stakeholder engagement activities in the context of Task 9.2 that informed the research on demand-side flexibility and interoperability and data access carried out in Task 9.4. Relevant results of the INTERRFACE demonstrators inspired the proposals for the adoption of new European rules formulated in this deliverable.

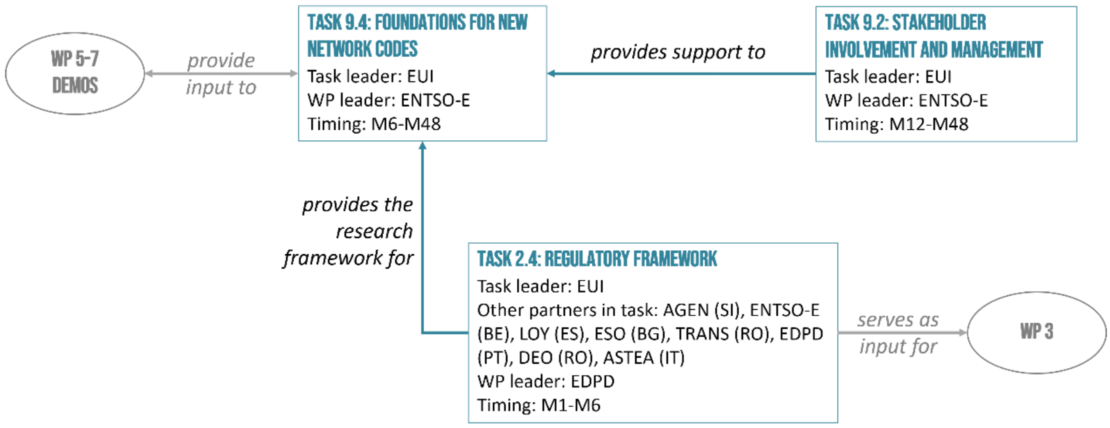

Figure 1: Interrelation of tasks relevant for this deliverable

The interim results of the research presented in Reif et. al (2021) also served as input for the INTERRFACE demonstrators. Demand-side flexibility and, specifically, the regulatory framework for independent aggregation were relevant topics for the INTERRFACE project. Our interim findings could inform those INTERRFACE demonstrators that aimed to unlock (demand-side) flexibility via aggregation, of the implementation of an appropriate regulatory framework for independent aggregation and the relevant practical implementation challenges.

Equally, data exchange, management and interoperability were core topics of the INTERRFACE project and its aim to develop an Integrated Pan-European Grid Services Architecture (IEGSA). Our interim findings on interoperability could inform the development process of the INTERRFACE system architecture design and could also serve as an input for the INTERRFACE demonstrators. More specifically, the analysis of the current status of data exchange and management showed how different software and hardware are currently used to manage data flows in the different parts of the electricity value chain. Also, with increasing system complexity on all levels of grid and market operation, be it transmission or distribution level, wholesale or retail markets, interoperability will become more and more important. This has been recognised some time ago for data exchanges related to TSOs, RSCs and ENTSO-E and is now also on top of the European agenda for data exchanges that directly concern (end)-consumers.

2.5 Overview of the publications, stakeholder interactions and other dissemination activities relevant for this deliverable

During the development of this deliverable there were several interactions with stakeholders that are active in the relevant fields such as from academia, industry associations or private sector. To receive well-informed feedback, the preliminary results were presented in online webinars, closed-door workshops and seminars. Both final and intermediary results were published in working papers, technical reports and academic articles. The authors also made use of the closed-door Policy Advisory Councils regularly organised by the Florence School of Regulation of the European University Institute. Experts represented in these events typically include academics, policymakers, regulators, TSO/DSO representatives, industry representatives, and other stakeholders. Table 1 gives an overview of the relevant publications and stakeholder engagement and other dissemination activities carried out as part of Tasks 2.4, 9.2 and 9.4.

Table 1: Overview of relevant publications and stakeholder engagement and other dissemination activities carried out in Tasks 2.4, 9.2 and 9.4

Type of activity	Details
Research stream "demand-side flexibility"	
Publications	• Nouicer, A., Meeus, L., and Delarue, E., (2023). The economics of explicit demand-side flexibility in distribution grids, ISSN: 1028-3625, Energy Journal, DOI: 10.5547/01956574.44.1.anou. • Nouicer, A., Meeus, L., and Delarue, E., (2023). Demand-side flexibility in distribution grids: Voluntary versus mandatory contracting, Energy Policy, Volume 173, 2023, 113342, ISSN 0301-4215, https://doi.org/10.1016/j.enpol.2022.113342. • Nouicer, A., Meeus, L., and Delarue, E., (2022). A bilevel model for voluntary demand-side flexibility in distribution grids, RSC Working Paper 2022/06. • Nouicer, A., Meeus, L., and Delarue, E., (2022). Demand-side flexibility in distribution grids: voluntary versus mandatory contracting, RSC Working Paper 2022/55. • Nouicer, A., Meeus, L., and Delarue, E., (2020). The economics of explicit demand-side flexibility in distribution grids: the case of mandatory curtailment for a fixed level of compensation. RSCAS Working Paper 2020/45. • Schittekatte, T., Reif, V., and Meeus, L (2021). Welcoming New Entrants into European Electricity Markets. Energies 2021, 14, 4051. DOI: 10.3390/en14134051. • Schittekatte, T., Deschamps, V. and Meeus, L. (2021). The regulatory framework for independent aggregators. The Electricity Journal Vol. 34, Issue 6. 2021 July. • Schittekatte, T., Deschamps, V., and Meeus, L. (2021). The regulatory framework for independent aggregators. EUI Working Papers. RSC 2021/53. • Schittekatte, T. and Meeus, L. (2020). Flexibility markets: Q&A with project pioneers. Utilities Policy, Volume 63, pp. 101017.
Stakeholder engagement and dissemination activities	• Nouicer, Athir., (2022) Distributed resources and flexibility. FSR Topic of the Month. Available at: https://fsr.eui.eu/distributed-resources-and-flexibility/ • Presentation at the Young Energy Economists and Engineers Seminar (May 2022) • Presentation at the ESIM seminar at KU Leuven (March 2022) • FSR Policy Advisory Council (May 2021, closed door event) • Online event "Welcoming new entrants in electricity markets" (Feb 2021). Recording available at: https://fsr.eui.eu/event/welcoming-new-entrants-in-electricity-markets/ • Online event "Enabling flexibility in electricity markets and networks" (Sept 2020). Recording available at https://fsr.eui.eu/how-to-unlock-the-flexibility-potential-in-electricity-systems-a-regulatory-debate/ • Presentation at the Energy Infrastructure Forum organised by the European Commission (23-24 May 2019) • FSR Policy Advisory Council (closed door event, 9 May 2019) • Online debate with representatives of start-ups and innovators (24 April 2019)
Research stream "interoperability and data access"	

Type of activity	Details
Publications	• Reif, V. and Meeus, L. (2022). Smart metering interoperability issues and solutions: Taking inspiration from other ecosystems and sectors. Utilities Policy, Volume 76, 2022, 101360, ISSN 0957-1787, DOI: 10.1016/j.jup.2022.101360. • Reif., V. and Meeus, L. (2021). Smart metering interoperability issues and solutions: taking inspiration from other ecosystems and sectors. EUI RSC Working Papers. 2021/69. • Reif, V. and Meeus, L. (2020). Getting our act together on the EU interoperability acts, FSR Policy Briefs 2020/30. • Schittekatte T., Reif. V. and Meeus, L. (2020). The EU Electricity Network Codes. Chapter 9 Data and Data Exchange. Technical Report.
Stakeholder engagement and dissemination activities	• Online event “Interoperability related to smart metering, electro mobility and buildings under the Green Deal” (June 2021). Recording available at https://fsr.eui.eu/event/interoperability-smart-metering-electro-mobility-and-buildings-under-the-smart-metering/ • Online event “Digitalisation of energy infrastructure and data interoperability: what can we learn from other sectors?” (Jan 2021). Recording available athttps://fsr.eui.eu/event/digitalization-of-energy-infrastructure-and-data-interoperability-what-can-we-learn-from-telecom-and-healthcare/ • Online expert panel in FSR online training on the Evolution of Electricity Markets (November 2020) • Online event “Facilitating interoperability of energy services in Europe” (July 2020). Recording available at https://fsr.eui.eu/event/facilitating-interoperability-of-energy-services-in-europe/ • FSR Policy Advisory Council (May 2020, closed door event) • Online expert panel in FSR online training on the EU network codes (November 2019)

3 Overview of the INTERRFACE demonstration pilots

In this subsection, we provide a brief introduction on the different demonstration pilots and the related use cases. The INTERRFACE project includes seven large-scale demonstrators that cover the electricity networks of Italy, Hungary, Slovenia, Estonia, Finland, Latvia, Bulgaria, Romania, and Greece. The demos are grouped into three areas as is shown in Table 2. Their aim is to test in real-life situations integrated markets and platforms defined and incorporated in the Interoperable pan-European Grid Services Architecture (IEGSA) developed within the project. Table 3 provides an overview of INTERRFACE pilots' business use cases and the main flexibility services addressed.

Table 2: Overview of INTERRFACE demonstration pilots[8]

Demo area	Pilot name	Countries involved
Congestion Management and Balancing Issues	DSO and Consumer Alliance	Italy
	Intelligent Distribution Nodes	Bulgaria
	Single Flexibility Platform	Finland, Estonia, Latvia
Peer-to-peer trading	Asset-enabled TSO-DSO flexibility	Hungary, Slovenia
	Blockchain-based TSO-DSO flexibility	Bulgaria, Romania
Pan-EU clearing market	Spatial Aggregation of local flexibility	Romania
	DERs into Wholesale	Greece, Romania, Bulgaria

Demo area 1: Congestion Management and Balancing Issues

This demo area consists of three pilots. The common aspect of these geographically diverse demos was the development and validation of solutions for improved congestion management and balancing market efficiency based on the innovative IEGSA architecture (TUT et al., 2023).

The **Italian pilot "DSO and Consumer Alliance"** focuses on a centralised energy management system for microgrids. The microgrid has city scale with 35.000 inhabitants and is characterised by a single point of common coupling with the Italian TSO, a high share of renewable generation and a CHP-District Heating network that serves 1000 final users. The aim is to improve the quality of the local DSO network and implement an early-stage demand-response (DR) program to exploit synergies in a municipal scale and multi-energy microgrid. The pilot uses a combination of Electric Energy Storage and demand response involving both large and residential users.

The Italian pilot covers three Business Use Cases (BUCs)[9]:

- **BUC 5.1a "SO-Supplier"** covers the provision of flexibility by means of power production from a programmable DG system (CHP plant). The aim is to provide flexibility in the congestion management – short term planning.
- **BUC 5.1b "LV regulation Power quality"** covers the use of battery storage and a DR program to optimally exploit the local production of renewable energy. The aim is to increase power quality in suburban branches of the LV grid with a high share of renewable energy.
- **BUC 5.1c "Local Energy Community"** covers the exploitation of synergies among energy network in a municipal scale multi energy microgrids in order to maximize the self-consumption of locally

[8] A more detailed description of the INTERRFACE pilots is available in OPEN DEI (2021).

[9] A detailed description of the BUCs is available in TUT et al. (2023) and INTERRFACE Deliverable D3.1, available at http://www.interrface.eu/public-deliverables.

produced renewable energy. The aim is to increase the flexibility of the microgrid in order to reduce the amount of electricity flow back to the TSO.

The **Bulgarian pilot "Intelligent Distribution Nodes"** focuses on an intelligent controller (Intelligent Distribution Node) to be connected at the point of supply of a group of buildings and demonstrate a common set of grid services for DSOs and TSOs but also aiding a Balancing Responsible Party (BRP). The pilot uses a battery energy storage system (BESS) that is operated to provide balancing services, congestion management, and non-frequency ancillary services to TSOs and DSOs. The pilot also introduces a new mechanism for end-user aggregation to provide grid services.

The Bulgarian pilot covers one BUC:

- **BUC 5.2 "Aggregated CM to TSO/DSO; Balancing mFRR to TSO; Non-frequency services to TSO/DSO"** covers the provision of congestion management services to the TSO/DSO by using part of the power/energy capacity of one (or more) Battery Energy Storage Systems installed in multi-user buildings (or group of homes) with PV and particular loads, such as EV and data centers. The aim is to form a controllable aggregated demand resource.

The **Baltic-Nordic pilot "Single Flexibility Platform"** focuses on the cross-border exchange of demand-side and small-scale DER flexibility to create more opportunities for optimal grid management for TSOs and DSOs as well as increased balancing markets for TSOs. The pilot bridges together Estonia, Latvia and Finland through one marketplace that aims to enable the efficient trading of flexibility within the region. It aims to increase the effectiveness of flexibility usage by introducing locational bid information in balancing offers and combine existing products for balancing and frequency management with new products for congestion management. A single market interface is used to enable simultaneous bid offers across markets for different purposes.

The Baltic-Nordic pilot covers six BUCs:

- **BUC 5.3a "mFRR demonstration: Single Flexibility Platform"** covers the provision of mFRR in Estonia, Latvia and Finland. The aim is to integrate MARI and the Single Flexibility Platform in terms of information exchange.
- **BUC 5.3b "aFRR demonstration: Single Flexibility Platform"** covers the provision of aFRR in Estonia, Latvia and Finland.
- **BUC 5.3c "FCR demonstration: Single Flexibility Platform"** covers the provision of FCR in Estonia, Latvia and Finland.
- **BUC 5.3d "Congestion management operational demonstration: Single Flexibility Platform"** covers the use of flexibility with locational information for congestion management by TSOs and DSOs. The aim is to analyse direct activation and coordination mechanisms between TSOs and DSOs to ensure that flexibility bids do not cause congestion in the TSO/DSO grid.
- **BUC 5.3e "Congestion management short-term demonstration: Single Flexibility Platform"** covers the same as above only to solve short-term planning timeframe internal congestions by TSOs and DSOs.
- **BUC 5.3f "Congestion management long-term demonstration: Single Flexibility Platform"** covers the use of flexibility with locational information for congestion management by TSOs and DSOs. The aim is to analyse an envisaged service that may serve network reinforcement deferral, network support during construction and planned maintenance, where location-specific flexibility assets are being activated for shaving or shifting peak demand and production in order to compensate for the lack of network connections, loads or production units.

Demo area 2: Peer-to-Peer Trading

This demo area consists of two pilots.

The **Hungarian-Slovenian pilot "Asset-enabled TSO-DSO flexibility"** focuses on enabling an automated Peer-to-Peer (P2P) marketplace that incentivises the participation of low- and medium-voltage-grid users based on the capabilities of the grids' assets. The functional specification of an automated marketplace for local electricity transactions is developed. Also, the cooperation of this marketplace and an integrated asset condition management system (IACMS) are demonstrated and benefits from the exchange of heterogeneous data with the IACMS are examined. The objective of using these tools is to enable end users to behave as "market participants", use dynamic pricing efficiently, and take into considering the effects of network asset constraints.

The Hungarian-Slovenian pilot covers one BUC:

- **BUC 6.1 "Distribution grid users participating in P2P local market"** covers the enablement of small-scale consumers (households and other low and medium voltage users) and distributed assets to exchange energy in a peer-to-peer manner and simultaneously to participate in (existing) markets. The aim is to support DSOs' congestion management through a smart asset management system that considers the type of asset, their age, condition and, where relevant, sensored parameters.

The **Bulgarian-Romanian pilot "Blockchain-based TSO-DSO flexibility"** focuses on the integration of an intelligent platform with blockchain-based technology, allowing the trading of flexibility services among prosumers at the TSO and DSO levels in a transparent and cost-effective way. The use of a blockchain-enabled procurement process, smart contracts and smart billing allows for greater visibility to market parties. The approach also aims to ensure secure, reliable and transparent cooperating agreements and information sharing exploiting the blockchain's decentralized approach. The pilot aims to simplify the entry of demand response to balancing and other reserve and flexibility markets.

The Bulgarian pilot covers one BUC:

- **BUC 6.2 "Flexibility services for DSO congestion management and allowing more renewable connection without unreasonable DSO network investments"** covers the TSO and some DSO grids in Bulgaria and Romania. The aim is to support DSOs in the organisation of a decentralized local market for distributed resources connected to DSO-grid in order to solve local-grid constraints, aggregate and offer remaining bids to TSO. Multiple services are addressed including congestion management, network reinforcement deferral, and network support during construction and planned maintenance.

Demo area 3: Pan-EU Clearing Market

This demo area consists of two pilots.

The **Romanian pilot "Spatial Aggregation of local flexibility"** focuses on using zonal spatial information to enable local energy usage (flexibility) and solve grid-related constraints at the DSO level. The aim is to introduce spatial dimensions into the existing wholesale market design to enable collaboration between participants of various sizes. Moreover, the pilot aims to adjust the existing EUPHEMIA algorithm to achieve a novel intraday electricity market structure.

The Romanian pilot covers two BUCs:

- **BUC 7.1a "Regional inter-zonal provision of Balancing (FCR, aFRR, mFRR) services in South-East Europe"** focuses on the market design for the regional intra-zonal provision of balancing (FCR, aFRR, mFRR) services in the South-East European power system, including the description of the market clearing algorithm to be developed. It is aimed at the regional integration of balancing markets in order to foster, but not limited to, effective competition, non-discrimination, transparency, new entrants and liquidity while preventing undue distortions.
- **BUC 7.1b "Regional inter-zonal provision of Congestion Management services in South-East Europe"** focuses on the same as above only for congestion management services.

The **Greek-Romanian-Bulgarian pilot “DERs into Wholesale”** focuses on the development of actual and realistic scenarios for integrating wholesale and retail markets, incorporating demand and RES forecasting. The pilot materializes a proposal for promoting DER participation into the wholesale market in an applicable market platform scenario simulator. The aim is to provide clear price signals in market coupling, and to incorporate DERs’ flexibility potential and engage consumers/prosumers in electricity markets.

The Greek-Romanian-Bulgarian pilot covers one BUC:

- **BUC 7.2 “Direct participation of local flexibility on the wholesale market using a single auction-based market platform”** focuses on the introduction of a spatial dimension into the existing wholesale market design, the development of a market tool that facilitates TSO-DSO coordination, and the use of an auction-type market platform that incorporates complex constraints. The aim is to add a spatial dimension to flexibility bids from distributed sources to enable zonal pricing, and connect the local flexibility providers through distribution level aggregation and flexibility usage to the wholesale market and TSO level.

Table 3: Overview of INTERRFACE pilots’ business use cases and the main flexibility services addressed

	5.1a	5.1b	5.1c	5.2	5.3a	5.3b	5.3c	5.3d	5.3e	5.3f	6.1	6.2	7.1a	7.1b	7.2
Congestion Management	X		X	X				X	X	X	X	X		X	X
Balancing services				X	X	X	X						X		
Network investment deferral										X		X			
Non-frequency services (voltage control, power quality …)		X		X											

4 Demand-side flexibility

This section combines our research output on demand-side flexibility with results from the INTERRFACE demonstration pilots. Subsection 4.1 provides the background to this research stream by exploring relevant demand-side flexibility use cases and laying out the policy and regulatory framework for the development of new European rules. Subsection 4.2 includes the research output on demand-side flexibility. Subsection 4.3 assesses the relevance of the demonstration pilots' results for the development of a new European network code.

4.1 Background to this research stream

This subsection puts our research stream on demand-side flexibility into context. We first present the different use cases related to flexibility that exist as well as those that our research has focused on. We then give an overview of the ongoing legislative process at EU level that may lead to the adoption of new European rules on demand-side flexibility.

4.1.1 Demand-side flexibility use cases

Demand-side flexibility benefits are multifaceted and address different use cases. The use cases typically serve different flexibility needs from long-term to short-term. Flexibility provision can be organised through bilateral agreements, e.g., established between the DSO and a grid user, or market-based. Table 4 shows the different use cases for DSOs' use of flexibility and their temporal scope. Some use cases are more relevant for DSOs, such as the investment deferral. Others are more relevant for TSOs in charge of system balancing, while both congestion management and voltage control could be relevant for TSOs and DSOs.

Table 4: Main use cases of flexibility

Temporal needs	**Long-term needs**	**Short-term needs**		
Use cases	Investment deferral	Congestion management	Voltage control	Balancing
Contracting party	DSO	DSO/TSO	DSO/TSO	TSO

In what follows, we first present the flexibility temporal needs of electricity systems. Then, we discuss two flexibility mechanisms that are particularly relevant for demand-side flexibility in distribution networks that are flexibility markets and smart connection agreements.

TEMPORAL NEEDS FOR FLEXIBILITY

In electricity systems, the need for flexibility occurs during all timeframes from the very long-term to short-term/real-time. The system users (generation, demand, storage, and network operators, e.g., SO owned storage or grid reconfiguration) can provide flexibility with different characteristics. Figure 2 shows a non-exhaustive schematization of electricity system technologies provision of flexibility services for different timeframes. In the short term, the common sources of flexibility are short-term market trading or a market participant's own resources. Flexible generation, e.g., gas turbines, pumped hydro, batteries, and demand-side flexibility, are common sources for short-term trading. Underground gas storage can provide seasonal flexibility for gas and for electricity and would be complemented by low-carbon hydrogen and biomethane. Networks, e.g., through the provision of sufficient cross-zonal capacity, can provide flexibility across all timeframes.

To manage the increasing changes occurring in the electricity systems, a combination of these flexibility sources allows for smooth planning and operation of distribution electricity networks in view of the increasing challenges. It should be noted that a combination of efficient network development and operation, energy efficiency as well as an increased sector integration can strengthen the impact of flexible resources or even substitute them (ACER, 2022a).

	Source \ Need	Periods of vRES shortage	Balancing/ congestion management	Stability/ inertia	Voltage control	Reliability/ restoration
Generation	Fossil thermal generation	↓	↓	↓	↓	↓
	Hydrogen power generation	●				○
	Dispatchable RES (hydro, bio)	●	○	○	○	●
	Variable generation		●	●	●	○
Demand	Smart charging EVs/small DSR	○	●	●	○	○
	Large DSR	○	●	●	○	●
Storage	Chemical batteries/V2G		●	●	●	●
	Supercapacitators			○		
	Hydro pumping storage	○	●	●	●	●
	Flywheels			○		
	LAES/CAES, thermal storage	○	○	○		
Coupling	Power-to-hydrogen		●	○	○	
	Power-to-heat		○	○		
Grid	Interconnections (incl. HVDC & conversion stations)	●	●	○	●	○
	Grid flexibilities (power flow, voltage control)		●	●	●	●

↓ Phase-out by 2050 ● Most promising ○ Contributing

Figure 2: Qualitative analysis of flexibility sources potential with respect to current use, source: (ENTSO-E, 2022)

SELECTED FLEXIBILITY MECHANISMS: FLEXIBILITY MARKETS AND SMART CONNECTION AGREEMENTS

The contracting of flexibility for the different use cases can be done via markets or bilateral agreements. For investment deferrals, flexibility markets are complementary options for optimizing network investments for DSOs together with smart connection agreements. For instance, SSEN distribution aims to procure at least 5 GW of flexibility from markets and 3.7 GW flexible connection (or smart connection agreements) by 2028. This would allow saving over £460m in reinforcement costs (SSEN, 2022). Such markets represent a matching platform between DSOs and Flexibility Service Providers (FSPs), for instance, distributed generation (DG) owners, load consumers, storage owners, or aggregators. They allow the competition between FSPs and the possibility for DSOs to acquire flexibility at the most competitive prices.

Smart connection agreements are constrained or non-firm connections between the system operator, TSO or DSO, and a customer, typically a DG owner or a consumer. They consist of a connection to the network that is subject to output/input curtailment of the DG/load customer. Such curtailment would typically take place when there is not enough (distribution) grid capacity to serve the total generation or consumption at a certain moment. This would allow to save on network investments for the system operators and reduce the connection costs for the DG owner or the network tariffs for the consumers. In Europe, system operators, in particular DSOs, and regulators are investigating these new types of grid connections as they can represent a possibility for decreasing network investment and consumers' electricity bills (Furusawa et al., 2019; ENTSO-E et al., 2019). Different studies and reports investigated the benefit of smart connection agreements when considered at the network planning stage (BMWi, 2014a; Enedis & ADEeF, 2017). In Belgium, the electricity and gas regulator VREG indicated that introducing smart connection agreements in distribution networks would always lead to lower social costs if combined with suitable regulatory choices (Beckstedde et al., 2020). Smart connection agreements are being introduced on the demand side, given system operators' needs for network cost reduction, which has an impact on the consumers' bills (CE & VVA Europe, 2016). In fact, connecting new customers, particularly those having variable imports and exports, may result in high network reinforcement costs or long waiting times for connections.

The particular use case of flexibility procurement in flexibility market to defer network investments usually involves a reservation or availability payment, that is, a flexibility price per MW in addition to the activation or utilization payment per MWh. This would allow a flexible capacity from the supply or demand side to be reserved in advance for the settlement period. Such reservation is crucial for the DSO as the investment deferral use case requires the guarantee of the availability of flexibility during the settlement period. Indeed, the network reinforcement cannot occur quickly if the DSO does not find flexibility in a short-term flexibility market.

Also, DSOs procure flexibility on a short-term basis in flexibility markets. The most common use case for DSOs is congestion management (Frontier Economics & ENTSO-E, 2021). It is used, for instance, in Piclo Flex and the NODES-IntraFlex project to procure market-based flexibility services.

A particularity of flexibility markets for short-term and long-term contracting compared to other flexibility schemes is that they reveal the Willingness-To-Accept (WTA) of the FSPs for offering their services to the DSO, generally in a pay-as-bid price formation. The DSOs, in turn, can choose the most convenient offers based on a range of criteria, revealing their Willingness-To-Pay (WTP) for the flexibility needed to defer the network investments (Frontier Economics & ENTSO-E, 2021). Other use cases are voltage control, where Distributed Energy Resources (DERs) connected to the distribution network provide reactive power support, and outage management either for planned or unplanned interruptions.

4.1.2 New European rules for demand-side flexibility

Directive (EU) 2019/944 of the Clean Energy Package called on the Member States to develop regulatory frameworks that incentivize DSOs to consider the use of flexibility as an alternative to network expansion (Nouicer & Meeus, 2019). DSOs will have to develop and publish network development plans that consider the trade-off between flexible resources and network expansion. The CEP also includes demand-side flexibility as a new network code area, recognizing the need to elaborate on a regulatory framework for demand-side flexibility.

DEVELOPMENT PROCESS FOR A NEW NETWORK CODE ON DEMAND RESPONSE

On 1 June 2022, the European Commission asked the ACER to submit non-binding framework guidelines that set out clear and objective principles for the development of a network code on demand response. (EC, 2022c). Such guidelines are the first step in the development process of new network codes and guidelines. They aim to guarantee the consistency with the existing regulatory framework and identify the relevant provisions in the existing network codes and guidelines. Existing provisions may have to be extended or amended in the context of the development of the new rules, i.e. drafting the network code on demand response.

FWGLs are subject to a two-month public consultation as stipulated in Art. 59(5) of the Electricity Regulation (EU) 2019/943. After that, the FWGL is submitted to the EC pursuant to Article 59(6) of the Electricity Regulation (EU) 2019/943. Article 59 lays out the further process: Based on the FWGL, the EU DSO entity in cooperation with ENTSO-E, shall convene a drafting committee to provide support for the development of the network code and submit it to ACER within twelve months. ACER shall then revise the network code and ensure that it is in line with the relevant framework guideline and submit it to the European Commission within six months of the reception. If ENTSO-E or the EU DSO entity fails to develop a network code within the set period of time set, the EC may request ACER to prepare a draft network code based on the framework guideline. ACER may also launch further consultation on the development. The EC may adopt one or more network codes per focus area, on its own initiative, where ENTSO-E or the EU DSO Entity have failed to develop it, or ACER has failed to develop it, or upon proposal of ACER after revising the submitted draft from ENTSO-E or the EU DSO entity. When the EC decides so, it shall consult ACER, ENTSO-E and all relevant stakeholders regarding the draft network code during a period of no less than two months.

For the avoidance of doubt, in this deliverable we consider the draft version of the framework guideline made available by ACER (2022b) for public consultation in June 2022.

CONTENT OF THE DRAFT FRAMEWORK GUIDELINE ON DEMAND RESPONSE

The FWGL is shaped based on the scoping exercise that the EC in 2021 had asked ACER to perform (EC, 2021a). It focuses on market access and market-based provision of flexibility. Its scope goes from the general requirements for access to wholesale markets to the more specific use cases, mainly congestion management and voltage control (Figure 3). FWGLs generally set up high level principles and requirements, clarify terminologies and processes at EU level and can include further requirements for the development of national Term, Conditions and Methodologies (TCMs) to be developed by system operators at national level.

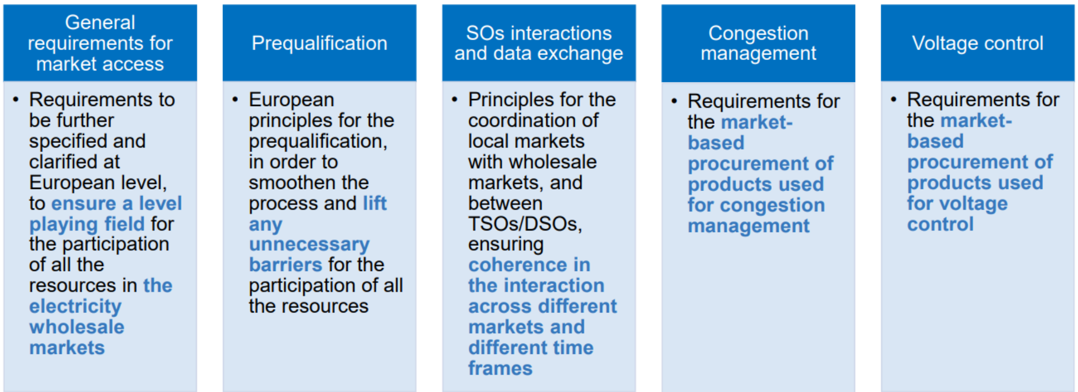

Figure 3: Scope of the FG; source: (ACER, 2022c)

In the network code development process, there should be an assessment the balance between EU harmonization and the freedom of Member States to define rules at national level. In this context and for the development of the FWGL for demand-side flexibility, ACER assesses the cross-border relevance of various requirements and aspects of market access. It also evaluates the need for enhancing competition in markets with cross border interaction while also considering local/regional specificities and the different achievement in terms of the implementation of Directive (EU) 2019/944.

The scope of the FWGL has diverse links with existing regulations. Figure 4 highlights the parts of Regulation (EU) 2019/943 and the existing network codes that are relevant for the FWGL (white boxes). These provisions are either restrictive ones or provisions that should be amended to include requirements for all resources or TSO/DSO coordination. The connection network codes are generally deemed to be out of the scope of the FWGL. However, there are some links with the Network Code on Demand Connection that are limited to the part of service provision of demand response.

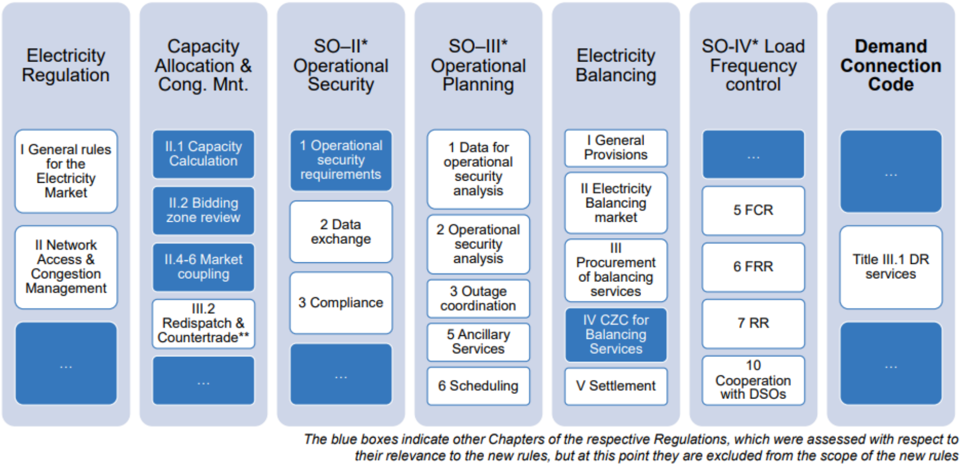

Figure 4: Relevant rules in the existing EU regulations to the FG; source: (ACER, 2022c)

In the development process of the FWGL, in the general requirements for market access are in line with those of the wholesale electricity markets. The importance of the retail part (aggregator/suppliers) is not neglected, and its importance is recognized. However, it is considered to be a national discussion and not included in the FWGL. At this point, the FWGL focuses only on wholesale part, e.g., the access to markets and the market-based provisions of congestion and balancing services.

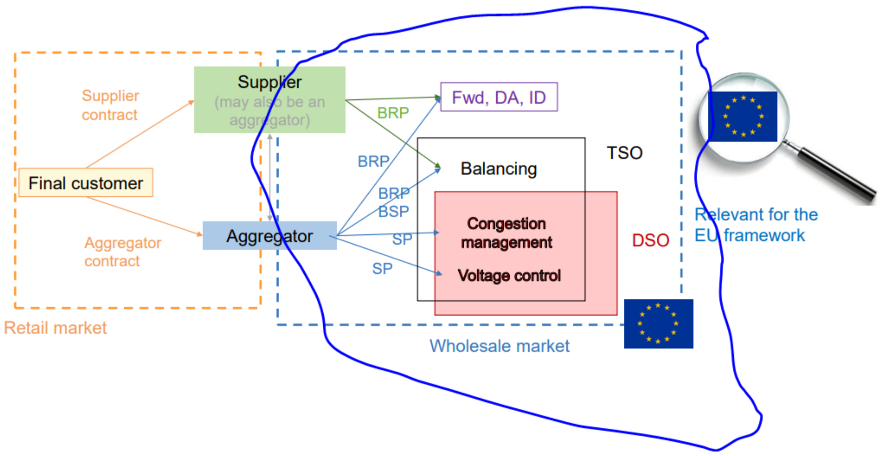

Figure 5: Scope of the FWGL; source: (ACER, 2022c)

The following elements of the FWGL (ACER, 2022b) are considered relevant for the work in this deliverable and are, therefore, described in more detail in the following: aggregation models, prequalification, products and pricing for local SO services, and market design and market interaction.

First, aggregation models. At this stage, no aggregation model is decided at the EU levels for the different Member States. No matter which model is selected for aggregation in each Member State, the calculations of the following values should be clearly indicated in the European rules: final position, allocated volume, imbalance adjustment, imbalance, regardless of the aggregation models. Also, there is no obligation of applying a specific baseline methodology. When a baseline is used, the system operator should follow some general principles regarding transparency and neutrality, i.e., requirements for creating a level playing field. However, further standardization, e.g., deciding on a single baseline methodology, is possible in the future if benefits are demonstrated.

Second, the prequalification process. It is split into a product prequalification and grid prequalification, the latter of which is itself split into in the initial and the bid phase (IAEW, 2020). Currently, there are different proposals to simplify the product prequalification process. It differentiates between standard balancing products and other products. For standard balancing products, since they are harmonized, FWGL propose a unique prequalification process to be adopted by all TSOs with the same timelines. The rules should be more specific than those included in the System Operation Guideline (SO GL) and the Demand Network Code (DC NC), and the FWGL will propose different principles to simplify the process.

For the remaining products (specific balancing products, congestion management and voltage control products), the FWGL proposes by default an ex-post verification process, which could differ depending on the product. This allows for a quick ex-ante administrative process for the qualification of the standard products at national level (settlement accounting, and financial liability) instead of performing a lengthy technical process ex-ante.

ENTSO-E and the EU DSO Entity should propose an EU methodology for further harmonization of national prequalification methodologies. This aims to indicate how national methodologies could further be streamlined.

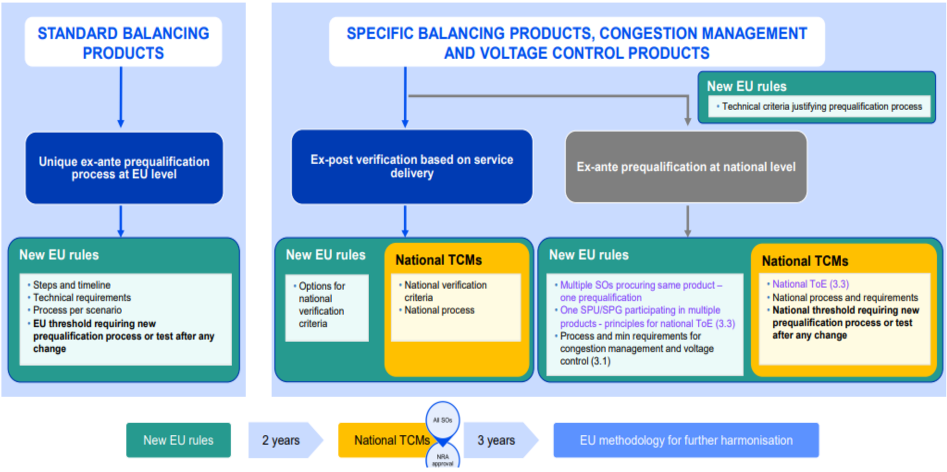

Figure 6: product prequalification processes; source: (ACER, 2022c)

Third, products and pricing for local SO services. The FWGL does not restrict congestion management services much with regards to the contracting time, energy or capacity products. For voltage control, the active power provision is similar to CM (see Figure 7) and therefore is to be market-based, while for the reactive power, it is today rarely procured market-based. The existing EU regulatory framework defines mandatory requirements for the provision of voltage control, thus market-based voltage control is considered not realistic in the short-term. If system operators will need further capacity than the current one, then market-based procurement can become more relevant.

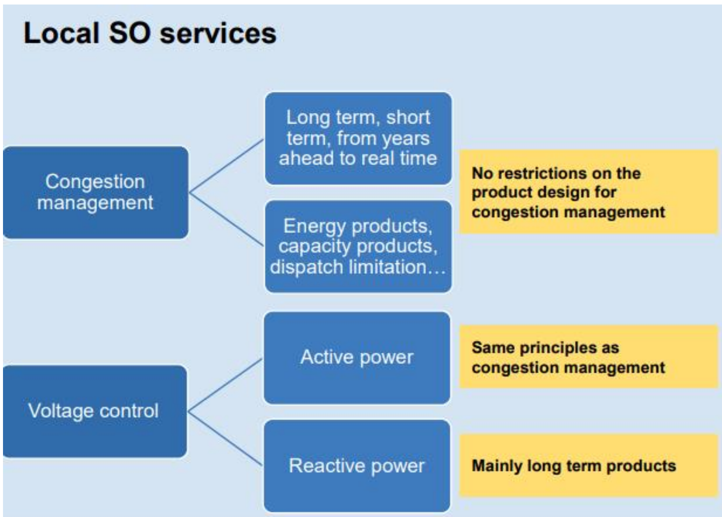

Figure 7: Rules for congestion management and voltage control; source: (ACER, 2022c)

Fourth, market design and market interaction. Based on the initial process of FWGL development, product definition, flexibility pricing and market platform for flexibility services are to be defined at national levels. Thus, their exact features will be defined at national level, developed by system operators and approved by NRAs. The new European rules, as described by the FWGL initial development process, shall also provide principles for interaction of local markets with wholesale markets, such as:

- Minimizing the possibilities of withholding of capacity and for market abuse
- Maximizing liquidity in each electricity market
- Possibility to propose bids that are not procured in one market in another
- System operators shall not unduly distort electricity wholesale markets when procuring flexibility services

4.2 Research output on demand-side flexibility

As described in section 3, the majority of the INTERRFACE demonstration pilots focuses on use cases related to congestion management, balancing and voltage control services. In this subsection 4.2, we first investigate the least represented use case, that is network investment deferral, through the developed optimization models. In subsection 4.3, we then present the demonstrator results for the other use cases.

4.2.1 Modelling framework

The modelling contribution of this report builds on the previous academic works on implicit demand-side flexibility, i.e., distribution network tariffs (Schittekatte et al., 2018; Govaerts et al., 2019; Schittekatte & Meeus, 2020). It develops different bi-level equilibrium models where the DSO, in the Upper Level (UL) of the model, makes the trade-off between investing in the network and using demand-side flexibility, incorporated as demand curtailment, at the planning stage, i.e., as in demand-side connection agreements. In the Lower Level (LL), consumers are modelled. They can be residential or commercial consumers. Residential consumers are split into prosumers who can invest in solar PV and batteries, like commercial consumers, and passive consumers who cannot. The DSO also sets the level of network tariff to recover the network and flexibility costs from the LL. Figure 8 shows the variants of the bilevel optimization models used in this report, where the decision variables change from a model to another.

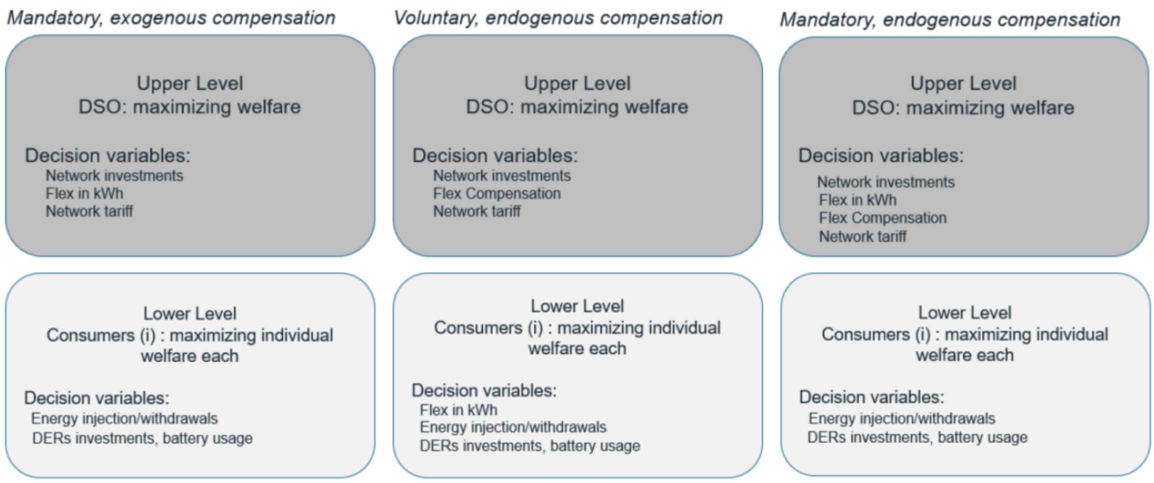

Figure 8: Optimization models' variants used in report, source: (Nouicer, 2022)

In subsection 4.2.2 we use a model for a mandatory scheme for demand-side flexibility with exogenous compensation for flexibility. This means that the DSO decides, at the same time, on the network investment level and on the demand-side flexibility volumes to be contracted. The compensation for flexibility is introduced as a parameter in this model, where different values are integrated in steps. In subsection 4.2.3, we model a voluntary scheme for demand-side flexibility with endogenously set compensation. Compared to the model in subsection 4.2.2, the first modelling difference is that the DSO sets the flexibility compensation as a decision variable of the model. The second one is that the consumers set the volumes of demand-side flexibility they are ready to offer for such a price. Such an approach allows for investigating how consumers respond to the flexibility price signals. It also enables finding the welfare-maximizing flexibility price the DSO sets to attract enough demand-side flexibility to save network investments. In subsection 4.2.4, we compare two contracting schemes for demand-side flexibility: a mandatory scheme with an endogenously set flexibility pricing, which is an extended version of the model applied in subsection 4.2.2, and a voluntary scheme developed in subsection 4.2.3.

In recent years, the application of bi-level equilibrium models to the electricity sector has proven to be very insightful (Gabriel et al., 2013; Dempe, 2002). Bi-level models have also been used to study regulatory issues related to distribution network investments. This started with the debate on distribution tariffs. Several authors used the bi-level set-up to show how consumers react to different types of tariffs, such as fixed, volumetric or capacity-based tariffs, with different levels of locational and spatial granularity. These studies have highlighted the importance of cost-reflective distribution tariffs to align consumers' interests with the system needs (Schittekatte et al., 2018; Govaerts et al., 2019; Schittekatte & Meeus, 2020; Pediaditis et al., 2021; Hoarau & Perez, 2019). The model, developed in subsection 4.2.2, is the first to include the option for the DSO to curtail demand for a fixed compensation in a bi-level set-up. It illustrates how demand-side flexibility and network tariffs could be complementary tools to save unnecessary network investments. However, we only consider a case with residential consumers, and we assumed that the DSO could curtail consumers for an administratively determined compensation. As it might not always be acceptable that the provision of demand-side flexibility is mandatory, we consider, in the following subsections 4.2.3 and 4.2.4 voluntary approach and compare its outcomes. In this voluntary approach, the DSO sets a price, and consumers then respond with the volume of flexibility they are willing to offer at that price. In what follows, we present the bi-level model for the voluntary approach. The model for the mandatory one has been presented in Reif et al. (2021).

The model consists of a stylized game-theoretical optimization model with a bi-level set-up (Gabriel et al., 2013; Dempe & Zemkoho, 2020). In the UL, the DSO, considered as perfectly regulated, maximizes welfare. It decides on the network investment level and the compensation to be offered to consumers to trigger the necessary demand-side flexibility levels. The DSO also sets the magnitude of network tariffs that are predominantly capacity-based to recover the grid investment and flexibility costs. Consumers optimize their individual welfare levels in the LL and voluntarily offer flexibility based on the implicit (network tariffs) and explicit prices signals (market-based flexibility). They can be active and invest in DERs, rooftop solar PV and batteries, or passive with no possibility for such DER investments. Commercial consumers are also able to invest in DERs. The flow chart of the model underlying the proposed approach is shown in Figure 9.

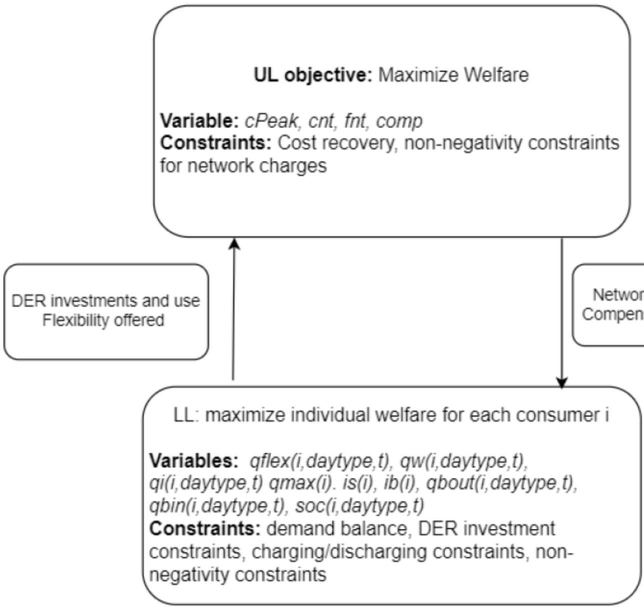

Figure 9: Flowchart for the interaction between the UL and the LL in the voluntary demand-side flexibility model

THE UPPER-LEVEL: THE REGULATED DSO

The UL level optimization problem is a welfare maximization one, based on the decision variables: the compensation for flexibility as an alternative to network investment, $comp$, the magnitude of network tariff, being the capacity-based charge, cnt, and the fixed charge, fnt. The related objective function, Eq. 1, is as follow

Maximizes $Welfare$

$$\text{Max} \quad GrossWelfare - TotalSystemCosts \tag{1}$$

Where:

$$GrossWelfare = \sum_{i=1}^{N} PC_i * \sum_{Daytype=1}^{M} \sum_{t=1}^{T} (D_{i,daytype,t} - qflex_{i,daytype,t}) * VoLL * WDT_{daytype} + FlexibilityRevenue \tag{2}$$

$$FlexibilityRevenue = \sum_{\text{Daytype}=1}^{\text{M}} \sum_{t=1}^{T} \left(comp * qflex_{i,daytype,t}\right) * WDT_{daytype} \tag{3}$$

$$TotalSystemCosts = FlexibilityCosts + GridCosts + EnergyCosts + DERCosts + OtherFixedCosts \tag{4}$$

With

$$EnergyCosts = \sum_{Daytype=1}^{M} \sum_{t=1}^{T} \sum_{i=1}^{N} \left(qw_{t,daytype,i} * EBP_t - qi_{t,daytype,i} * ESP_t\right) * WDT_{daytype} \tag{5}$$

$$DERCosts = \sum_{i=1}^{N} is_i * AICS + ib_i * AICB \tag{6}$$

$$Flexibility\ costs = \sum_{Daytype=1}^{M} \sum_{t=1}^{T} \left(comp * qflex_{i,daytype,t}\right) * WDT_{daytype} \tag{7}$$

$$\text{GridCosts} = \text{IncrGridCosts} * (\text{cPeak}) \tag{8}$$

The $OtherFixedCosts$ are a fixed fee and do not interfere with the optimization process.

The gross welfare is calculated in Eq. 2, which represents the actual electricity consumption, being the original demand ($D_{\mathrm{i,daytype,t}}$) minus the flexibility procured levels ($qflex_{i,daytype,t}$), multiplied by the Value of Lost Load (VoLL) and annualised by the weighting factor, $\mathrm{WDT}_{\mathrm{daytype}}$. $\mathrm{PC_i}$ is the proportion of each type of consumer i. The original demand $D_{\mathrm{i,daytype,t}}$ is indexed by consumer, i, hours of the representative day, t, and type of the representative day, $daytype$.

Eq. 4 represents the total system costs that are the sum of four different elements. The aggregated energy costs are calculated by Eq. 5 where $qw_{t,daytype,i}$ is the electricity quantity withdrawn from the grid and EBP_t is the corresponding withdrawal price, while $qi_{t,daytype,i}$ is the electricity injected in the grid with ESP_t the corresponding injection price.

The DER costs are calculated by Eq. 6 where is_i is the investment in solar PV (in kWp) and ib_i the investment in batteries (in kWh) by consumer i. AICS and AICB are two parameters for annualizing investment costs in solar PV and batteries, respectively.

The flexibility revenue represents the welfare surplus coming from the flexibility sold by all the consumers and is calculated by Eq. 7. It is equal to the aggregated flexibility revenue of Eq.3, and therefore, both terms are cancelled out in the UL objective function. Eq. 8 represents the grid investment costs that are a function of the maximum network coincident utilization peak, $cPeak$, and the parameter, IncrGridCosts, that is the cost of increase/decrease in the coincident peak per kW. It is set at 400 €/kW in the reference scenario.

The $cPeak$, being the maximum of the demand and injection peaks, is calculated via the following equations 9 to 11.

$$cPeak = max\ (cPeakDemand, cPeakInjection) \tag{9}$$

$$cPeakDemand \geq \sum_{i=1}^{N} PC_i * \left(qw_{t,daytype,i} - qi_{t,daytype,i}\right) \quad \forall t, daytype \tag{10}$$

$$cPeakInjection \geq \sum_{i=1}^{N} PC_i * \left(qi_{t,daytype,i} - qw_{t,daytype,i}\right) \quad \forall t, daytype \tag{11}$$

The cost recovery of grid investment and flexibility procurement costs is imposed by the constraint in Eq. 12. The regulated DSO sets the magnitude of the capacity and fixed components of the network tariffs to recover these costs. The variable $qmax_i$ represents the maximum observed capacity of consumer i for withdrawal or injection.

$$\sum_{Daytype=1}^{M} \sum_{t=1}^{T} \sum_{i=1}^{N} PC_i * \left(comp * qflex_{i,daytype,t}\right) * WDT_{daytype} + IncrGridCosts * cPeak = cnt * \sum_{i=1}^{N} PC_i * qmax_i + fnt \tag{12}$$

THE LOWER LEVEL: CONSUMERS

The LL represents the individual consumers' optimization problems. They can be passive or active residential consumers, or commercial consumers in the latter part of the analysis. They react to the implicit price signal set via the DSO through the network tariffs and to the explicit one that is the demand-side flexibility compensation, also set by the DSO, and offer their flexibility in kWh accordingly. Active residential consumers and commercial ones can invest in DERs to maximize their individual welfare and be more independent from the electricity supplied via the grid. They can also choose to invest less in DERs if the set compensation is high enough that the revenues from demand curtailment outweigh the bill reduction benefits of investing in DER.

The LL optimization problem is expressed in Eq. 13 for each consumer:

$$Maximise \quad grossConsumerSurplus_i - costs_i \tag{13}$$

The gross consumer surplus is composed of two components and expressed in Eq. 14: the first corresponds to the value of electricity consumption for each consumer, and the second is the revenue from the flexibility that every consumer gets based on his/her offered levels.

$$grossConsumerSurplus_i = \sum_{Daytype=1}^{M} \sum_{t=1}^{T} (D_{t,,daytype,i} - qflex_{i,daytype,t}) * VoLL * WDT_{daytype} + \sum_{Daytype=1}^{M} \sum_{t=1}^{T} \left(comp * qflex_{i,daytype,t}\right) * WDT_{daytype} \qquad \forall\, i \qquad (14)$$

The second part of the consumers' objective functions is the total costs paid by each one. They are divided into four components, being energy costs, network charges, DER costs, and fixed costs. They are calculated in the following equations 15 to 17.

$$EnergyCost_i = \sum_{Daytype=1}^{M} \sum_{t=1}^{T} \left(qw_{t,daytype,i} * EBP_t - qi_{t,daytype,i} * ESP_t\right) * WDT_{daytype} \qquad \forall\, i \qquad (15)$$

$$Gridcharges_i = cnt * qmax_i + fnt \qquad \forall\, i \qquad (16)$$

$$DERCosts_i = is_i * AICS + ib_i * AICB \qquad \forall\, i \qquad (17)$$

The fixed costs are a set of fees, e.g., VAT and taxes, that does not interfere with the LL optimization problems. The UL and LL remaining constraints

4.2.2 Economics of mandatory demand-side flexibility[10]

In this subsection, a long-term bi-level equilibrium model is developed. In the UL, the DSO optimizes social welfare by deciding the level of investment in the distribution network and/or curtailing consumers. The regulated DSO also sets a network tariff to recover the network and flexibility costs. In the LL, the consumers, active and passive, maximize their own welfare. This subsection addresses the interaction between implicit and explicit incentives for demand-side flexibility and shows that they are complementary regulatory tools, but there are limits. If network tariffs are too imperfect, the resulting consumption profiles can become too expensive to fix with curtailment.[11] The subsection also investigates the issues of compensation and highlights that it is difficult to set an appropriate level of compensation because of the reaction by prosumers.

In this subsection, we first present the role of demand-side flexibility in saving distribution network investments. We then assess its impact on system welfare in order to find the optimal demand-side flexibility level. Next, we investigate the impact of network tariffs and explicit demand-side flexibility compensation. Finally, we assess the role of some context-related elements in the demand-side flexibility framework.

DISTRIBUTION NETWORK INVESTMENT SAVINGS

In a first step, we run our model to assess the savings in distribution network investments that the DSO can realize by adopting different levels of demand-side flexibility. To do this, we calculate the network investment in the case where no flexibility is procured. In steps, we then integrate the different demand-side flexibility levels, which are calculated as percentages of the annual demand. This forces the model to solve for the flexibility levels indicated. Figure 10 shows the network investment savings for different demand-side flexibility levels that are procured. It resembles the BMWI (2014) system expansion savings curve, which focuses on DG curtailment.

[10] This section summarises the main results of (Nouicer et al., 2023a).

[11] In Meeus et al. (2022) we explain that "*most countries have started to reform their distribution tariffs to include components that are partly fixed (to share the costs of past investments that still need to be recovered), and party driven by peaks (to signal the costs of future investments that need to be made to handle peaks).*" And that in previous "*research on the topic, we concluded that tariffs can be significantly improved, but will never be fully cost reflective. Tariffs alone will not enable the full potential of using flexibility to save distribution grid investments*." See Govaerts et al. (2021) and Schittekatte and Meeus (2020). In our INTERRFACE research we show that if tariffs are too imperfect, it can become too costly to fix the corresponding behaviour with flexibility contracts.

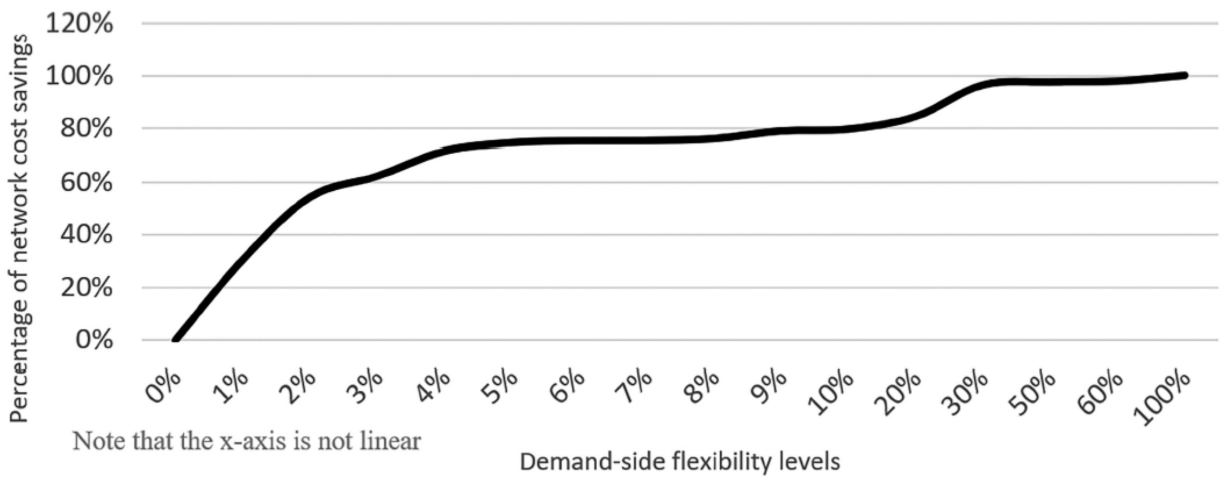

Figure 10: Distribution network investment savings

Network cost savings increase rapidly for demand flexibility volumes below 6 %, and then the curve has a less steep incline. We find that a 3 % level of demand-side flexibility allows 62 % of distribution grid investment savings, and a 5 % level allows 75 %. The flexibility costs are not considered in Figure 10. They are considered as operational expenditures (OPEX), while the savings on grid investment are purely on capital expenditure (CAPEX).

IMPACT ON SYSTEM WELFARE

In a second step, we extend our analysis to look at the system welfare for different demand-side flexibility levels. This encompasses the introduction of gross welfare, which is measured through the VoLL, valuing the socio-economic loss involved in the non-provision of an electricity unit to the consumer (CEPA, 2018a). In addition, the different system costs are considered. The aim is to have a more holistic view of the impact of demand-side flexibility levels on the opportunity costs of electricity consumption and the different associated costs at the system level.

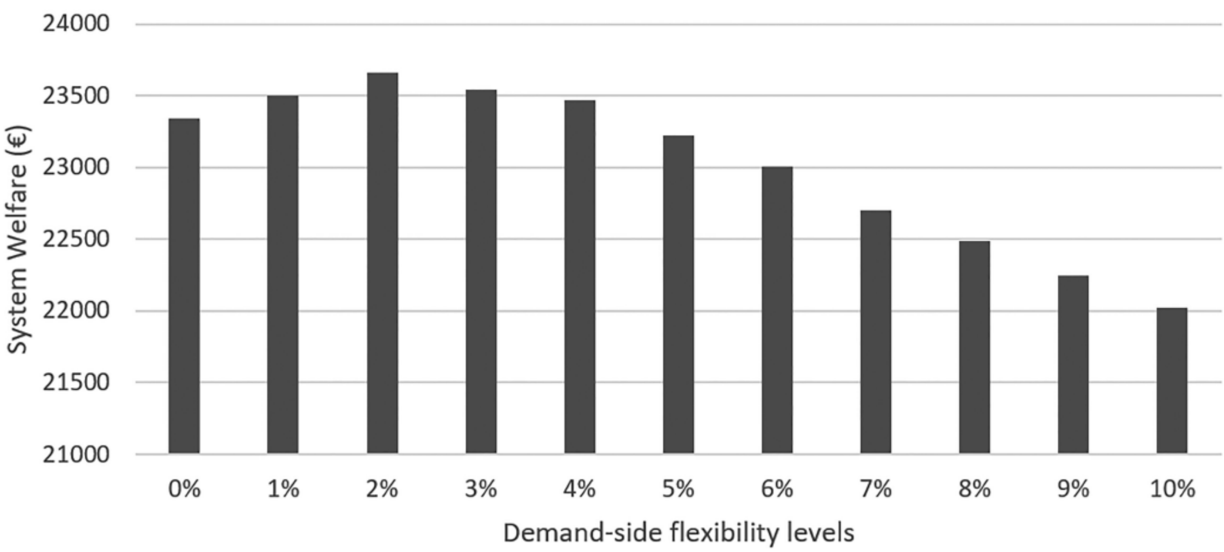

Figure 11: System welfare for different demand-side flexibility levels

As in the previous figure, in Figure 11, we integrate the different demand-side flexibility levels in steps and then plot the system welfare levels. We find that for low levels of demand-side flexibility from 0 % to 2 %, there is an increase in system welfare as demand-side flexibility increases. From 2 % onwards, the system welfare starts to decrease. This means that the optimal demand-side flexibility level is between

1 % and 3 %. The decrease in system welfare for higher demand-side flexibility volumes is driven by two effects: a decrease in gross system welfare and an increase in flexibility costs, and consequently in total system costs.

We then allow the model to decide on the optimal demand-side flexibility level. For the reference scenario, this results in an optimal level of 1.48 % demand-side flexibility and € 23,816 system welfare, normalized to the (average) consumer. This flexibility allows a € 476 annual welfare gain per consumer compared to the case where no demand-side flexibility is introduced. Passive consumers are more curtailed than prosumers, with a 65 %/35 % ratio of the total flexibility volume, as is shown in Figure 12. Note that the passive consumers do not respond to the implicit signals (by definition), so the only way to reach them is with an explicit mechanism. The active consumers do respond to the implicit signals, but even network tariffs that are trying to be cost-reflective will have simplifications that make them slightly imperfect. The imperfection in the reference case is that the tariff is flat rather than dynamic.

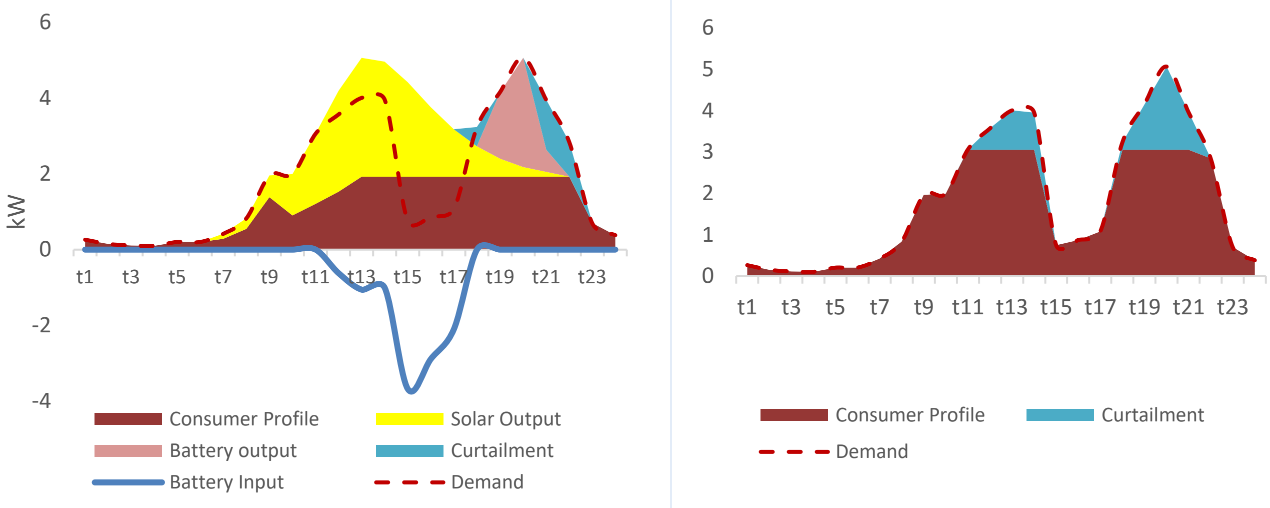

Figure 12: Load profiles for the different types of consumers in the reference scenario: left: prosumers, right: passive consumers

To grasp the underlying contributions of the implicit (network tariffs) and explicit demand-side flexibility, we report, in Table 5, the welfare levels with the different types of demand-side flexibility. First, the table confirms the results of the state-of-the-art literature on network tariffs that argue in favour of more cost-reflective tariffs. By moving from volumetric tariffs to simple capacity tariffs, there is a welfare gain of € 531 per year per consumer in our numerical example. If we then also correct the imperfections of the relatively simple implementation of the capacity tariff by using explicit demand-side flexibility, we gain an additional € 475 per year per consumer. To achieve this system benefit, the average payment to consumers would be € 70 per year per consumer to compensate them for curtailment.

Table 5: Contribution of different types of demand-side flexibility tools

Setting	**Volumetric-based tariffs with no flex**	**Capacity-based tariffs with no flex**	**Capacity-based tariffs with flex** **Reference scenario**
System welfare	22809	23340	23816

The curtailment occurs during the hours when the network is congested. As illustrated in Figure 13, the network is used 100 % in 121 hours during the year that we simulate, and the loading of the line also varies significantly in the other hours.

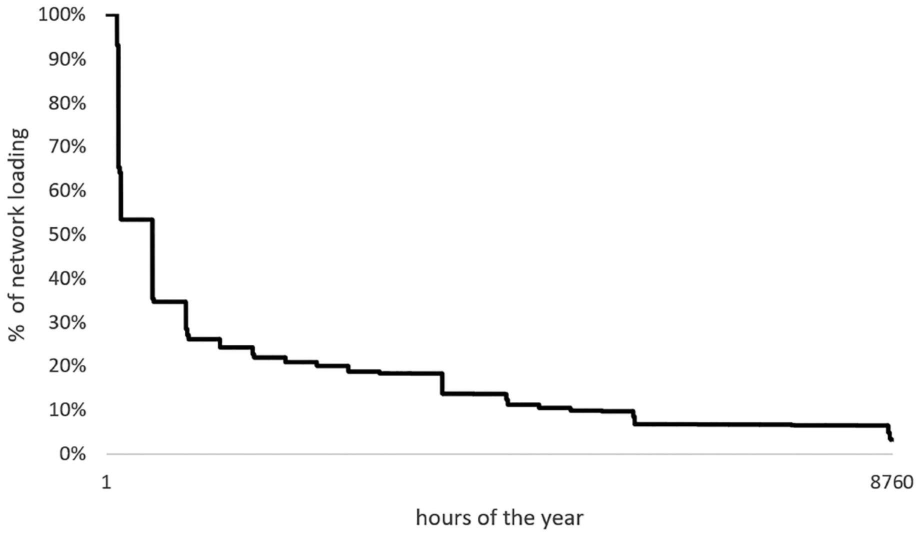

Figure 13: Loading of the network

AN IMPERFECT PROXY FOR NETWORK COST DRIVERS, WF=0.5

In order to assess the interaction with network tariffs in more detail, we introduce an imperfect proxy for the network cost drivers. We consider a weighting factor (WF) equal to 0.5 as proxy for network cost drivers, meaning that a 1 kW reduction in the consumer profile peak contributes to a 0.5 kW reduction in the system peak. This is also equivalent to having heterogeneous demand profiles among consumers that are optimizing their individual profiles. Passey et al. (2017) find that the correlation coefficient between consumer payments under capacity-based tariffs and responsibility for the network peak is very low, at 0.56.

WF can be interpreted as how imperfect the proxy of the network cost driver is. A WF equal to 1 means that the proxy for the network cost driver is very accurate, as in the previous subsection. Under such conditions, the actions of prosumers have a stronger impact on the total grid costs. The lower the WF gets, the more imperfect is the proxy for network cost drivers and the less cost-reflective are the network tariffs. This mean that the action of prosumers to reduce their individual peak demand would not affect the total grid costs much. This is the case when network tariffs incentivize consumers to reduce their demand at a time that does not correspond to the system peak.In this subsection we move from WF=1 to WF=0.5, the optimal demand-side flexibility level drops from 1.48 % to only 0.35 %. The resulting annual welfare gain per consumer drops too, to € 41.8. Figure 14 shows the load profiles of both types of consumers for a *WF* equal to 0.5. If network tariffs are too imperfect, the resulting consumption profiles can become too expensive to fix with curtailment. By increasing curtailment, we also increase the network tariffs that are used to recover the costs from compensation, which increases the imperfect signal from the tariff. It can then become relatively cheaper to invest more in the network. In other words, implicit and explicit incentives for demand-side flexibility are complementary regulatory tools, but there are limits. Explicit demand-side flexibility is not an alternative to tariff reforms, but tariffs will always remain somewhat imperfect, and these imperfections can be remedied with explicit flexibility mechanisms.

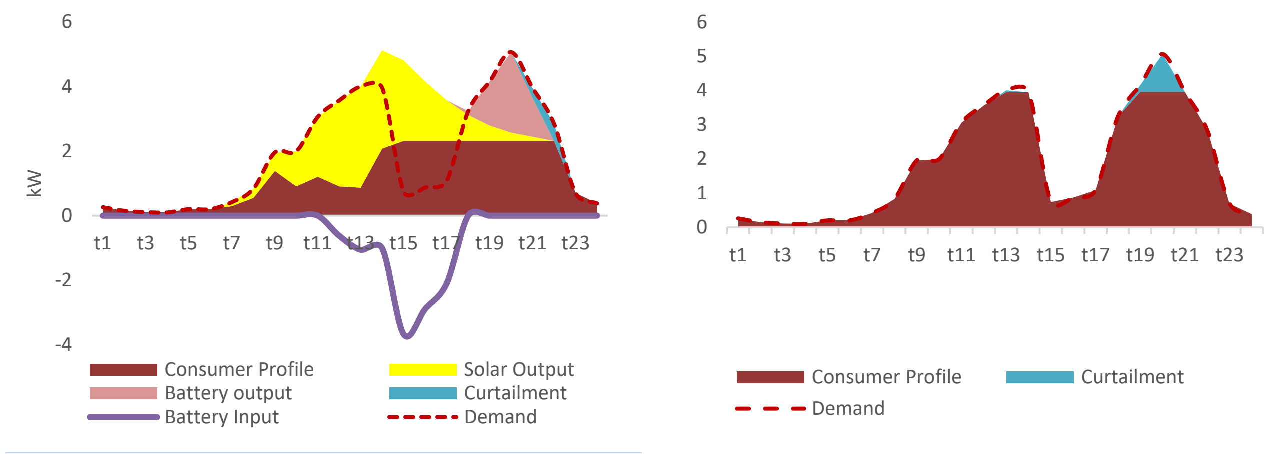

Figure 14: Load profiles for the different types of consumers with WF =0.5, left: prosumers, right: passive consumers

THE ROLE OF PROSUMERS AND DER INVESTMENTS

We further expand our assessment by analysing cases with different prosumers' shares and types. We find that when all consumers are passive, the optimal demand-side flexibility level stands at 1 % while allowing a € 313 welfare gain. With 25 % prosumers, the overall optimal demand-side flexibility remains the same, while there is a higher welfare gain. In the case of 100 % prosumers, on the other hand, the optimal demand-side flexibility level is 0.34 %, allowing only € 124. When only batteries are allowed, there is a lower optimal demand-side flexibility, as the contribution of prosumers is limited. In Table 6, we present the optimal demand-side flexibility levels and the annual welfare gains per consumer for the different cases.

Table 6: Flexibility levels and welfare gains for different shares/types of prosumers

	100% Passive consumers	**25% prosumers / 75% passive consumers**	**50%-50% Reference Scenario**	**50%-50% With only battery systems allowed**	**100% Prosumers**
Flexibility level	1%	1.1%	1.48%	0.54%	0.34%
Welfare (Welfare gain) (€)	23,111 (313)	23393 (338)	23,816 (476)	23411 (381)	23,922 (124)

In the case of 100 % passive consumers, there is no implicit demand-side flexibility that will change consumer behaviours. The DSO procures 1 % of explicit demand-side flexibility. Compared to the reference scenario, the optimal flexibility level is lower. The reason is that, in the reference scenario, the contribution of implicit demand-side flexibility allows more explicit demand-side flexibility, mainly among passive consumers, and leads to more system cost savings. However, with all passive consumers, this difference between profiles is non-existent. For 100 % prosumers, there is 0.34 % explicit demand-side flexibility, which is also lower than in the reference scenario. The rationale behind this is that prosumers are able to flatten their consumption profiles in reaction to the network tariff signals sent by the DSO. However, with an already flattened profile, there is limited room for further welfare gain, considering the effect of the gross consumer welfare loss and the reduction in total system costs. This results in a small welfare gain in the case of 100 % prosumers. For the case of 25 % prosumers and 75 % passive consumers, we find a 1.1 % optimal level of explicit demand-side flexibility while creating more welfare gain than in the case with 100 % passive consumers due to the prosumers' contribution to lowering system costs. The case where only battery systems are allowed may reflect a situation where prosumers have no access to an individual rooftop. There is a lower level of optimal demand-side flexibility, being 0.54 %. Battery systems are used to cover the day peak for the prosumers that used to be covered by solar PV generation.

STRATEGIC BEHAVIOURS AND THE IMPACT OF COMPENSATION LEVELS

Another parameter that is key in the economics of explicit demand-side flexibility in distribution networks is flexibility compensation. In this part, we run the model for different levels of compensation. We set a low compensation, compared to the reference scenario, at € 0.5 and a high compensation equal to the VoLL at € 5.33. Table 7 shows the demand-side flexibility levels and the annual welfare gains per consumer for the different compensation levels.

We see that with low compensation, the optimal flexibility level decreases, as does the welfare gain, as this compensation is too low for passive consumers. It, therefore, decreases the optimal flexibility level and the related welfare gain. For a compensation equal to the VoLL, the optimal flexibility level remains almost the same. However, the welfare gain is reduced compared to the reference scenario. This is due to strategic behaviour by prosumers, which is shown in their load profiles in Figure 15. We explain this further in the next two paragraphs.

Table 7: Flexibility levels and welfare gains for different compensation levels

Compensation	€0.5	€1 Reference scenario	€5.33
Flexibility level	0.8%	1.48%	1.49%
Welfare gain	€239	€476	€152

Compared to the load profile in the reference scenario (in Figure 12(a)), we see in Figure 15(a) that prosumers use their battery output differently. Indeed, at *t20*, which corresponds to the evening peak, prosumers' battery input is 1.7 kW instead of 2.9 kW in the reference scenario. In addition, at *t21*, there is no battery output from prosumers, compared to 0.6 kW in the reference scenario. Therefore, the DSO has to curtail more prosumers, including at the night peak, even though we have a perfect proxy for the network cost drivers. Indeed, with this behaviour, prosumers are more curtailed than passive consumers, with a 65 %/35 % ratio, which is the reverse of the reference scenario.

Another effect that is seen with high compensation is that the prosumer profile has a smaller magnitude in Figure 15(left) than in Figure 12(left). We may think that this is a positive reaction to the perfect proxy for the network cost. However, if we look again at the battery output during and following the night peak, we see that with no or little battery output in these hours, and that there is more curtailment of prosumers.

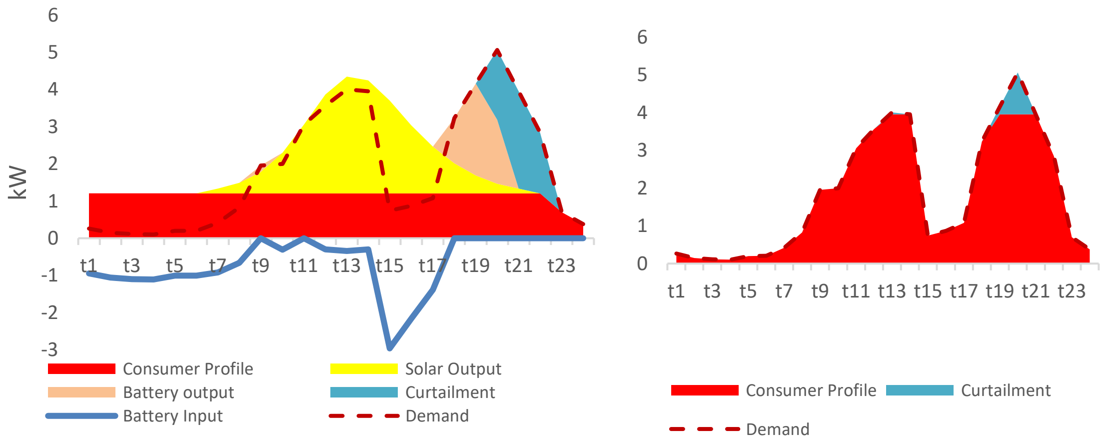

Figure 15: Load profile for the different types of consumers with Comp= €5.33: right: prosumers, left: passive consumers

We may tend to think also that a compensation set at the VoLL will lead to higher welfare gain. However, we find that this does not happen in the case of prosumers as they value electricity consumption less, which leads to them behaving strategically in order to benefit from the relatively high compensation. The rationale behind this is that prosumers and passive consumers value electricity differently. Therefore, the VoLL for prosumers is lower than for passive consumers. Studies on VoLL estimates segment consumers into different groups based on their economic activity, e.g. domestic consumers and industrial consumers (CEPA, 2018a). However, there is no differentiation between active and passive consumers in the VoLL estimations. For instance, ENW (2019) highlights that vulnerable and low-income electricity consumers have higher VoLLs than average. Further effects of the VoLL will be presented in the next section.

SENSITIVITY RESULTS

In the following, a sensitivity analysis is carried out in order to assess the impacts of four context-specific parameters in the demand-side flexibility framework. These parameters are the VoLL, a cap for maximum allowed curtailment, the frequency of critical days and network investment costs. The sensitivity analysis aims to validate the model results and to highlight the extent to which the potential of demand-side flexibility is context-specific.

A. Impact of VoLL levels

In the first sensitivity analysis, we consider two other VoLL values: 2 €/kWh, which is a low VoLL across the EU Member States, and 9.6 €/kWh, which is high.

Table 8: Flexibility levels and welfare gains for different VoLL levels

VoLL	2 €/kWh	5.33 €/kWh Reference scenario	9.6 €/kWh
Flexibility level	4.4%	1.48%	0.2%
Welfare gain	€334.5	€476	€266.4

First, we observe that VoLL levels are inversely proportional to demand-side optimal flexibility levels. For a low VoLL of 2 €/kWh we observe higher levels of demand-side flexibility: 4.4% of the total demand. This is explained by the fact that consumers value electricity consumption less. The lower annual welfare gain per consumer is due to the decrease in gross system welfare caused by higher flexibility levels compared to the reference scenario. In addition, as gross welfare is a product of VoLL multiplication, then a lower VoLL will also lead to lower welfare gain.

Another element that impacts the potential of demand-side flexibility is the notice factor. This translates into whether consumers are notified (e.g., via email or SMS) about the curtailment event or not. According to CEPA (2018), implementing a notice factor reduces the impact of electricity disruption. It also translates into a reduction of VoLL by about 50%, which is then called the value of lack of adequacy (VOLA). Indeed, in the case of Belgium VoLL is equal to 9.6 €/kWh, and VoLA is equal to 5.33 €/kWh. This means that the effect of introducing a notice factor is the same as moving from the third to the second column in Table 8. It, therefore, results in higher optimal demand-side flexibility and, more importantly, higher welfare gains.

B. The impact of a cap on hourly curtailment

For the second sensitivity analysis, we introduce a cap on the maximum allowed curtailment by the DSO applied to consumers being 1.5 kWh for every hour, that translates in the following constraint: $qflex_{i,daytype,t} \leq 1.5\ kWh$. This could be indeed a real constraint faced by the DSO to not include cases with complete consumers' disconnection during network planning.

Table 9: Capped flexibility levels and welfare gains for different VoLL levels

VoLL	2 €/kWh	5.33 €/kWh Reference scenario	9.6 €/kWh

Flexibility level	3.4%	1.1%	0.2%
Welfare gain	€230	€246	€266.4

We find that the total flexibility levels are lower for the case of a VoLL equal to 2 €/kWh and for the reference scenario. This is due to the fact that for those two scenarios, there are a few hours where the curtailment $qflex_{i,daytype,t}$ is higher than 1.5 kWh when no cap constraint is applied. This is also translated into fewer annual welfare gains per consumer from explicit demand-side flexibility than when no flexibility is allowed. For the case where VoLL is equal to 9.6 €/kWh, there is no change in the flexibility level and in the welfare gain. The reason is that with a high VoLL, there is less curtailment, and it did not exceed 1.5 kWh. The higher welfare gain, in this case, is due to higher VoLL values.

C. The impact of the frequency of critical days

For the third sensitivity analysis, we choose frequencies of critical days from 5 to 104 days a year (Table 10). The choice of 104 as the maximum frequency corresponds to the frequency of weekend days a year. This is in order to assess how an optimal flexibility volume interacts with the frequency of critical days, inter alia, when they become as frequent as weekend days.

Critical days are days of the year with higher electricity consumption in the day and evening peaks due, e.g., to critical weather events. The concept of critical days in network planning is analogous to critical peak pricing (CPP) for electricity network tariffs. For instance, in Australia, CCP retail tariff schemes, in combination with network capacity charge, assume 10 to 15 days with extreme demand (Norris et al., 2014). In France, 22 days are considered critical in retail tariffs offers within the TEMPO programme (EDF, 2019), while for demand curtailment, RTE considers 10 to 15 days critical based on weather forecasts (RTE, 2019a).

Table 10: Flexibility levels and welfare gains for different frequencies of critical days

Frequency of critical days	**5**	**15** **Reference scenario**	**104**
Flexibility level	2.1%	1.48%	0%
Welfare gain	€612	€476	€0

We observe that the optimal levels of flexibility are inversely proportional to the frequency of critical days. For low frequencies of critical days, there are higher optimal demand-side flexibility volumes. There are two main reasons behind this observation. First, with low frequencies of critical days, the regulated DSO would need fewer flexibility volumes to reduce the peaks on the critical days. Second, as we increase the frequency of critical days, the total annual demand volume increases. This is natural since the demand during a critical day is higher than on a normal day. Substituting a normal day with a critical one increases the total demand volume. This could be neutralized by reducing the demand on the other normal days. However, we do not change this for practical reasons, as changing the normal day profile may create other unwanted effects. The two above-mentioned effects happen in opposite directions in the two first columns in Table 10. Indeed, for five critical days, there is higher welfare gain and higher optimal levels of flexibility, as it is easier to neutralize the critical day' peaks.

Another observation is that in the case with 104 critical days, meaning that they are as frequent as weekend days, the optimal flexibility level is 0 %. This confirms the fact that the variation in demand profiles between weekdays and weekends does not result in the use of explicit demand-side flexibility during weekends. Weekend days usually have different consumption levels and peaks. For instance, in the Belgian SLP of Synergrid (2019), weekend days have slightly higher peaks. With a high frequency of critical days, higher volumes are needed to reduce peaks to realize system cost savings, as these peaks are very frequent, which in turn will impact gross system welfare. Therefore, it is better to fully build the distribution network and size it to fit the critical day's demand without procuring any flexibility.

D. The impact of network investment costs

Network expansion costs are particularly relevant in DSOs network planning. High network expansion costs can incentivize DSOs to further use demand-side flexibility. In order to assess the impact of this, we consider three scenarios with different incremental network costs, as is shown in Table 11.

Table 11: Flexibility levels and welfare gains for different network expansion costs

Network expansion costs	200€/kW	400 €/kW	600€/kW
Flexibility levels	0.3%	1.48%	3%
Welfare gain	€55	€476	€464

The results confirm that optimal demand-side flexibility volumes increase with higher network expansion costs. With low expansion costs, reinforcing the network is the most logical pathway. Demand-side flexibility of 0.3 % is deemed optimal. This will only allow a € 55 annual welfare gain per consumer. With low network expansion costs, the regulated DSO will naturally favour network reinforcement as it is not costly. Only a very small part of the consumer's demand is curtailed.

For high network expansion costs, the optimal flexibility levels increase. The rationale behind this is that with these high costs, the contribution of demand-side flexibility to system cost savings is more significant. However, the welfare gain is limited due to higher volumes of demand-side flexibility impacting gross system welfare in comparison with the reference scenario.

E. The Impact of uncertainty

Another sensitivity is the information available to the DSO. In practice, the DSO needs to forecast the demand profile of consumers. For simplicity and computation time, we consider two scenarios for the consumers' demand during critical days, with a 50-50 probability of occurrence.

The scenarios differ in the level of the demand peaks during the critical days, i.e., four hours around the daily peak and five hours around the evening peak. The low demand scenario (sc1) has X kWh/h less demand during the peak hours, while the high demand scenario (sc2) has X kWh/h more compared to the reference scenario. This means that when averaging sc1 and sc2, we get the reference scenario.

Figure 16 shows the electricity demand profiles per scenario for X=1kWh/h representing an uncertainty of circa 20% at the highest demand peak. We also run the model for 10% uncertainty, i.e., X= 0.5 kWh/h.

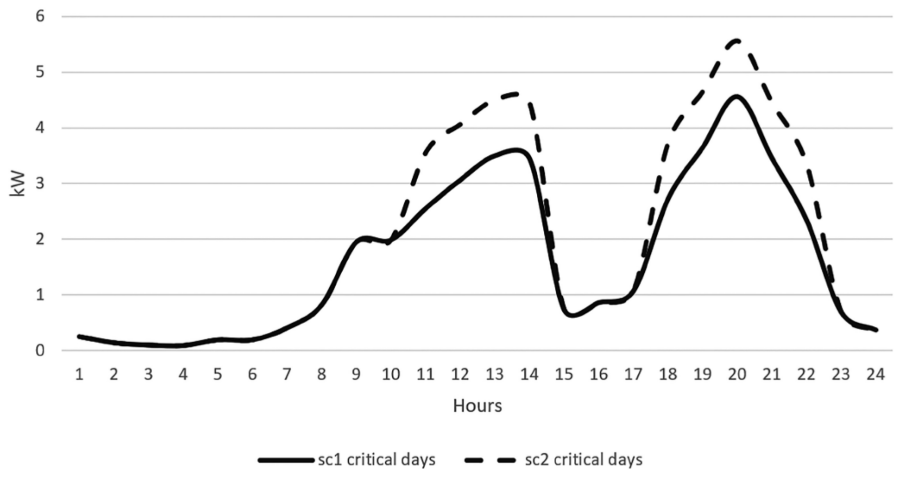

Figure 16: Scenarios for X=1 kWh

We show in Table 12 the resulting optimal flexibility level that is used by the DSO and the resulting reduction in network investment compared to the reference scenario.

Table 12: Impact of uncertainty on DSO's investment and flexibility levels

Uncertainty of the maximum peak	10%	20%
Optimal flexibility level	3%	2.3%
Investment increase	2%	6%

We find that introducing a 10 % uncertainty leads to increased network investment of 2% and an optimal level of explicit demand-side flexibility of 3 %. While for a 20 % uncertainty, the DSO network investment is 6% more than in the reference scenario, and the optimal level of flexibility is 2.3 %.

Therefore, with the introduction of uncertainty, the DSO is more conservative regarding network investment. It considers the worst-case scenario with the highest demand peaks when building the network. Still, the DSO also continues to use flexibility to reduce the need for network investments, even in scenarios with demand uncertainty as high as 20 %.

4.2.3 Voluntary demand-side flexibility[12]

This subsection explores the price setting of voluntary demand-side flexibility, modelled as consumers' voluntary load reduction, in distribution grids. It develops a long-term equilibrium optimization model with a bi-level setting for a voluntary demand-side connection agreement. In the UL, the DSO maximizes welfare by deciding the level of network investments and setting the price for demand-side flexibility. LL's active residential and commercial consumers react to network tariffs and to the price offered for their flexibility by investing in rooftop solar and batteries and offering a certain volume of demand-side flexibility when requested by the DSO. The passive residential consumers also provide flexibility by decreasing their load, but they do not invest in rooftop solar or batteries. This subsection finds that voluntary demand-side flexibility increases welfare and saves significant network investment. The underlying benefits can reach all types of consumers. Besides, it is opportune to apply price differentiation when setting the price for demand-side flexibility between residential and commercial consumers.

In what follows, we first present the impact of different compensation levels for demand-side flexibility on the welfare and the different components of the invoice that consumers pay. We then let the model decide the optimal level of compensation. Subsequently, we look at the optimal under uniform pricing

[12] This section presents the main results of Nouicer et al. (2022a).

and under price discrimination. Finally, we do a sensitivity analysis in which we add a commercial consumer to the system to see how that changes the results.

IMPACT OF DIFFERENT PRICES FOR DEMAND-SIDE FLEXIBILITY

To understand the effects that drive the model towards a welfare-maximizing price for demand-side flexibility, we start by running the model iteratively for different compensation levels. In what follows, we explain what happens with three figures.

First, Figure 17 illustrates the evolution of gross welfare if we gradually increase the price for demand-side flexibility. The figure also illustrates the level of flexibility that is voluntarily offered by the consumers and procured by the DSO at these different prices (the volume of flexibility is expressed as a % of the total volume consumed in a year on the secondary y-axis).

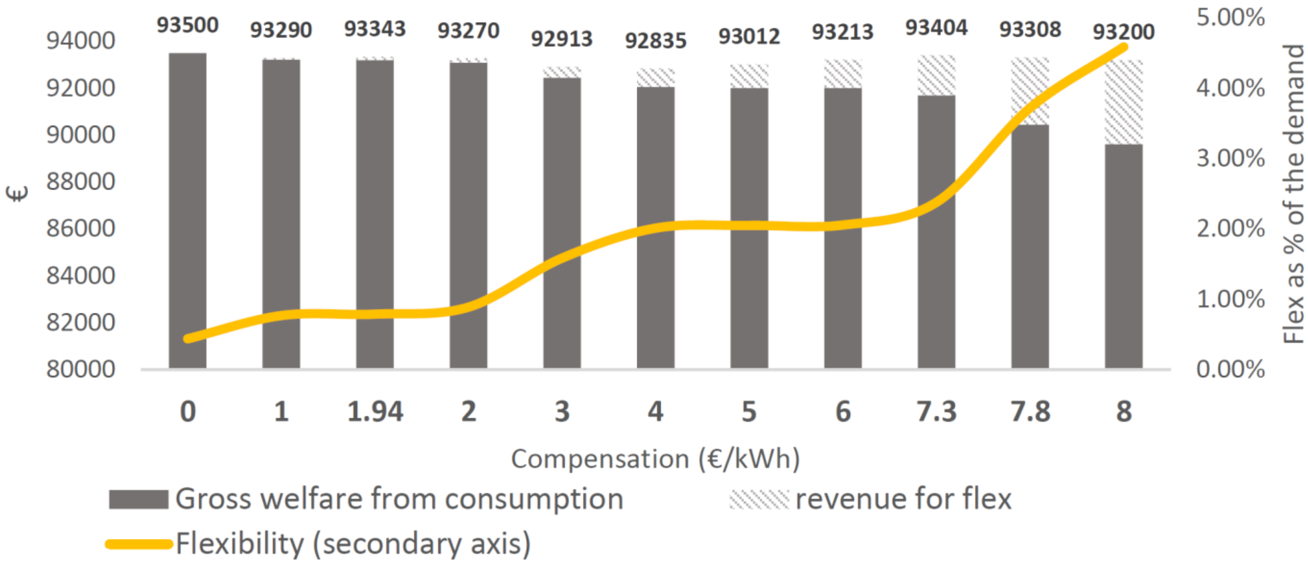

Figure 17: Gross welfare and flexibility offered for different levels of compensation

Second, Figure 18 illustrates the evolution of the invoice that consumers pay if we gradually increase the price for demand-side flexibility. The invoice consists of the energy sourcing costs, network charges, fixed charges, and annualised investment costs in DERs (solar PV and battery systems) minus the income from providing flexibility services.

In Figure 18, we show the level of network charges that are used to recover the network investment on the one hand and to recover flexibility costs on the other hand, in dotted bars and striped bars, respectively. The remaining part of the consumer invoice, being energy sourcing costs, the fixed charges, and the annualised investment costs in DERs, is shown in the dark area of the bars. Just like in the previous figure, this figure also includes the level of flexibility that is voluntarily offered by the consumers and procured by the DSO at these different prices. The figure reminds us that there are many interactions in this model. By offering a higher price for demand-side flexibility, the DSO can save network investments, which can help to lower network charges and increase the revenues consumers get from providing flexibility services. However, the DSO also allocates the costs of procuring flexibility via network tariffs to consumers. Therefore, the consumers' payment for network charges increases for high flexibility prices. The net effect on network charges and the total bill of consumers is positive for low demand-side flexibility prices but becomes negative for higher prices, i.e., higher than 4 € in this case.

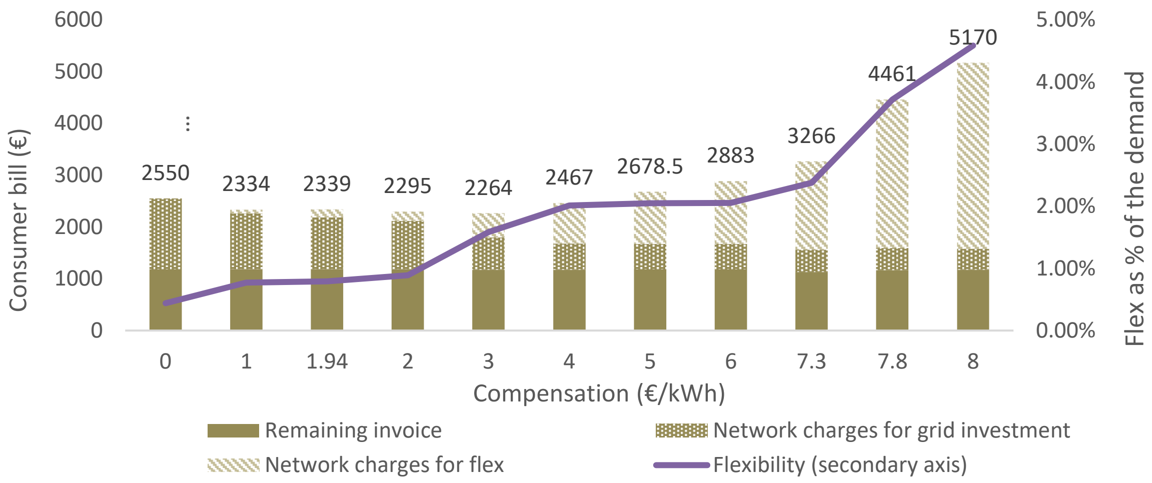

Figure 18: Consumers' aggregated bill (y-axis) for different compensation prices (x-axis)

Third, Figure 19, illustrates the evolution of the net welfare if we gradually increase the price for demand-side flexibility. Note that the welfare is the objective function of the DSO in the UL. What happens with the welfare is, of course, the combination of the above two effects on gross welfare and the total system costs or the (aggregated) invoice for consumers. In the numerical example that we modelled, the welfare-maximizing price for demand-side flexibility is just below 2 €/kWh triggering 0.79 % of voluntarily curtailed demand, as a percentage of their annual demand. This price is uniform for both types of consumers, referred to as uniform pricing for demand-side flexibility. We also notice that for a compensation equal to 0 €/kWh, the system welfare is close to the optimum level (Figure 19). In this case, consumers offer lower levels of demand-side flexibility (0.44%) to reduce network investment and consequently the network charges they pay. These limited levels of flexibility translate into higher gross welfare, without impacting network charges' part used to recover flexibility costs, explaining the close to optimum net system welfare.

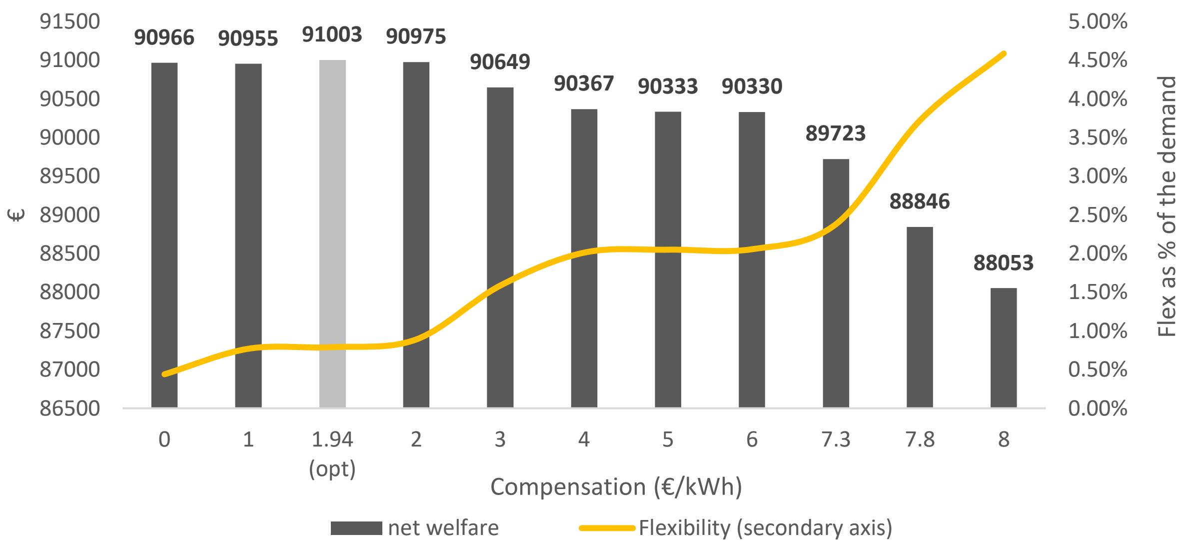

Figure 19: System welfare for different levels of compensation

WELFARE-MAXIMIZING PRICES FOR DEMAND-SIDE FLEXIBILITY: UNIFORM PRICING VERSUS PRICE DIFFERENTIATION

In what follows, we first present the detailed results for using demand-side flexibility under uniform pricing. Then we compare them with the results for price differentiation. Finally, we assess the impact of the pricing approach on the distribution of costs and benefits between the two residential consumer types.

First, Table 13 and Figure 19 show the output of the model under uniform pricing, which means that the passive and active consumers are offered the same price for flexibility services. The welfare-maximizing price for demand-side flexibility is 1.94 €/kWh. This translates into a net welfare of 91003 € with a gross welfare of 93343 €, and costs of 2339 €. The consumers' aggregated revenue for demand-side flexibility, paid by the DSO, is 151 €. The reason why the compensation is set at a level lower than VoLL is the fact that compensation revenues are recovered via network tariffs. When the DSO offers high compensation to consumers, the gross welfare increase, and so do network tariffs levels used to recover flexibility costs to a higher extent (Figure 18). This impacts negatively net welfare (Figure 19). The optimal level of compensation is set in a way that mobilizes the necessary flexibility from consumers to save network investment without heavily increasing network charges and consequently system costs.

With this relatively limited compensation to curtail peak consumption during critical days, the DSO can save up to 50% of the network investments in our example. The active consumer, C1, provides slightly more of the total volume of demand-side flexibility than the passive consumer, C2, (53% versus 47%, for a flexibility revenue of €161.14 versus €142.03). Figure 20 illustrates the impact of the curtailment on the two types of consumers on a critical day. Prosumers invest in DERs (4 kW for solar PV and 6 kWh in batteries) and use their solar PV self-generated electricity to cover their day peak, while they use their battery storage to partly cover their evening peak. The voluntary curtailment happens both at the day and evening peak for the passive consumers. Both consumption peaks are reduced to the same level in our example.

Table 13: Results of the flexibility procurement, C1: prosumer, C2: passive consumer

	No flex	Uniform pricing	
		C1	C2
Welfare (€)	90656	91003	
Flex level	-	0.79%	
Annualised network investment € (per consumer)	2001	1000.25(-50%)	
Compensation (€/kWh)	-	1.94	
Flex offered per consumer		53%	47%
Flex revenue per consumer(€)		161.14	142.03

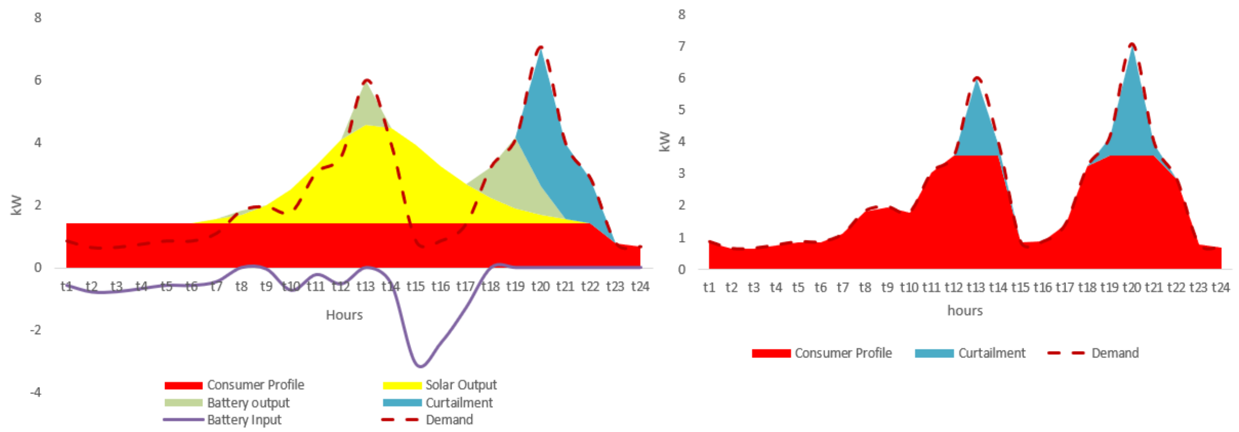

Figure 20: Consumers' load profiles, left: prosumers, right: passive consumers

Second, Table 14 and Figure 21 show the results of the model with price differentiation, which means that the DSO is allowed to offer a different price for the flexibility services of the passive and active consumers. The net welfare of the solution with price differentiation is higher than in the case with uniform pricing. Under uniform pricing, the compensation needed to manage the passive consumers' peaks triggers bad behaviour from the active consumers. The active consumers would be able to manage their own peaks with their PV and battery systems, but they anticipate that they can receive relatively high compensation for curtailment. With price differentiation, the DSO can offer an optimized lower compensation to the active consumers (0,23 €/kWh) than to the passive consumers (2,45 €/kWh). As illustrated in Figure 21, the most visible change is in the way the active consumers operate their batteries.

Table 14: Comparison between a uniform and a differentiated compensation, C1: prosumer, C2: passive consumer

	Uniform		Differentiated	
			C1	C2
Welfare	91003		91037	
Flex level	0.79%		0.55%	
Annualised network investment € (per consumer)	1000.25(-50%)		1199.00 (-46%)	
Compensation (€/kWh)	1.94		0.23	2.45
Flex offered per consumer	53%	47%	32%	68%
Flex revenue per agent (€)	161.14	142.03	7.92	178.27

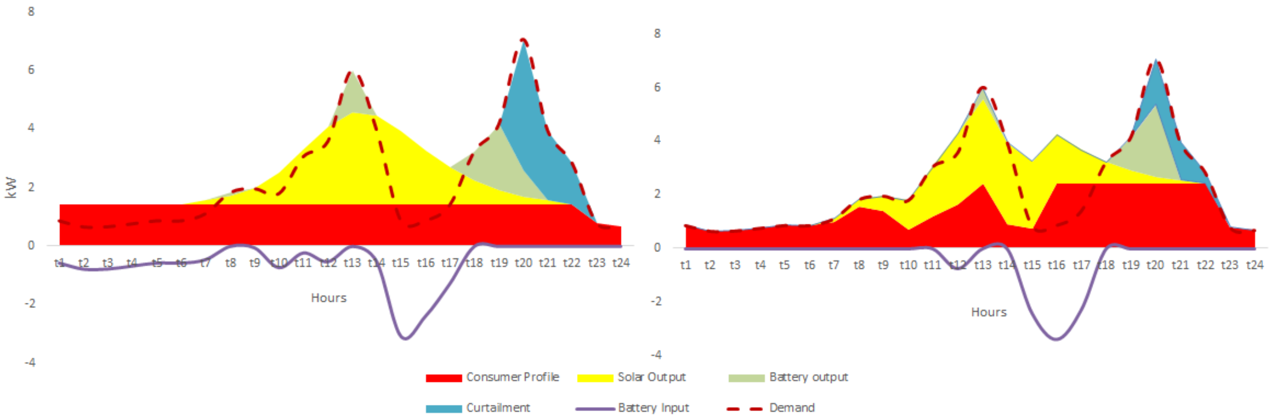

Figure 21: Load profiles for prosumers, left: uniform compensation, right: differentiated compensation

Third, Figure 22 compares the impact of the pricing approach on the distribution of costs and benefits between the two consumer types. The academic literature on network tariffs concluded that cost-reflective distribution tariffs are more efficient, but not necessarily fair, see for instance Schittekatte and Meeus (2020b), which measure fairness as increase in grid charges for passive consumers in comparison with a baseline and Neuteleers et al., 2017. Most of the benefits of cost-reflective tariffs are for the active consumers that invest in PV and battery systems. However, the table below illustrates that demand-side flexibility can help reduce the gap between active and passive consumers. We assess fairness, here, as the change in the relative gap between active and passive consumers invoices compared to the case where no flexibility is contracted. In our example, the gap reduces from 1685 euro to 1206 euro if we introduce demand-side flexibility with uniform pricing, and the gap reduces further to 478 euro if we can apply price differentiation.

Note that this, of course, assumes that we would be able to mobilize passive consumers to participate in these demand-side flexibility schemes that the DSO sets up. We think that this is a reasonable assumption, at least for some of them. Investing in PV and battery is indeed more time and resource-consuming than signing up for a smart connection agreement or other types of demand-side management schemes. Also it could be argued that fairness should be assessed with reference to vulnerable consumers and not all the passive ones. However, we did not include such a consumer category in our model. This could be investigated in future research, especially with the increasing trend of electricity bills over the past year and the relevance of the vulnerable consumers issue.

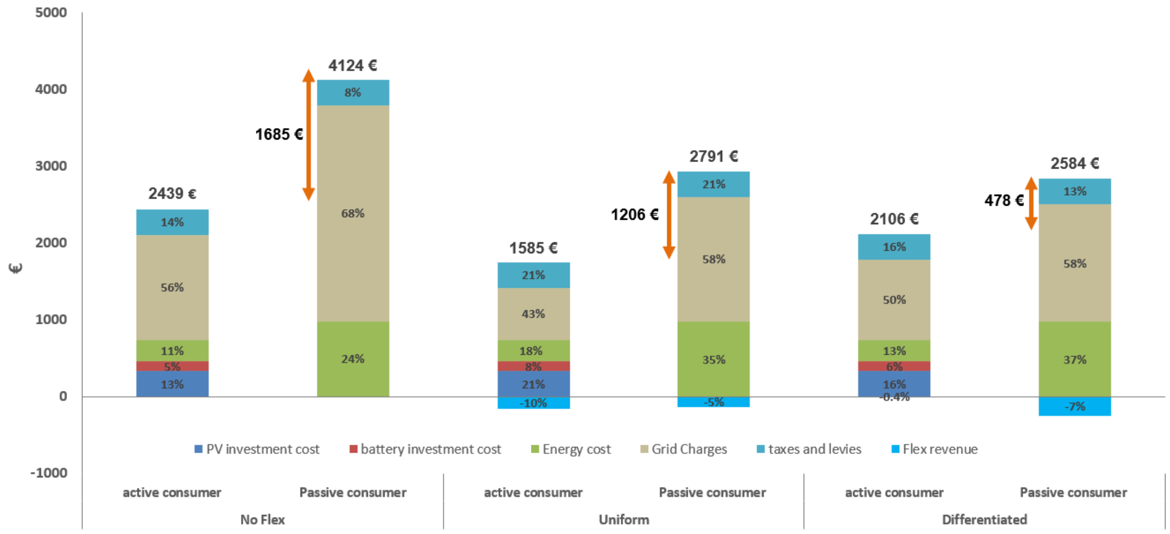

Figure 22: Annualized consumers' expenditures for the different flexibility schemes

SENSITIVITY WITH A COMMERCIAL CONSUMER

Full price differentiation may not be feasible as it is difficult to distinguish between passive and active residential consumers. Also it may be considered discriminatory. In what follows, we present an alternative that may be more feasible: to apply a partial price discrimination for consumers based on their type, meaning that the differentiation is between residential consumers on the one hand and commercial consumers on the other hand. Therefore, we add a third type of consumer to the model, a commercial consumer with a VoLL equal to 3.96 €/kWh. Table 15 reports the results, where C1 refers to prosumers, C2 refers to passive consumers, and C3 refers to commercial consumers. The findings are in line with expectations. The welfare levels for demand-side flexibility with partial price differentiation are better than the results with uniform pricing but worse than with full price differentiation. This could be explained by the fact that the commercial consumer has a different load profile from the residential consumers. The system peak coincides with the residential peak, which is why partial price differentiation is less beneficial than full price differentiation. Note finally that the commercial consumer can game the compensation scheme, similar to the active residential consumer, which is why the price for demand-side flexibility is so low, much lower than the VoLL.

Table 15: Results with residential and commercial consumers, C1: prosumer, C2: passive consumer, C3: commercial consumer

	No flex	Flex with uniform pricing			Flex with full price differentiation			Flex with partial price differentiation		
		C1	C2	C3	C1	C2	C3	C1	C2	C3
Net welfare	75150	75281			75315			75308		

Flex level	-	0.5%			0.3%			0.4%		
Annualised network investment € (per consumer)	1469	849 (-43%)			1017 (-31%)			920 (-38%)		
Compensation (€/kWh)	-	1.4			0.25	1.72	0.1	1.48		0.08
Flex offered per consumer	-	49%	46%	5%	17%	77%	4%	54%	42%	3%
Flex revenue per consumer (€)		109	102	11.8	4.16	125	0.7	101.6	79.42	0.5

4.2.4 Voluntary vs mandatory[13]

This subsection investigates two main schemes for contracting demand-side flexibility by the DSO at the planning stage: a voluntary demand-side connection agreement and a mandatory demand-side connection agreement. A different bilevel equilibrium model is used for each demand connection agreement scheme. In both models, the DSO, in the UL, decides on the flexibility price and network tariffs. Residential consumers react to those signals in the LL. This subsection focuses on some of the regulatory choices impacting the use of flexibility in distribution grids. It highlights that mandatory contracting of flexibility results in higher welfare gains compared to a voluntary one and a lower price for flexibility. However, it may entail some implementation issues for regulators and different curtailment levels among consumers. For regulators, there might be good reasons to introduce a pro-rata-constrained mandatory scheme, curtailing consumers equally. Such schemes are more easily implementable. They result in welfare levels that are still higher than with the voluntary scheme, but relatively lower than in the unconstrained mandatory scheme.

WELFARE LEVELS FOR MANDATORY VERSUS VOLUNTARY DEMAND-SIDE FLEXIBILITY

We start our analysis by comparing the welfare levels achieved when using mandatory demand-side flexibility and voluntary demand-side flexibility. In Figure 23, we show three levels. First, we use as a benchmark the welfare level that is achieved when there is no contracting of explicit demand-side flexibility, meaning that only capacity-based network tariffs are used. Second, we calculate the welfare level achieved with voluntary demand-side flexibility. Third, we report the levels for mandatory unconstrained demand-side flexibility, which means that there are no constraints, at this stage, regarding flexibility volume distribution between the different consumers.

[13] This section presents the main results of (Nouicer et al., 2023b)

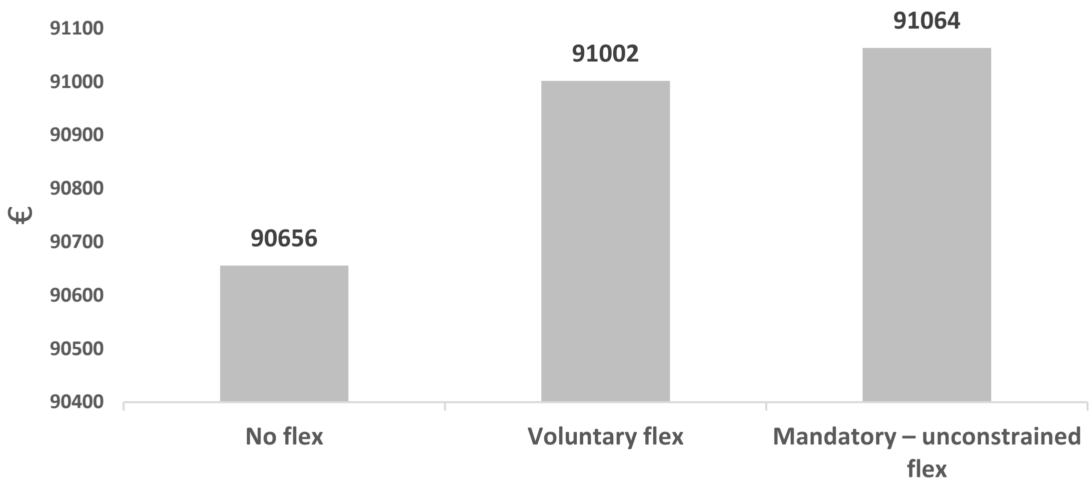

Figure 23: Welfare levels for voluntary and mandatory demand-side flexibility

The first message from Figure 23 is that incorporating explicit demand-side flexibility in distribution grid planning does increase the welfare gains regardless of how it is contracted, either voluntary or mandatory. The DSO contracts demand-side flexibility to save on network investments. Such investments would be very costly if the network is designed to meet the critical days' high demand peaks, which are not so frequent. This is also in line with the existent literature on mandatory flexibility (Tavares & Soares, 2020) and on voluntary flexibility schemes from Spiliotis et al. (2016) and Askeland et al. (2021). Our contribution here is to compare both schemes. We find that unconstrained mandatory demand-side flexibility allows higher welfare gains than voluntary schemes. This is because the DSO has the decision-making power under the mandatory scheme for demand-side flexibility and can more optimally decide on the flexibility levels as well as the flexibility price without the risk of having consumers offering less or more flexibility than needed. We further detail the results in Table 16.

The difference between the welfare levels resulting from the optimisation model is relatively slight. This is due to the relatively high VoLL and annual electricity consumption, which makes the impact of the reduction in total system cost, compared to the gross welfare, small in the total net welfare. However, the differences in total system costs averaged per consumer are more pronounced (see Table 16). These costs represent the annualised total consumer expenditure in energy bills and DER investments, averaged between prosumers and active consumers. Consumers would pay 938€ less per year with a voluntary demand-side connection agreement compared to the case where no explicit demand-side flexibility is used. Under a mandatory unconstrained demand-side connection agreement, they would pay 1128€ less.

Table 16: Results for voluntary versus mandatory demand-side flexibility contracting

	No explicit demand-side flexibility	Voluntary flex	Mandatory flex-unconstrained
Flex level (as % of the annual demand)		0.79%	0.46%
Annualised network investment € (per consumer)	2001	1000(-50%)	1237 (-39%)
Total system costs € (per consumer/ annualised)	3241	2303	2113
Compensation (€/kWh)		1.94	1.4

Under the voluntary demand-side flexibility scheme, the DSO contracts higher levels of flexibility than under the mandatory one (0.79% Vs 0.46%, as a percentage of annual demand). This is also combined with higher prices for the flexibility that are offered to the consumers (1.94 Vs 1.4 €/kWh). Note that the flexibility from the demand-side is only used during the critical days (Figure 25) that occur ten times a year.

The compensation is set to indemnify the consumers for the curtailed demand and discomfort. The resulting compensation levels are lower than the VoLL, included in the UL objective function. Indeed, VoLL is a relevant parameter to inform DSOs on how consumers value the loss of electricity supply, and it can be used as an administrative price to compensate consumers when disconnections occur (CEPA, 2018b). In our model, VoLL signals the value the consumers give to undisrupted electricity supply. The compensation price is calculated endogenously to maximise the welfare. As we impose the recovery of the flexibility as well as network investment costs, all these costs are to be recovered via the network tariffs, as it is applied in 16 Member States (ACER, 2021). This limits the flexibility prices' welfare-maximising levels. Indeed, when forcing the model to set compensation close to VoLL, the capacity-based network charges paid by consumers increase, and so do the consumers' electricity bills (see subsection 4.2.3). In addition, the curtailment levels that occur are limited and do not result in complete load disconnection, which is measured at VoLL. The compensation is set at a level that partly compensates the consumers for the discomfort from the supply disruption without leading to a strong increase in the distribution network tariffs.

The network investments under voluntary demand-side flexibility are lower, but the total systems costs are higher mainly due to higher compensation and over-contracting flexibility. The DSO sets a higher compensation price to spur flexibility from the consumers. To maximise their individual welfares, consumers choose to adapt their consumption profiles and set the level, and the timing of the flexibility offered, based on the signals of capacity-based network tariffs and the flexibility price set by the DSO. In the voluntary scheme, the lower welfare levels are due to imperfect price signals for explicit demand-side flexibility and strategic behaviour from prosumers. The signals sent by network tariffs are not perfect either, as we use flat capacity-based rates instead of dynamic ones. However, network tariff imperfection applies to both schemes, unlike explicit demand-side flexibility, whose levels are decided by different agents in each scheme.

With different types of consumers in the LL, prosumers and passive consumers, the DSO has to set an attractive enough compensation for passive consumers. Typically passive consumers value higher the discomfort linked to the reduction of electricity, as they don't have an alternative to self-produce or store electricity, e.g., solar PV or battery systems.

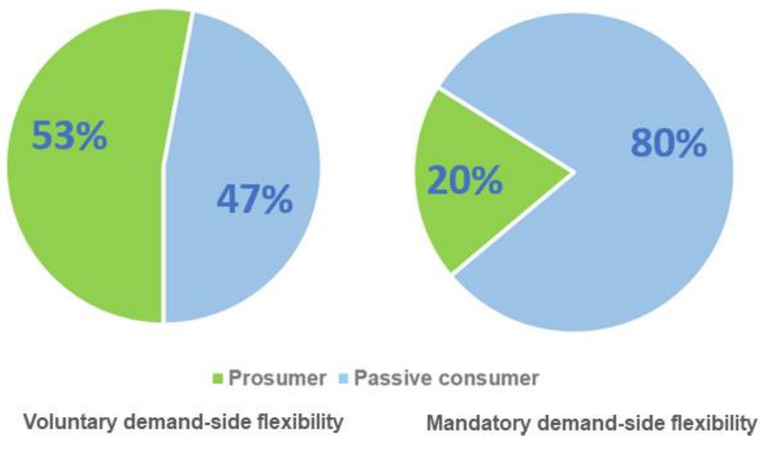

Figure 24: Distribution of flexibility contracting between consumers: left voluntary demand-side flexibility, right: mandatory unconstrained demand-side flexibility

We show, in Figure 24, the distribution of explicit demand-side flexibility contracting between prosumers and passive consumers for voluntary and unconstrained mandatory demand-side flexibility. Prosumers and passive consumers, which are equally represented with a 50%-50% distribution, contract different levels of demand-side flexibility for each scheme. In both schemes, prosumers are strongly incentivised, through the capacity-based network charges, to invest in solar PV (4 kWp per prosumer) and batteries (6 kWh per prosumer), covering their consumption during the day and evening peaks to avoid paying grid and energy charges. Such installed capacities are the maximum allowed for solar panels and battery batteries by the model. Low DER investment costs combined with high electricity price levels also contribute in making the investment in DERs more attractive.

For the voluntary scheme, prosumers benefit from the relatively high compensation of 1.94 €/kWh set by the DSO for all consumers to provide more flexibility and receive the related compensation. Out of the 0.79% total demand-side flexibility levels (see Table 16), prosumers offer 53% of it. As shown in Figure 25(a), prosumers use sub-optimally their battery, injecting at hours 19-20 instead of 20-21, which are the evening consumption peaks.

For the mandatory scheme, the distribution of the contracted flexibility among the consumers is different. There is less flexibility contracting from the prosumers than under the voluntary scheme. Indeed, as shown in Figure 24 (right), the DSO gets 20% of the flexibility from the prosumers and 80% from the passive consumers. Under the mandatory scheme, the DSO anticipates the ability of the prosumers to rely on their DER to reduce their consumption peaks and sets lower overall demand-side flexibility levels (0.46% for the mandatory scheme Vs 0.79% for the voluntary one) combined with a lower price for flexibility. In Figure 25 (a) & (c), we compare the prosumers' load profiles under both schemes and see that under the mandatory scheme, the curtailment of prosumers is lower and is combined with a more efficient battery output that is more aligned with the evening peak.

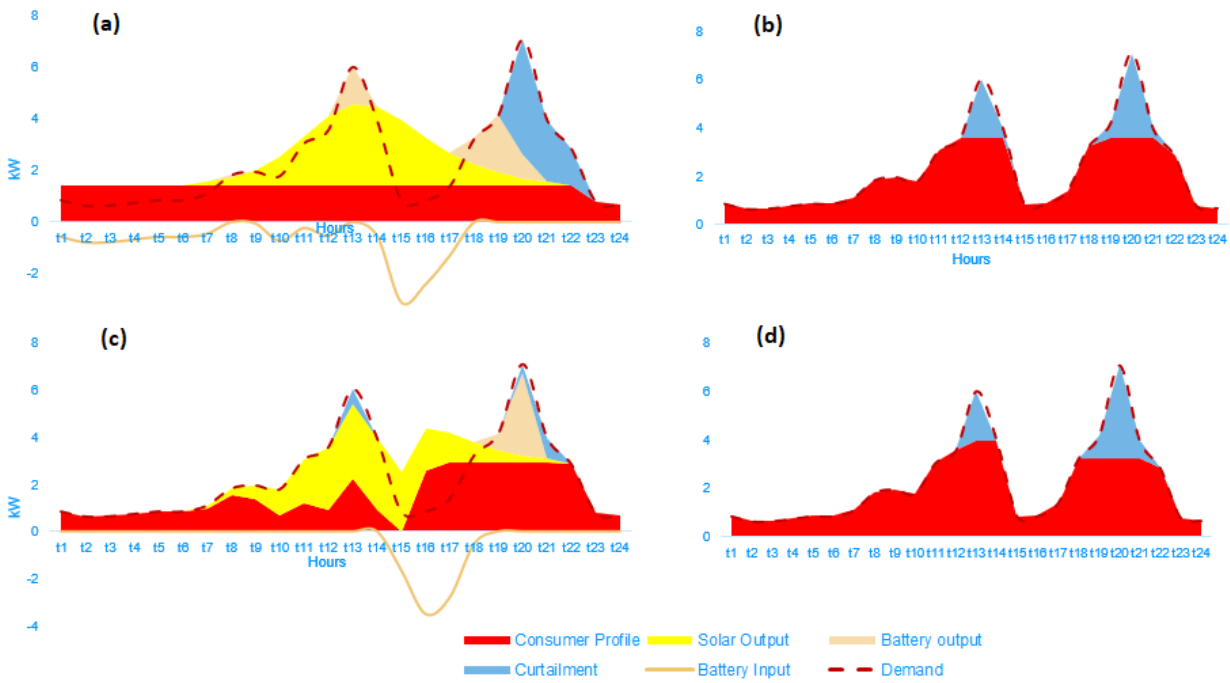

Figure 25: Load profiles for the critical days:
(a): prosumer-voluntary, (b): passive consumer-voluntary,
(c): prosumer-mandatory, (d): passive consumer-mandatory

PRO-RATA MANDATORY CONTRACTING

In order to further investigate the role of contracting different flexibility volumes per consumer type in realising welfare gains under the mandatory demand-side flexibility scheme, we introduce a pro-rata constrained mandatory demand-side flexibility scheme. The pro-rata scheme means that curtailment is shared equally among all types of consumers at the moment of the flexibility event. Such a scheme can be used either because it is not so evident for the DSO to profile the connected consumers as prosumers or passive ones following their behind-the-meter installations or for equity issues, i.e., indirectly offering higher payments for a certain category of consumers. We report in Table 17 the welfare level for the pro-rata constrained scheme and compare it with the previous values. The pro-rata constraint naturally reduces the welfare compared to the unconstrained mandatory scheme. However, the welfare levels remain higher than the voluntary demand-side flexibility scheme. Also, the total system costs are slightly higher under the pro-rata scheme compared to the mandatory unconstrained demand-side connection agreement. They are still lower than the voluntary scheme by 177 €.

Table 17: Results for voluntary and the two schemes of mandatory demand-side flexibility

	Voluntary flex	Mandatory flex - unconstrained	Mandatory flex – Pro-rata constraint
Annualised welfare levels (€)	91002	91063.8	91022
Flex level (as % of the annual demand)	0.79%	0.46%	0.51%
Ann. network investment € (per consumer)	1000.25(-50%)	1237 (-39%)	1251 (-38%)
Total system costs € (per consumer/annualised)	2303	2113	2126
Compensation (€/kWh)	1.94	1.4	1.2

The pro-rata scheme results in higher flexibility levels compared to the mandatory unconstrained scheme. Indeed, the DSO is obliged to curtail the consumers equally and is therefore not free to allocate less curtailment on the prosumers. This is also reflected in the annual network investment per consumer. Even though there is higher flexibility contracting under the pro-rata scheme, the network investments are also higher. The compensation under the pro-rata scheme is lower than the unconstrained scheme. This is due to the fact that under the unconstrained scheme, the DSO sets a higher compensation as most of the remuneration is targeted to the passive consumers, while under the pro-rata scheme, the curtailment is higher and less cost-efficient. Therefore a lower compensation is set (1.2 €/kWh) to limit the increase in system costs.

CURTAILMENT PROFILES FOR THE DIFFERENT DEMAND-SIDE FLEXIBILITY SCHEMES

To further analyse the differences between the contracting schemes, we report in Figure 26 the curtailment profiles for prosumers and passive consumers. For the voluntary scheme, most of the prosumers' flexibility is offered during the evening peak to benefit from the high compensation and increase the prosumers' welfare. Passive consumers offer flexibility for both consumption peaks, as they cannot invest in solar PV to partly cover the day consumption peak like prosumers do to reduce the charges paid for network investment. The mandatory unconstrained scheme allows the DSO to curtail the prosumers less, obliging them to rely efficiently on their DER and reducing their strategic behaviours. Passive consumers are curtailed to higher levels while receiving adequate compensation in a way that reduces the network investment and does not increase the network charges much. The pro-rata scheme contracts similar levels from both types of consumers by definition. Most of the curtailment happens during the evening peak, when the consumption is higher than during day-time. The pro-rata constraint results in the highest curtailment levels of prosumers during the day peak across all the schemes. The DSO has to set the same level between prosumer and passive consumers who cannot invest in solar PV.

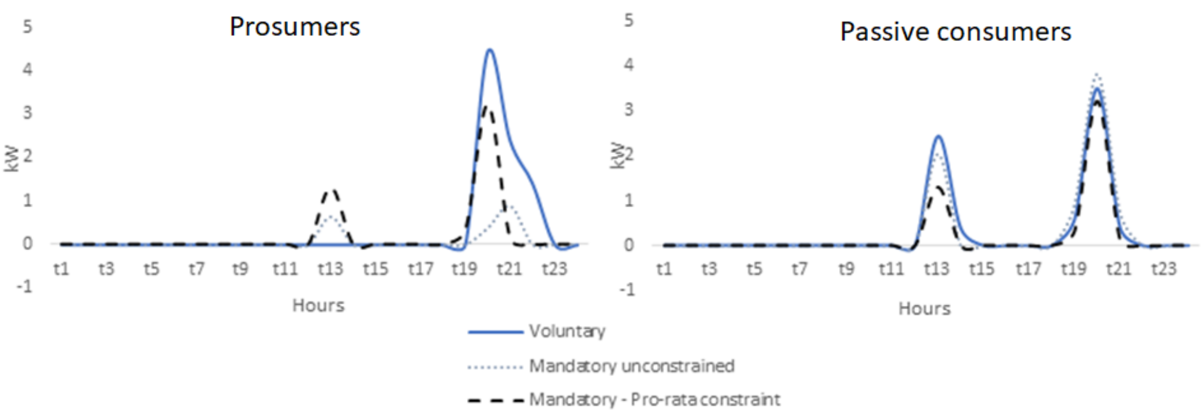

Figure 26: Curtailment profiles for the different schemes

The difference in welfare levels between the unconstrained and the pro-rata constrained mandatory demand-side flexibility suggests that there is a potential for a secondary flexibility mechanism to fill the welfare difference. Such a mechanism would start from the outcome of the pro-rata mandatory mechanism with a 50/50 distribution of flexibility. Then consumers could trade their flexibility in order to reach the flexibility distribution levels of the unconstrained mandatory scheme and the related welfare levels.

BATTERY OUTPUT FOR THE DIFFERENT SCHEMES – PROSUMERS

The use of battery systems is an important indicator of potential strategic behaviour with the voluntary demand-side flexibility scheme. We show, in Figure 27, how prosumers discharge their battery systems, maximizing their individual welfare.

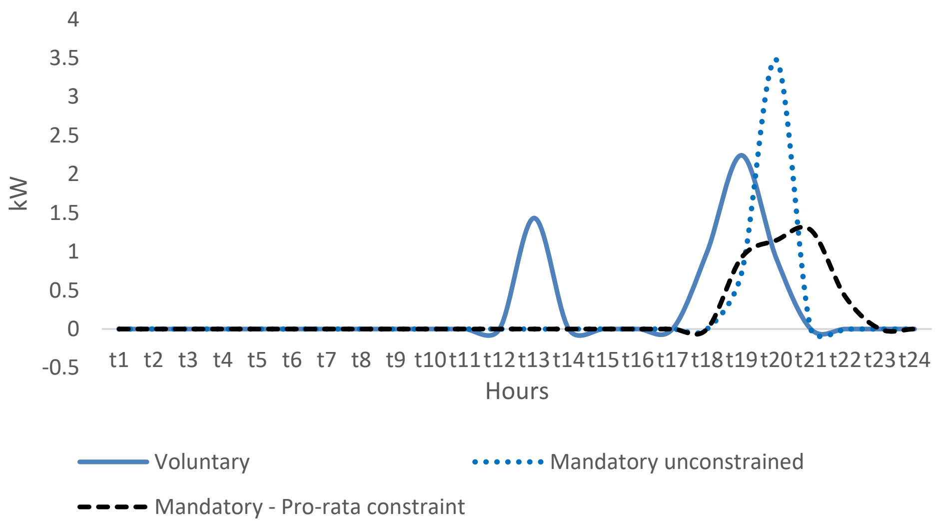

Figure 27: Battery output for the different schemes

Under the voluntary scheme, prosumers cover the day peak with the battery output in addition to solar PV and do not offer flexibility then. In the evening, the discharging starts earlier than in the mandatory schemes so that more flexibility is offered during the evening consumption peak to benefit from the corresponding compensation. For the mandatory unconstrained scheme, the battery output is scheduled following the curtailment action by the DSO. Such output is centred on the evening peak where it is most needed. The DSO sets lower levels of curtailment for the evening peak in a way that incites prosumers to use their battery in an optimal way to cover a large part of the peak. For the pro-rata constrained scheme, prosumers are curtailed by relatively high levels during the day peak. Therefore, they do not use their battery then, as solar PV injection suffice. The output of the battery is scheduled around the evening peak to respond to the high electricity demand then.

4.3 Relevant demonstrators' results on congestion management and relevance for a new European network code

In this section we highlight results of the INTERRFACE demonstration pilot that may be relevant for the FWGL based on ENTSOE-E (2021), TUT et al. (2023), UPRC and BME (2023), and input on the demo results of WP6 provided to us via e-mail. We focus on their contribution related to the congestion management and balancing use cases. A description of the demos and the use cases they address is provided in Section 3.

The **Italian pilot "DSO and Consumer Alliance"** validated short-term congestion management using distributed generation. It developed a platform to monitor and handle flexibility resources managed by FSPs to mitigate congestion in distribution grids and enhance network quality. The pilot included a Combined Heat and Power (CHP) plant (with a Thermal Energy Storage (TES) system), low-voltage power quality improvement using a battery aggregator and DR, as well as a renewable energy-producing local energy community smart coordination to reduce the reverse power flows into the TSO network. (TUT et al., 2023)

The main outcomes of the Italian pilot are related to

- the chance to handle both operational and short-time CM problems through an FSP (which can also be the prosumers of a Local Energy Community (LEC) in a well-defined area, also considering small-size devices,
- the effectiveness of using multi-energy networks (i.e. electricity, district heating) to address CM problems,
- the role of a small DSO in the new European internal market for electricity, as a super-party facilitator for global ancillary services and purchaser of local ancillary services,
- the testing of different incentive mechanisms for LECs/RECs based on flexibility services,
- the chance to use IEGSA as the common architecture to participate in the pan-EU market including for LECs.

The **Bulgarian Pilot "Intelligent Distribution Nodes"** (IDN) validated a concept that enables its users to achieve efficient energy use while minimizing their costs. Additionally, it demonstrated how the IDN could be used for the DSO operational CM service in two different ways – as an automatic and a manual CM provider. Similarly, it was shown how the same resources could also be exploited for TSO needs, i.e., for aFRR and mFRR. (TUT et al., 2023)

Several outcomes of the Bulgarian pilot are summarised below:

- Regarding frequency restoration, the demo highlighted the need for TSOs and DSOs to cooperate to facilitate and enable the delivery of FRR services by units located at the distribution level.
- Regarding additional flexibility services, the pilot showed the advantages of using a cloud-based operational platform and its inherent information hub (IH), which analyses the IDN dataspace to make predictions and to process operational data. The IH integrates data from different sources and formats, running different analyses and becoming a crucial asset in the system. In addition, the IH enables the system to minimize uncertainties during exploitation, increasing efficiency and providing unified data information for all the information consumers.
- Finally, the pilot adopted a value-stacking approach that enabled the unification of different objectives given the different nature of the services targeted.

The **Baltic-Nordic pilot "Single Flexibility Platform"** validated the use of existing mFRR and ID marketplaces to also provide bids for novel CM services, both within the short-term and operational framework. It was found that minimum additional technical developments (related to additional locational properties for bids and bid forwarding) are needed to enable such a functionality. The pilot also showed how IEGSA and its processes could be used to perform resource and grid qualification of a bid to ensure that, for example, TSO balancing market bid activations from resources connected to the distribution grid do not cause infeasible conditions within the DSO network. Moreover, IEGSA functionalities related to flexible grid contracts were tested.[14] (TUT et al., 2023)

Several main results of the Baltic-Nordic pilot are summarised below (TUT et al. 2023):

- The importance of the flexibility resource register as an enabler of efficient flexibility marketing and procurement was confirmed. The register was paramount in sharing prequalification information, streamlining distributed flexibility asset registration and grouping, and providing ease-of-use for both FSPs and SOs in, respectively, selling and buying flexibility.
- Different ways to perform grid prequalification were successfully tested to ensure that the activation of flexibility bids does not create issues in electricity networks.
- Locational mFRR and intraday bids were integrated into the CM market with relatively little technical modifications to share information and include a locational attribute. Whenever the need arises, this approach could help to jumpstart a CM marketplace and improve its liquidity.
- To ease market access for small-scale flexibility, CM products should be aligned (harmonised) with existing balancing products. In addition, IEGSA should be technology-agnostic and open to third party market operators. The pilot achieved the latter by defining a separate role for MOs that could be taken up by independent MOs.
- Positive effects of data interoperability could be demonstrated with IEGSA and the Common Information Model.
- Regarding flexible grid contracts use cases, their piloting was a success from the technical point of view and all processes were functioning as expected. However, the need to improve several business processes was identified, mostly related to the solving of contractual issues concerning activation conditions and subsequent imbalance settlement.

The abovementioned **three pilots of WP5 (Italian, Bulgarian, Baltic-Nordic)** were able to show, overall, how CM could be provided in an efficient and innovative way. The combination of CM with other services ensured that resources are not locked in to provide only one service, but instead enabled their participation in several marketplaces. Moreover, a level of coordination between marketplaces was achieved, and an efficient pre-qualification algorithm was implemented for improved TSO and DSO coordination. It has also been shown that IEGSA can support the uptake of flexibility resources. (TUT et al., 2023)

The **Hungarian-Slovenian pilot "Asset-enabled TSO-DSO flexibility**" promoted a data-driven local asset-enabled peer-to-peer energy market, where transactions beneficial for the distribution grid are facilitated via dynamic pricing (DNUT – dynamic network usage tariff). The demonstration of a local market was simulated at three sites, two of which located in Hungary and one in Slovenia. Local distribution system operators were involved to provide grid and consumption/production data. The state of the network was monitored by the Integrated Asset Condition Management system (IACMS), which allowed real-time estimation of component loadability values.

[14] TUT et al. (2023) define flexible grid contracts as "*a form of connection agreement whereby the injection/withdrawal capacity is higher than it would normally be based on grid constraints alone. The increase in capacity is achieved by marking a part of the contracted capacity as flexible, which enables the SO to restrict it at times when there are risks of overloading grid elements. However, during normal operating conditions, the customer has full use of the contracted capacity.*"

The pilot successfully demonstrated the usage of IEGSA for its use case, i.e. "distribution grid users participating in P2P local market" (see also section 3). Some of the relevant results are listed below:

- To enable user participation in the P2P marketplace, a user interface to the local market platform was established, and the local market platform acknowledged or refused user registration. The registered user was recognised through her grid connection point and other data (e.g., user limit, profile type). The verification process was based on a database provided by the DSO as part of the initialisation listing the users with connection points and other parameters stored in the flexibility register of the IEGSA platform.
- Metering data was uploaded to IEGSA by the DSOs using the coordination platform (single interface to market). Historical metering data was available in the flexibility register of the IEGSA platform.
- Grid data was requested from IEGSA's Single Interface to Market. Topology changes were handled by an automatic function. IEGSA was also used by DSOs for the management of their assets as well as for information exchange coordination between SOs through the TSO-DSO coordination module.
- Market results were sent to the IEGSA and stored in the flexibility register. They were also forwarded to the settlement unit.
- Overall, the results of the simulations provided significant information (loss, voltage deviations, etc.) about how the network would respond to each trading scenario. Significant changes were only found in a minority of cases. This led the demo leaders to conclude that the trading did not have any significant impact on the network, probably due to the low number of local RES.

The **Bulgarian-Romanian pilot "Blockchain-based TSO-DSO flexibility**" developed a solution for congestion management that successfully contributed to reducing investment in costly hardware/network upgrades and enabling the participation of flexibility assets at the distribution level to ensure system stability. TSO-DSO coordination mechanisms were tested, especially concerning the validation of the viability of data transfer between the SOs. Moreover, the pilot solved the issue of double activation of flexibility assets through sound coordination and effective signalling. The pilot uses the EFLEX architecture that incorporates blockchain technology and is easily usable also by non-experts due to its simple trading rules.

A summary of the results of this pilot is provided in the following. The piloted solution

- enhances transparency in data communication, also facilitating coordination between entities.
- contributes to a better visualization of demand and supply forecasts which aids in congestion management and balancing.
- uses an algorithm to automatically match requests and offers. The solution benefits from an optimized transaction time from minutes to <10 seconds. It also enables faster transaction settlement and avoids double auctions with the help of blockchain.
- is inexpensive and fast compared to previously used solutions due to the elimination of intermediaries and inefficient back-office processes. It also eases book-keeping since all transactions are automatically recorded on the blockchain network.
- helps prosumers to be active participants in the market and earn revenues while also helping reduce grid loads. It includes an easy-to-use user interface which is accessible to all and preserves privacy through authentication. The role of smart meters was found to be of highest importance.
- is secure, reliable and scalable, and is also capable of handling significant numbers of grid users with sufficient efficiency and security levels.

The **Greek-Romanian-Bulgarian pilot** "**DERs into Wholesale**" developed a specific feature in the IEGSA platform to promote DER participation in wholesale markets. The objectives were to produce clear price signals in market coupling and to incorporate DERs' flexibility potential and engage consumers/prosumers in the electricity markets. The developed prototype was based on a representation of the wholesale and retail markets in Romania, Bulgaria and Greece in a 2030 market operation scenario. It incorporated modelling frameworks and technologies developed in the horizontal INTERRFACE work packages and utilised a large amount of data from the TSOs, DSOs, MOs, and market participants. (UPRC and BME, 2023)

Some of the main outcomes of the Greek-Romanian-Bulgarian pilot are summarised below:

- While the pilot demonstrated a high potential for DER participation energy and reserve markets in high-RES power system, unlocking this flexibility potential may require harmonising product definitions and effective interoperability among different markets.
- Harmonised rules for aggregation are needed to facilitate an effective way of clustering flexibility means for the optimal provision of services to SOs.
- To fulfil the objectives of the pilot, extensive modeling and computational efforts were required. In terms of IEGSA scalability, computational performance and data handling capabilities should be carefully considered, as operational processes will compute a significant amount of data.
- Data transparency requirements may need to be enhanced to ensure optimal interaction among existing market facilitation platforms (e.g. ENTSO-E Transparency Platform) to provide transparent and predictable information for current and future flexibility owners and other market parties.

The **Romanian pilot** "**Spatial aggregation of local flexibility**" introduced refined spatial dimensions (i.e. geolocational information) into the existing wholesale market design with the aim to facilitate the participation of local flexibility in solving local grid issues and in wholesale markets. It developed a mathematical formulation for optimal market outcomes and use of local flexibilities based on the pan-European day-ahead energy market coupling's EUPEHMIA model. In this context, the demo preferred a zonal representation of the electricity grid to align the market algorithm to the existing market optimisation algorithm. UPRC and BME, (2023) highlight that the applied zonal configuration shall be carefully considered as the exact congestion locations vary frequently. Please note in this context that it will be challenging to define the optimal bidding zone configuration and that a bidding zone review process is currently ongoing at EU level following the recast of the Electricity Regulation (EU) 2019/943.[15]

Several of the INTERRFACE demonstrators' results may be relevant for the development of future European rules on demand response. In the following, we refer to their results on product definition and harmonisation, coordination between SOs and FSPs, data exchange, and the flexibility resource register.

On **product definition and the integration of different technologies in one marketplace**, the design of flexibility products is an important parameter to enable the wide participation of actors in flexibility markets. Two views have emerged on flexibility product design and potential needs for harmonization. The European Smart Grids Task Force (2019a) report on demand-side flexibility highlights that the design of flexibility products should be done in concertation with stakeholders, i.e., to consider existing products. The harmonization of products at the regional or EU level should be addressed to avoid having a situation with diverse and non-comparable products. For instance, locational information should be necessary for congestion management products. The "Roadmap on the Evolution of the Regulatory Framework for Distributed Flexibility" report states that the final choice on how to design products should be left to the Member States and their national regulatory authorities so that they can consider local circumstances inherent to local services such as intra-zonal redispatching (ENTSO-E et. al, 2021). It adds that it is not necessary to harmonise flexibility products at the EU level due to the diversity of flexibility mechanisms across Member States and in order to keep product innovation and future development open.

[15] https://www.acer.europa.eu/electricity/market-rules/capacity-allocation-and-congestion-management/bidding-zone-review

Nevertheless, some principles and a list of attributes could be defined at the EU level to reduce market barriers for flexibility providers active in different EU markets. Member States can then pick the attributes they deem necessary for specific product definition at the national level.

The results of the INTERRFACE demos highlight that defining and harmonising product requirements (e.g., minimum capacity, response time etc) is key. However, the demos have also recognized that product definition is a difficult task, especially when residential users are involved. In general, it was found that products and markets used for trading flexibility need sufficient alignment with existing products, in particular balancing products. This enables the better utilisation of especially small-scale flexibility resources and their access to electricity markets. The demonstration results show that such alignment can be achieved by adding a requirement for locational information. For the specific case of local energy communities, the demos have successfully established the product definitions, while it was difficult to set a market for flexibility achievable by these communities. It was found that an incentive mechanism might be more apt in such case.

The INTERRFACE experience with product harmonisation is relevant for the new European rules on DR. The FWGL foresees that SO services can be procured in dedicated local markets or through locationally tagged bids in wholesale markets, in particular intraday and balancing markets. Currently, the FWGL does not see a need to define common European products for local SO services. It does, however, advocate for a certain level of harmonisation, making the markets recognisable from one Member State to another. It is foreseen that rules at EU level provide for common attributes to describe the products and common principles for their procurement, while SOs at the national level should define the detailed products and pricing mechanisms for SO services. (ACER, 2022b)

Furthermore, the **coordination between system operators and FSPs** could help to mitigate congestion management issues in the DSO network. In this context, demos results point to a possible future role of small DSOs in the new European internal market for electricity, as a super-party facilitator for global ancillary services and purchaser of local ancillary services.[16] In the demos, SO coordination was embedded in grid qualification processes. This aims to ensure operational stability between TSO and DSO networks through evaluating the FSP resources using network information directly from the system operators. SO coordination is also closely linked to the topic of data exchange.

On **data exchange**, the demos development process stresses the importance of utilizing grid data as part of the flexibility trading to handle network constraints and flexibility needs. The grid data common observability area should accurately represent the situation of the network with an optimal granularity level, as too granular data would make the process heavy. In addition, the way data exchange is organized and implemented is also important role for unlocking the flexibility and the procurement of such services. Such data relate to information from all market parties, flexibility service providers and their portfolio of flexibility resources. ENTSO-E (2022) highlights the important role of IEGSA in providing data exchange tools and communication channels to support interactions with market parties. Data exchange and SO coordination are two of the main areas in the FWGL. SO coordination aims to ensure the optimal use of available resources. The FWGL specifies that SOs may activate resources in the grid of another SO but each SO will be responsible to solve congestions or voltage issues in its own grid. Good SO coordination to avoid issues in the networks is thus of utmost importance. The FWGL proposes to split data exchange in three phases, namely the preparation, operation and settlement phases, and for each foresees either principles to be developed at EU level or detailed processes and rules to be developed at national level. (ACER, 2022b)

The demos' results also provide insights on the use of a **flexibility resource register**. It is a metadata register that (i) manages the flexibility resources and grants them access to specific market products, (ii) gives visibility to the buyers of flexibility on the location of relevant resources, their technology, responsible FSP, etc. In other words, the register collects all the significant data/information of flexibility

[16] Super-party means that small DSOs will not contract flexibility themselves, but would facilitate the process for TSOs or other contractors of the resources connected to their grids.

resources, including spatial information and this, when combined with grid and bid data, enables TSOs and DSOs to procure flexibility from the right locations. FSPs can themselves insert all the information necessary for the resource registration. ENTSO-E (2022) describes the important role of the register in the prequalification processes.

The experience with a flexibility resource register gained in INTERRFACE is relevant in the context of the FWGL. Indeed, the FWGL proposes the use of a “SO service provision tool”, i.e. a flexibility resource register that supports SOs and service providers in the preparation phase (i.e. from long to shorter before real-time). The FWGL proposes to introduce at least two functionalities, namely, to centralise all applications to participate in different products and services (including at least balancing, CM and VC) as well as all prequalification processes, and to register all service providers that are qualified and can participate in different products and services. The FWGL foresees one tool per Member State.

Related to the future implementation and upscaling of the flexibility resource register in IEGSA to meet potential requirements of a new network code on DR, several challenges were identified by the demos and INTERRFACE partners. A first challenge is related to scale. The INTERRFACE demos have proven the functionalities of the flexibility resource register in IEGSA for a number of parties in their demo countries. However, on a larger scale, the flexibility register should be capable to handle significant numbers of users while ensuring efficiency and security.

A second challenge is related to functionalities. ENTSO-E (2022) highlights that the functionalities of the register in IEGSA already go beyond the minimum specifications of those flexibility registers that had already been deployed in several European countries like Belgium or the UK. This is because, in case of IEGSA, the tool is not only intended to support TSOs and DSOs to have a common view of the resources located in their grid to support the grid prequalification process, but also as a supporting tool for the MO to perform the product prequalification, and for FSPs to manage their portfolio. In the future, some degree of alignment between the flexibility resource register in IEGSA and those already used by TSOs and DSOs will be necessary.

A third challenge, as described by ENTSO-E (2022), is related to the perimeter of flexibility register functions belonging to the regulated domain. There is an open question on whether and how, under a decentralised approach to the register concept, one would split the regulated and the commercial domains. A split would likely increase complexity with regards to data exchanges and would require strong alignment among SOs, FSPs, platforms, and regulators across multiple dimensions.

A proper design of the flexibility register’s architecture with corresponding roles and responsibilities will be required. INTERRACE proposed the introduction of new roles to the Harmonised Electricity Market Role Model (HEMRM) that, based on the project results, are considered vital in the future setting of the digitalised energy system (ENTSO-E, 2022). One example is the Flexibility Register Operator with a number of proposed responsibilities related to the operation of the flexibility resource register. The allocation of real-life actors to these new (and existing) roles will need to be properly assessed. For example, the role of DSOs with regard to the implementation of the flexibility register will need to be clarified as well as requirements for TSO-DSO coordination in this context.

The new network code on demand response will have an important role in addressing these and other challenges, and well-positioning the flexibility register in the normative framework to avoid barriers for its implementation and ensuring efficient and seamless data exchanges.

5 Interoperability and data access

This section combines our research output on interoperability and data access with results from the INTERRFACE demonstration pilots. Subsection 5.1 provides the background to this research stream by introducing the main features of interoperability and laying out the policy and regulatory framework for the development of new European rules. Subsection 5.2 includes the research output on interoperability and data access. Subsection 5.3 discusses the relevance of selected demo results for the development of a new European network code.

Note that the research presented in this report focuses on consumer data. In Reif et al. (2021), we also analysed data exchange and interoperability practices regarding market and network data at transmission level. The reason was that there was limited experience with interoperability of consumer data at the time of publication of the Clean Energy Package in 2019. However, vast experience existed at transmission level in the context of market and network data exchange among TSOs, ENTSO-E and RCCs that could inspire emerging practices at distribution level regarding consumer data. As a result of the implementation of the Clean Energy Package, the policy and regulatory debate was centring around consumer data exchange practices and the development of the implementing acts for interoperability and data access for those few years during which the main body of research in this section was developed. More recently, with the publication of the Fit for 55 Package[17] in 2021 and the Digitalisation of Energy Action Plan in 2022 (EC, 2022b), the scope of attention was again broadened.

5.1 Background to this research stream

This subsection puts our research stream on interoperability and data access into context. We first introduce the topics of interoperability and data access. We then describe the ongoing legislative process at EU level to develop new European rules.

5.1.1 Introduction to interoperability and data access

Data is quickly becoming a key commodity in the electricity sector and data management is increasingly important for all actors involved. At distribution level, data volumes are increasing due to the deployment of smart grids and smart metering systems. Business models of both incumbents and new actors in the energy sector are increasingly built on large volumes of different types of data including market and consumer data. The Clean Energy Package has brought new consumer rights to retrieve and share their energy data that increase the importance of organising and handling consumer data exchanges.

One fundamental challenge is that the electricity system is a ‘system of systems’, which means that it consists of multiple, smaller or larger systems that need to share information by means of exchanging data between their Information Communication Technology (ICT) systems. Such complex systems are not built from scratch. Rather, the integration of electricity networks and markets takes place gradually and new requirements, actors, technologies, applications and components must be integrated into an existing system. As a result, IT systems from different vendors are in place across the power system, often even within the same company. The traditional way to interconnect the often proprietary IT systems is to build specialized interfaces, but this is not considered a sustainable approach.

To address this issue and enhance standardization activities, the European Commission issued the *Smart Grid Mandate M/490* to the European Standards Organizations (ESOs) CEN-CENELEC-ETSI in 2011. The ESOs were asked to develop a framework to identify standardization gaps, required use cases and security requirements in the field of smart grids, which resulted in the creation of the Smart Grid Architecture Model (SGAM) framework. The SGAM is a three-dimensional model that is intended to present the design of smart grid use cases from an architectural, technology- and solution-neutral point of view (SGCG, 2012). An important feature of the SGAM is its focus on interoperability, which is seen as the key enabler for

[17] See the FSR blogpost on the Fit for 55 Package, available at https://fsr.eui.eu/fit-for-55-eu-rolls-out-largest-ever-legislative-package-in-pursuit-of-climate-goals/.

smart grids. The SGAM framework and the related methodology have so far been used in numerous European and national R&D projects, including in INTERRFACE.

Interoperability has received increasing awareness in the public debate. However, it is not straightforward to grasp as a concept as there is not one common definition for interoperability. Rather, many different definitions for interoperability exist that differ based on the sector and the context. One definition that is widely used is the one included in IEC 61850-2010, which states that interoperability refers to the '*ability of two or more devices from the same vendor, or different vendors, to exchange information and use that information for correct co-operation'*. This definition has technical focus, while other definitions account better for the various interoperability dimensions that exist (Reif and Meeus, 2022; Reif and Meeus, 2020). Indeed, interoperability is multi-dimensional, and all dimensions need to be considered to successfully deploy interoperable solutions. Interoperability is also increasingly a cross-sectoral challenge as the future energy system is understood to be integrated with other sectors, among them for example the mobility and buildings sectors (EC, 2021a).

Another fundamental challenge is that access to consumer data is primarily regulated at the national level and both data access and data exchange practices related to consumer data are widely divergent across Member States. Until recently, consumer data was only of interest to the DSOs and suppliers. With smart meter deployment, consumer empowerment and new rights of consumers to retrieve and share their own data with third parties, access to metering data is increasingly in the focus of regulators. Also, DSOs and other entities such as suppliers, need access to consumer data to fulfil regulated obligations. Moreover, innovative energy services, including for demand-side flexibility, can come from other sectors closely related to energy, such as electromobility and buildings. This holds under the condition that the data relevant for the creation of such services are (easily) accessible by final consumers as well as other parties based on the consumers' consent.

5.1.2 New European rules for interoperability and data access

The European Commission's initial proposal for the recast of Electricity Directive (EU) 2019/944 in the Clean Energy Package had included a requirement for Member States to define a common data format and a transparent procedure for eligible parties to have access to energy customer data. The European Commission would have been entitled to determine such common European data format and non-discriminatory and transparent procedures for accessing data that should replace the national data formats and procedures for access adopted by the Member States. Most stakeholders were not in favour of a common data format. For example, the European Smart Grids Task Force (2019b; 2016) argued that instead of a single data format, an approach should be adopted that would allow for compatibility or alignment with the existing systems already decided on in the Member States. The main argument against a single data format was the anticipated costs of moving from long-established business and IT processes which have been set up to handle traditional retail services such as change of supplier and billing to a new system. It was argued that even small changes to the existing systems would require dedicated projects and large investments, ultimately resulting in increased costs for consumers. Eventually the national and the common EU data formats were removed during Trilogue negotiations, and the final version centres around interoperability requirements.

Article 23 of the Electricity Directive (EU) 2019/944 of the Clean Energy Package requires Member States to "*organise the management of data in order to ensure efficient and secure data access and exchange, as well as data protection and data security.*" The directive, together with Regulation (EU) 2016/679 (General Data Protection Regulation), requires that consumers must be able to access their energy data and share it with third parties. Data access and exchange must be efficiently organised, the purpose of the data collection, use and processing must be clear to the consumer and data sharing processes must be secure and subject to the consumer's consent. Access to data by eligible parties must be easy and the relevant procedures for obtaining access to data shall be made publicly available.

The directive also requires Member States to "facilitate the full interoperability of energy services within the Union" (Art.24(1)). The European Commission is entitled to adopt, by means of implementing acts, interoperability requirements and non-discriminatory and transparent procedures for access to data that shall be based on existing national practices. As specified in Art. 23(1) this covers metering and consumption data as well as data required for consumer switching, demand response and other services.

At the European Electricity Regulatory Forum (Florence Forum) in June 2019, the European Commission defined the EU implementing acts on interoperability and data access as one of three legislative priorities. The official network code priority list in Commission Implementing Decision (EU) 2020/1479 confirmed this choice (EC, 2020a), as is also described in Section 2.1. The EC has tasked the European Smart Grids Task Force (ESGTF) with the preparation of these acts. The starting point is the diversity of existing solutions across Member States when it comes to handling consumer data. From July to September 2022, the European Commission held a public consultation and published the first draft implementing regulation.[18]

The published draft regulation is the first from a series of implementing acts that will be developed.[19] It applies to metering and consumption data in the form of *validated historical* and *non-validated near-real time* metering and consumption data. It lays down rules for final customers and eligible parties to access this data in a timely, simple and secure manner. It aims to ensure that suppliers and service providers have transparent and seamless access to customer data based on customer consent.

The draft regulation specifies that interoperability is typically separated into five layers according to industry practice (and in line with the SGAM):

- The *business* layer relates to the business objectives and roles for certain services or processes.
- The *function* layer relates to the use cases, data sharing and permission management.
- The *information* layer relates to data models and information models.
- The *communication* layer relates to the communication protocols and data formats.
- The *component* layer relates to data exchange platforms, applications and hardware such as meters and sensors.

Emphasis is put on the re-use of proven concepts and solutions, including the Harmonised Electricity Market Role Model[20], the International Electrotechnical Commission's (IEC) Common Information Model (CIM), and solutions for digital identification and authentication for final customers and eligible parties.[21]

The draft regulation sets out a reference model. The idea of a reference model is to ensure that market participants have a mutual and clear understanding of the roles, responsibilities and procedures for access to data. For the business, function and information layers, the reference model defines common rules and procedures *at EU level*, in line with national practices. At the same time, Member States are allowed to determine the communication and component layers in accordance with national specificities and practices.

[18] The public consultation including the draft implementing regulation is accessible at https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13200-Access-to-electricity-metering-and-consumption-data-requirements_en.

[19] The general idea is that a generic implementing act lays the common foundation for several other implementing acts on specific use case families, such as data access, demand response and traditional processes like billing and supplier switching.

[20] See https://www.entsoe.eu/Documents/EDI/Library/HRM/Harmonised_Role_Model_2022-01.pdf.

[21] Note also that ebIX® process models are currently the only available core process models for the downstream energy market. In the future, there may be a collaboration between ebIX® and the EU DSO Entity aimed at knowledge and results sharing and enabling the re-use of previous work. Such initiatives are important in the context of the EU implementing acts on interoperability and data access and the upcoming tasks on the reference model and documentation of national practices.

The reference model is technology-neutral and describes workflows that are required for specific services and processes based on a minimum set of requirements to ensure that a given procedure can run correctly, while allowing for national customisation. It is composed of three elements:

- a *role model* with a set of roles/responsibilities and their interactions,
- an *information model* that contains information objects, their attributes, and the relationships between these objects, and
- a *process model* detailing the procedural steps.

In other words, the reference model consists of a set of reference procedures for access to data and of the required information exchanges between roles (that are taken up by market players) relating to the specific case. The Annex to the draft regulation lists six procedures, namely access to validated historical metering and consumption data (1) by the final customer and (2) by an eligible party, (3) termination of service by an eligible party, (4) revocation of an active permission by the final customer, (5) active near real-time data flow from smart meter, and (6) read near real-time data from smart meter.

The reference model shall be implemented at national level. Member States are required to report information on its implementation, including the various roles, information exchanges, and procedures, to the European Commission. This information will be publicly accessible in a common repository of national practices. ENTSO-E and the EU DSO entity are assigned the joint responsibility for the repository, which includes providing guidance to Member States on the reporting of their practices, collecting the reports of national practices, and publishing them in the repository. The overall aim of the repository is to enable market participants to identify and better understand similarities, differences and relationships between the national arrangements in the Member States, and to help share best practices. The draft regulation also acknowledges the importance of testing and requires that eligible parties are given the possibility to test their products, procedures and services in advance before deployment, to avoid technical implementation problems, and to finetune their operations to ensure that their products and services run smoothly in line with the procedures of this Regulation.

In the context of the European Green Deal and the Fit for 55 Package, the interoperability debate has gained further momentum and has been extended to the gas and buildings sectors. The proposal for a gas directive (EC, 2021b) requires adoption of interoperability requirements and procedures for access to data both for natural gas smart meters and in hydrogen systems. The proposal for a recast of the Energy Performance of Buildings Directive (EC, 2021c) requires the European Commission to lay down implementing acts regarding interoperability and access to building systems data (i.e. all data related to the energy performance of building elements, the energy performance of building services, building automation and control systems, and meters and charging points for e-mobility). The Regulation on the deployment of alternative fuels infrastructure is foreseen to strengthen interoperability requirements, ensure adequate customer information, cross-border usability of charging infrastructure and seamless cross-border payments, and increase the deployment of smart charging infrastructure (EC, 2021d).

5.2 Research output on this topic

As described in subsection 2.3, the research on interoperability and data access was carried out in several steps. In subsection 5.2.1, we explore the fundamentals of consumer data exchange practices. In subsection 5.2.2, we make an informed contribution to the policy and regulatory debate surrounding the implementing acts on interoperability and data access. In subsection 5.2.3, we analyse interoperability frameworks, experiences from other sectors and at the national level, and governance issues in the cross-sectoral context of energy system integration and the digitalisation of the energy sector.

5.2.1 Consumer data exchange and interoperability[22]

USE CASES

Use of consumer data can be generally divided into two main categories. The first one is regulated obligations, which comprises of use cases connected to the entitlement of any customer to be connected to the grid, be supplied and billed and be provided with a high level of security of supply. It includes, traditional retail processes, such as billing, change of supplier, moving, settlement, cancellation of a contract, which have long been implemented in the Member States.

The second one is commercial services. New use cases are emerging in line with the new rights of consumers to retrieve and share their own data granted by the Clean Energy Package. These depend on consumers giving consent to third parties to access their energy data. Examples of such use cases according to the ESGTF (2016) are: ‘download my data’, ‘share my data’, ‘revoke consent’ and ‘terminate service’.

It is likely that future use cases will increasingly emerge in the area of integrated (energy) systems, for example with regard to forecasting of generation and demand, demand response and participation in energy and ancillary services markets, or home automation.

The line between regulated obligations and commercial services is not always easy to determine and depends on the national context. Generally, until recently, data processing was considered a DSO task and few to no other players were interested in consumer data. This situation is changing, however, and this change is bringing new roles and responsibilities to several actors. For example, DSOs, who are increasingly expected to adopt the role of neutral market facilitators and provide data to the market, but have in some cases found themselves in a position to services that can qualify as competitive data analysis services. The Clean Energy Package is clear in requiring any charges imposed by regulated entities that provide data services to be reasonable and duly justified. Data services can thus be provided by DSOs, but are subject to close regulatory supervision.

DATA MANAGEMENT MODELS

Member States have implemented different models for the management and exchange of consumer and metering data. Data Management Models (DMMs) typically consist of a set of different roles, responsibilities, legal frameworks, technical standards as well as informal rules. They can be categorised based on the level of (de)centralisation. CEER (2016) distinguishes between centralised, partially centralised and decentralised models. The choice of model is often largely due to legacy issues.

In the lead-up to the Clean Energy Package, the European Commission had considered a common EU data management model as one of three options. The others were national responsibility and common criteria and principles. The discussions with stakeholders showed that there is merit in providing a common framework at EU level, while respecting national requirement and specificities.

DATA ACCESS

Traditionally, consumers can consult their historical consumption data in different, country-dependent time granularities via their electricity bill and/or via request to the DSO or the supplier. The roll-out of smart metering systems in theory allows for access to historical consumption data and some real-time via the smart meter gateway. However, CEER (2016) found that the degree to which customers have access to their energy data is quite low. This is the case for both historical and near-real time consumption data.

The Clean Energy Package responded to this issue. Article 20 of Directive v(EU) 2019/944 provided that, in case of a positive cost-benefit analysis for smart metering or where smart metering systems are systematically deployed, and at the request of the final customer,

[22] This section is a summary of Chapter 9 in Schittekatte et al. (2020).

- *Validated historical consumption* data shall be made easily and securely available and visualized to the final customer at no additional cost.
- *Non-validated near real-time consumption data* shall be made easily and securely available to final customers, in an easily understandable format at no additional cost, through a standardized interface or through remote access, in order to support automated energy efficiency programmes, DR and other services.

It shall also be possible for final customers to retrieve their metering data or transmit them to another party at no additional cost and in accordance with their right to data portability under the GDPR. Moreover, Article 23 of the directive requires Member States to specify the rules on the access to data of the final customers by eligible parties.

INTEROPERABILITY ISSUES

A challenge for the interoperability of national data management models are the stark differences in the handling of use cases across Member States. Both business processes and data exchange procedures differ from country to country, and there is a lack of standardisation and harmonisation. For example, traditional retail processes such as switching, or billing vary with regard to the number of interactions needed between market participants to complete the process. Exceptions exists due to countries taking account of regional aspects related to public service obligations or taxes and levies. Member States have often already invested time, effort and money into specifying processes and developing standardized procedures and format, and are unwilling to introduce too much change.

New use cases are often dependent on the deployment of digital infrastructure, including smart meters. Interoperability issues are related to, for example, the level of smart meter deployment, the history and granularity of consumption data, and differences in the functionalities and features of smart metering systems. These issues are halting retail competition are posing barriers to entry for both incumbents and new players. For example, market parties that want to expand their business to other Member States are currently forced to set up parallel IT infrastructures to accommodate the different systems and processes in place across countries, resulting in increased cost and effort.

SOLUTIONS FOR THE INTEROPERABILITY ISSUES

The European Smart Grids Task Force published a report that maps a few national practices for data access and exchange and reflects on available options or for making them interoperable (ESGTF, 2019). It advocated for convergence over time, considering national practices, rather than obliging Member States to harmonise on a short term. Convergence of two or more different systems is understood as the gradual process of changing and developing similar characteristics in order to become interoperable. The Task Force suggested the adoption of different technology-neutral reference models, including a process model, a semantic information model and harmonised role model. This would allow a minimum level of harmonisation while allowing for national or regional specificities and customisation.

5.2.2 Contribution to the debate around the EU implementing acts on interoperability and data access [23]

INTEROPERABILITY FRAMEWORKS

Interoperability frameworks help to describe the way in which organisations have agreed to interact and exchange information with each other. These frameworks have been developed in multiple sectors, including electricity, public administration and healthcare, as is illustrated in Figure 28. There is no agreement on the exact number of interoperability categories, but all frameworks recognise that solutions can only be interoperable when agreement is reached across all layers of concern and all the relevant

[23] This section was published as an FSR Policy Brief in 2020 (Reif and Meeus, 2020), two years before the draft implementing act for interoperability and data access was published by the European Commission.

stakeholders are involved in the process. Across frameworks, six commonalities can be found that need to be addressed to achieve full interoperability of energy services as required by Directive (EU) 2019/944.

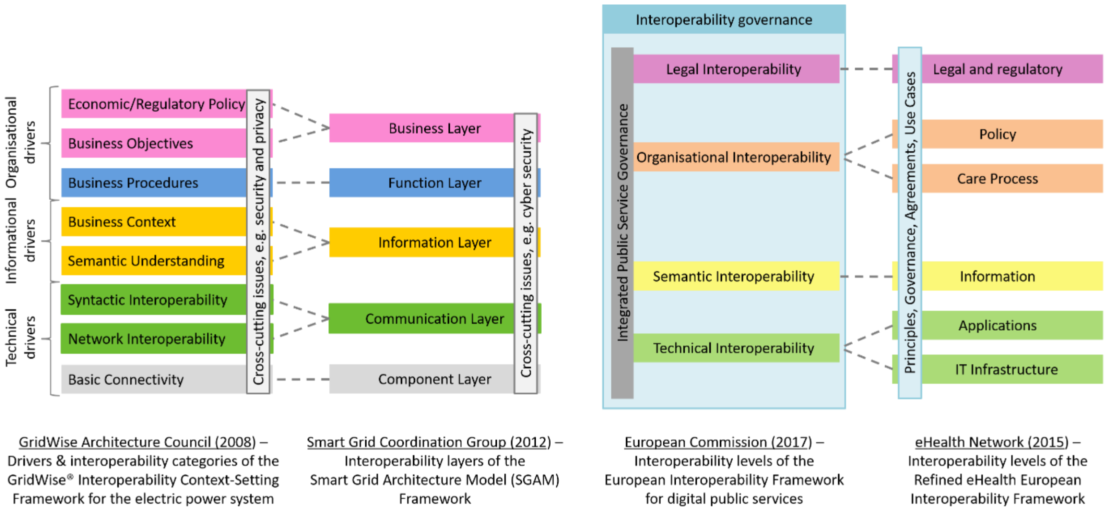

Figure 28: Selection of interoperability frameworks across sectors, source: Reif and Meeus (2020)

The first commonality concerns regulation and policy. The alignment of relevant policies and regulations is needed at different geographical levels from the European to the regional, national and local. This serves the provision of incentives and removal of barriers to facilitate interoperability.

The second commonality concerns roles and responsibilities. Responsibilities should be allocated to harmonised roles that are independent of real-world parties. This helps to standardise and harmonise information exchange, avoid a lock-in of responsibilities by specific parties and ensures flexibility concerning national implementation and future requirements. Role allocation to specific parties can happen depending on the national context.

The third commonality concerns business processes. Organisations wishing to work together, and exchange information are likely to have different internal business and IT structures and processes. They are also likely to use different languages. In addition, the objects of interest, the parties involved in the discussion and the language they use may be very different from interoperability layer to layer. For example, while there are policymakers and regulators involved in the highest layer, there are system engineers and developers involved in discussing software artefacts and information modelling in the more technical levels. Therefore, a first step towards interoperability is agreeing on a common language, including terms and definitions, to be used as the basis for common understanding. In a second step, methodologies are needed to define business goals and align existing business processes or establish new ones across organisational boundaries. To align business processes, they first need to be documented in a standardised way with commonly accepted modelling techniques. Together, these steps establish a common ground for comparison and ensure that all the parties involved can understand the processes and their role(s) in them. A use-case-driven approach is often adopted. This involves the definition of business use cases at a higher level and system use cases at a more technical level.

The fourth commonality concerns information models, data formats and communication protocols. Once the business processes are documented, the focus can shift to the content and structure of the information that is exchanged. Interoperability frameworks typically include the use of common descriptions, i.e. agreed processes and methodologies, to make sure that the format and the precise meaning of exchanged data and information is preserved and understood throughout the exchange process. They also include details of the technology involved in linking systems together, for example how information is transported across multiple communication networks and agreements on the data-transmission medium and the rules for accessing it.

The fifth commonality concerns the use of standards. Standards support and help to improve interoperability as they essentially specify an agreement between interacting parties. Since no single standard product will be able to cover all different viewpoints and layers of interoperability, a set or portfolio of standards is typically needed to address well-defined use cases. It is important for interoperability frameworks not to mandate or endorse the use of any specific (set of) standards. Priority should be given to open international standards instead of proprietary ones to guarantee the inclusion of all stakeholders in their development, enable their re-use and encourage innovation and supplier competition. Standardisation is not a one-off task and standards are likely to be adapted or substituted as technology changes and evolves.

The sixth commonality concerns interoperability testing. Although they are necessary, standards are not sufficient to achieve interoperability. A framework to test and certify how standards are implemented in devices, systems and processes is fundamental to ensure interoperability and security under realistic operating conditions. Note that conformity with communication standards does not necessarily translate into interoperability among communicating devices and systems due to certain degrees of freedom that developers typically face in implementing a communication standard. Testing therefore needs to cover conformity assessments to meet the requirements of standards and interoperability tests among devices and systems.

EXPERIENCES WITH INTEROPERABILITY IN ELECTRICITY AND HEALTHCARE

Different use cases can inspire different solutions. We look at three different experiences. First, the North American Green Button standard that has been used for newly emerging services based on data-sharing and could inspire solutions for these kinds of services in Europe. Second, the ENTSO-E approach that has been applied to existing services provided by European TSOs with many legacy systems and might inspire the approach for existing retail services. Third, achievements in the healthcare sector that can also be a source of inspiration.

The North American Green Button initiative is an industry-led effort launched in the US in January 2012, and it has since been expanded to Canada. The initiative was a response to a White House call-to-action to provide utility customers with easy and secure access to their energy usage information in a consumer-friendly and computer-friendly format via a green button on the websites of utilities for electricity, natural gas and water. Green Button essentially covers two capabilities which relate to different parts of the standards it is based on. First, the ‘Green Button Download My Data’ capability allows customers to download their data in a common XML format that is defined in the Energy Service Provide Interface (ESPI) standard for energy usage information communicated from back-end utility data systems. Second, the ‘Green Button Connect My Data’ capability is based on a data-exchange protocol defined in the ESPI standard for the automatic transfer of data from the utility to a third party based on customer consent.

ENTSO-E has gained experience with interoperability in the implementation of data exchange requirements related to the ENTSO-E Transparency Platform, the Ten-Year Network Development Plan and the electricity network codes and guidelines. In the following, we refer to coordinated capacity calculation.[24] Fundamental to the methodology applied by ENTSO-E is the aim to define a ‘common language’ as the basic building block for achieving interoperability across Capacity Calculation Regions (CCRs). An ‘implementation guide’ lists agreed terms and definitions and documents the coordinated capacity calculation business process in a standardised way by means of use case diagrams, roles and their descriptions, activity diagrams and sequence diagrams. Together, these build a generic framework that can accommodate specific local or regional needs, for example by including optional sequences in the sequence diagram to account for data exchanges only required in certain CCRs. Building on these elements, the specific data exchanges are defined in more detail using techniques based on Unified

[24] Capacity calculation is a challenging task for three main reasons: It is based on data exchanges among all European TSOs, Regional Security Centres (soon Regional Coordination Centres) and ENTSO-E. It is a cross-domain business process covering both the market and the network domain. And, different Capacity Calculation Regions follow different calculation methods (Flow-based and Net Transfer Capacity), which come with different data exchange requirements.

Modelling Language (UML). ENTSO-E uses international and European standards but has also been engaged in standardisation activities to develop technical specifications and standards tailored to the needs of European TSOs.

Table 18 maps the Green Button and the ENTSO-E experience onto the common aspects of interoperability frameworks introduced above.

In the healthcare sector[25], interoperability is recognised as one of the key drivers of eHealth as well as one of the greatest challenges in healthcare IT. What has proven successful in the health sector can be described as a multi-step use-case-driven profile-based test-oriented approach to achieving interoperability. A unique element in healthcare interoperability is how testing is carried out. Large-scale international test events are organised on a regular basis, and they provide implementers with the possibility of demonstrating component interoperability and compliance with standards or profiles. Testing typically takes place in a neutral environment with the activities covered by a non-disclosure agreement, which allows for cross-vendor collaboration and the removal of barriers to integration that might otherwise need to be addressed ex-post, on site and at the customer's expense already during the product development phase. A number of research projects, including the Austrian initiative "Integrating the Energy System (IES)" have provided proof-of-concept for transferring the healthcare approach to the energy sector (Gottschalk et al., 2018). Note that we are already experienced in drawing inspiration from the healthcare sector as the Green Button initiative was inspired by the Blue Button, which enables people to access and download their own health information.

Table 18: Mapping of selected experiences with interoperability in the electricity sector onto common aspects of interoperability frameworks introduced above, source: Reif and Meeus (2020)

	North American Green Button	ENTSO-E
Regulation/policy	U.S. states including California, Illinois, Colorado, Texas, New Hampshire and New York have Green Button data access and sharing policies in place. Several other states are in the process of reviewing data access policies.	EU Electricity Network Codes and Guidelines
Roles and responsibilities	Covered in the NAESB REQ.21 - *Energy Services Provider Interface* Model Business Practices standard	Harmonised Electricity Market Role Model
Business process	The model for business practices and use cases part of the Green Button standard	Business Process Implementation Guides incl. terms and definitions, business process description, use case diagram, sequence diagrams, etc.
Information model, data format and communication protocol	Common XML format and data exchange protocol as specified in the Green Button standard	Common Information Model (CIM) families of profiles: Common Grid Model Exchange Specification (CGMES) and European Style Market Profile (ESMP), 'harmonised data format' CIMXML and XML, Secure Advanced Message Queuing Protocol

[25] We mostly base this paragraph on the Interoperability Guideline for eHealth Deployment Projects, a deliverable of the eStandards project under call H2020-PHC-2014 that provides a comprehensive summary of the approach followed in healthcare. How this approach is implemented in practice can be seen in the example of Integrating the Healthcare Enterprise (IHE). IHE is an international non-profit organisation that is active worldwide to bring together healthcare IT system users and developers to address interoperability issues that impact clinical care. The term electronic health services ('eHealth') describes the use of information and communication technologies (ICT) in health-related products, services and processes, for example e-prescriptions and electronic health records.

Use of standards	The Green Button standard is based on the North American Energy Standards Board's Energy Services Provider Interface (NAESB ESPI) data standard and its underlying energy usage information model seed standard, the NAESB "PAP10" REQ 18/WEQ19 standard	International and European standards and technical specifications
Interoperability testing	Yes, conformance testing and Green Button certification via the Green Button Alliance Testing & Certification Program	Yes, CGMES conformity assessments and CIM interoperability tests

GOVERNANCE RECOMMENDATIONS

So far, the existing EU governance for interoperability in energy has covered stakeholder dialogue and standardisation. We could increase the ambition in these two activities, and in addition consider the creation of an EU entity for interoperability management that takes on ownership of the improvement process by formalising best practices and taking responsibilities in terms of implementation monitoring and reporting. Table 19 summaries our recommendations.

Table 19: Governance recommendations for the EU implementing acts on interoperability and data access

	Stakeholder dialogue (existing)	European standardisation (existing)	EU entity for interoperability management (new)
High ambition scenario	• Set up an interoperability stakeholder committee	• formally require ENTSO-E, ENTSOG and the new EU DSO Entity to contribute to standardisation activities, including testing and profiling	• set up an EU entity for interoperability management with three groups of tasks: (1) formalisation of best practices, (2) implementation monitoring and reporting, (3) interoperability testing
Low ambition scenario	• Renew the mandate of the ESGTF	• integrate customer data exchange and access into the annual Union standardisation work programme	–

First is stakeholder dialogue. Since its foundation in 2009, the European Smart Grids Task Force (ESGTF) has been the main body for formalised stakeholder dialogue with the European Commission and for sharing national experiences in the area of smart grids.

- In a low ambition scenario, the European Commission would renew the mandate of the Task Force to advise on emerging topics (e.g. demand side flexibility) and share experiences in Member States.
- In a high ambition scenario, the European Commission could aim to centralise the discussion at the EU level by setting up an 'interoperability stakeholder committee' to be co-organised by ACER, the EU DSO entity, ENTSO-E and ENTSOG following the example of the electricity network codes and guidelines. Given the scope of the complex challenge involved in achieving full

interoperability of energy services within the EU and the vast differences that currently exist between Member States, it is not unreasonable to assume that the implementing acts will require stakeholder coordination during the implementation phase, or even the development of so-called terms and conditions or methodologies as we have seen with network codes.

The interoperability stakeholder committee would ensure that relevant stakeholders are kept up to date with developments and provided with a forum in which to express their views and feedback throughout the implementation phase. As with the operations network code family, the committee could consist of various technical expert groups that are dedicated to groups of use cases, e.g. existing retail processes, emerging use cases based on data sharing or related to demand side flexibility. The working groups could be tasked with developing and documenting formal rules governing the related data exchanges using commonly agreed methods and tools. Such rules can include common terms and definitions, harmonised roles and responsibilities, generic use cases, activity and sequence diagrams, commonly agreed information standards, data models, profiles and specifications for data exchange and rules and architectures for data aggregation.

The second is European standardisation. For the application of Union harmonisation legislation, the European Commission is entitled to request the European Standardisation Organisations (ESOs) CEN-CENELEC-ETSI to develop harmonised standards. Examples of relevant mandates given to ESOs in the past are M/490 to support smart grid deployment, M/441 in the field of smart metering and M/468 concerning the charging of electric vehicles. ESOs are required to encourage and facilitate appropriate representation of all relevant stakeholders and their effective participation.

- In a low ambition scenario, the European Commission could integrate customer data exchange and access into the annual Union work programme on European standardisation. The European Commission may request one or several ESOs to draft a relevant European standard or European standardisation deliverable. An example of an existing standardisation gap seems to be customer consent management and customer authentication.
- In a high ambition scenario, the European Commission could formally require ENTSO-E, ENTSOG and the new EU DSO Entity to contribute to standardisation activities relevant to their formal tasks and responsibilities. In addition to standardisation, formal requirements for European associations to contribute to interoperability testing and profiling could also be considered in the future.

The third is an EU entity for interoperability management. Experience with interoperability in the healthcare sector has shown that reaching and maintaining interoperability requires a continual improvement process due to changing policies and regulations, emerging use cases and new requirements, the continual development of IT and ICT, rapid changes in the application of components, interfaces and software and continual developments in standardisation. Standardised processes and methods are needed as is described throughout this paper. An entity is needed that takes on the ownership of this improvement process and ensures comprehensive stakeholder participation, including the provision of non-discriminatory access to its results to all relevant stakeholders in the form of, for example, standards, documents or tools. The entity would need to be cross-domain in nature to integrate at least electricity and gas but should also remain open at the frontiers of the traditional energy sector in the light of trends like the internet of things and electric vehicles.

Three groups of tasks can be envisaged for the new EU entity.

- First, formalisation of best practices. We need to re-use and extend best practices with interoperability. The EU entity could be charged with creating and maintaining an 'interoperability repository' as a reference point for national implementation. The repository would serve as a collection of all documents specifying the formal rules governing customer data exchange developed by the working groups of the 'interoperability stakeholder committee' described above. Non-discriminatory access to the repository would need to be ensured for all relevant stakeholders. With increasing use cases that span domains, e.g. flexibility services offered by a (group of) customer(s) to a network operator, the repository could be integrated with similar ones (e.g. ENTSO-E's CIM library) at a later stage. It could be worth considering H2020 research projects as a multiplier of best practices and a facilitator for the identification of standardisation gaps. As they naturally deal with innovative practices, H2020 consortia could be well-suited to suggest expansions of existing methodologies and models according to the requirements of new use cases, for example the Harmonised Electricity/Gas Market Role Model and the Common Information Model.

- Second, implementation monitoring and reporting. It can be assumed that progress towards commonly defined interoperability targets for energy services will advance at varying speeds, given the existing differences at the national level regarding customer data management, access and exchange. With multiple implementing acts being probable, implementation speeds might also differ according to the type of service, i.e. existing, emerging based on data-sharing or emerging related to demand side flexibility. Member States could be required to draft national interoperability action plans defining their pathways towards the interoperability target model and to update them on a regular basis. The European Commission could require the EU entity for managing interoperability to administer and maintain an integrated framework for monitoring, assessing and reporting on progress in implementing the national interoperability action plans using key performance indicators and measurable targets.
- Third, interoperability testing. The example of the healthcare sector shows the importance of well-structured easily accessible recurrent testing events for component interoperability and standard/profile conformity. An EU entity for interoperability management would be well-placed to provide the necessary neutral environment for large-scale testing events.

Note that in the case of healthcare, the entity that takes on some of these tasks is the non-profit initiative Integrating the Healthcare Enterprise (IHE), which consists of vendors and users of healthcare devices. We are not certain about the feasibility of such an approach for electricity and gas customer data in Europe. However, there are other candidates that could be responsible for all or some of the above-mentioned tasks, for example the Joint Research Centre (JRC), ACER, the EU DSO Entity, ENTSO-E and ENTSOG.

5.2.3 Cross-sectoral interoperability in the context of smart electricity metering[26]

Different perspectives onto interoperability: Narrow vs. Broad

Many different definitions of interoperability exist, as was described in 5.2.1. They vary both between and within sectors. Generally, two perspectives can be adopted, that are also reflected in the definitions. The first is a narrow perspective onto interoperability, which translates into a focus on the technical levels of interoperability. It typically covers interoperability among ICT systems. The second is a broad perspective onto interoperability at the level of organisation, which considers legal, regulatory and social interoperability aspects. In this regard, the interoperability of ICT systems enhances the interoperability of organisations.

Interoperability definitions in smart electricity metering, electromobility and buildings

An analysis of interoperability definitions used in the context of smart electricity metering, electromobility and buildings has shown that they are typically dependent on the context (Figure 29). The formulation of a definition suggests whether a narrow or a broad perspective is adopted. It also gives a hint as to the most important interoperability issues in that context.

[26] This section is a summary of Reif and Meeus (2022).

In the context of building information models (BIMs), interoperability is the "*ability of BIM tools from different vendors to exchange building model data and operate on that data. Interoperability is a significant requirement for team collaboration*." (Eastman et al., 2008)

"*In the context of EV [electric vehicle] roaming, seamless interoperability means that, ultimately, a user (an EV driver) can charge at any public charge station, regardless of the CPO [charge point operator] of that station and regardless of the MSP [mobility service prover] the user has selected for mobility services and payment*." (van der Kam and Bekkers, 2020)

In the context of smart metering, interoperability means "*the ability of two or more energy or communication networks, systems, devices, applications or components to interwork to exchange and use information in order to perform required functions*." (Directive (EU) 2019/944 of the European Parliament and Council,2019).

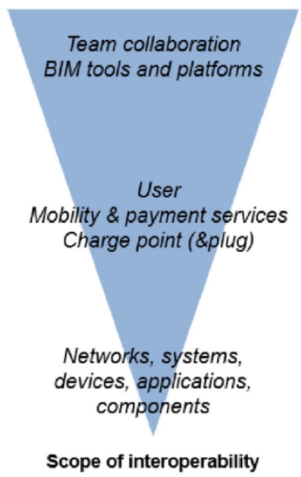

Figure 29: Definitions of interoperability in the contexts of smart electricity metering, electromobility and buildings, source: Reif and Meeus (2022)

In the context of smart electricity metering, the definition of interoperability as introduced in article 2(24) of Directive (EU) 2019/944 reflects a narrow perspective. The focus is on the interoperability of devices and their ability to exchange information to perform certain functions. Indeed, until recently the European debate around interoperability was focused on technicalities such as (common) data formats (see also Subsection 5.1.2), or smart metering standards and interfaces. The CEP brought a change in perspective as it requires Member States to facilitate the interoperability of energy *services*. Such services include traditional retail services like billing or supplier switching, emerging services based on data sharing, and future services based on real-time data. Facilitating the interoperability of energy services requires the solving of interoperability issues that go way beyond the technicalities of information exchange. Requirements include non-exhaustively legal and regulatory alignment across different geographical levels, the alignment of business processes among organisations, agreements on roles and responsibilities at least at the European level, agreements on data privacy and security, and common solutions for mechanisms such as customer authentication and consent.

In the context of electromobility, the perspective onto interoperability seems to be broader. Specifically, for electric vehicle (EV) roaming (i.e. any EV driver can charge at any charging station), van der Kam and Bekkers (2020) consider the need for interoperation of hardware and software to enable services which are requested (or offered) by users of EV roaming. The same authors list a number of issues that act as barriers to the seamless interoperability of EV charging infrastructure related to charge points and plugs, payment systems and charge point information exchange systems.

In the context of building information models (BIM), the scope of interoperability seems even broader.[27] To ensure the successful construction and operation of a building, data needs to move seamlessly between different tools and platforms and the involved teams and crafts need to be able to collaborate. Interoperability issues differ depending on the lifecycle phase of a building. A lack of interoperability between BIM systems represents issues during the planning and construction phase. During the operation phase, however, interoperability issues are more often related to, among others, the integration of a building as active participant in the energy system.

[27] BIMs are used to create, collect and manage data during the design, construction and operation phases of the building. They ensure that different teams and crafts can collaborate in real-time by integrating multi-disciplinary data in a detailed digital representation of the building.

EU-LEVEL SOLUTIONS TO INTEROPERABILITY ISSUES IN SMART ELECTRICITY METERING, PUBLIC ADMINISTRATION AND HEALTHCARE

Some sectors beyond electricity, including public administration and healthcare, have long-standing experiences with interoperability. Such experiences could act as inspiration to find sector-specific solutions to interoperability issues related to smart electricity metering and to address the cross-sectoral interoperability challenges related to an integrated energy system.

- In the public administration sector, over the past 20 years, interoperability initiatives have been driven by the European Commission. The aim has been to avoid a fragmented landscape of non-interoperable solutions to deliver public services across Member States. A governance system for public administration interoperability exists, which includes shared responsibilities between the EC and Member States.
- In the healthcare sector, the first eHealth Action Plan was published in 2004. Since then, the EC has developed targeted policy initiatives to foster the adoption of interoperable eHealth services, enable a seamless pan-EU exchange of health information and enable secure and fast access to public health data and patent information. Healthcare interoperability is typically a national matter, often supported by European networks.

EU-level interoperability solutions that have been implemented in the smart electricity metering, public administration and healthcare sector can be grouped into commonly applied and individually applied solutions. We have identified three solutions that have been applied across sectors (stakeholder engagement activities, tools and knowledge sharing and standardisation activities) and two solutions that have been applied by individual sectors (monitoring and reporting and interoperability profiling and testing). Table 20 summarises the solutions.

Table 20: EU-level solutions to interoperability issues in the electricity, public administration, and healthcare sectors

	Smart electricity metering	Public administration	Healthcare
Stakeholder engagement activities	• European Technology Platform • European Smart Grids Task Force • Implementing acts following Directive (EU) 2019/944, incl. a potential 'competent authority'	• ISA² committees and working groups	• eHealth Network • eHealth Stakeholder Group and eHealth Task Force
Tools and knowledge sharing	• H2020 BRIDGE initiative (incl. use case repository); Horizon Europe call for an 'Interoperability Community'	• Joinup platform • European Interoperability Reference Architecture and European Interoperability Cartography	• Large-scale European pilot projects (e.g. epSOS, Antilope)
Standardisation activities	• European standardisation mandates (e.g. M/490) • CEN-CENELEC-ETSI work (incl. Smart Grid Architecture Model (SGAM))	• Rolling Plan for ICT standardisation	• European standardisation mandates (e.g. M/403) • eHealth standardisation activities

Monitoring and reporting		• Compliance monitoring in the context of ISA² and reporting mechanism for National Interoperability Frameworks (NIFs)	
Interoperability profiling and testing			• Integrating the Healthcare Enterprise (IHE) process to implement and test standards-based interoperability[28]

Stakeholder activities

In the context of smart electricity metering, the European Smart Grids Task force has been acting as an advisory expert group to the European Commission since 2009. Relevant was also the set-up of the European Technology Platform for Smart Grids in 2005. The implementing acts following Directive (EU) 2019/944 (see Section 5.1.2) could bring certain level of centralisation of interoperability competences in the form of a dedicated "EU competent authority."

In the public administration sector, several programmes exist at EU level to provide financial support for interoperability. One example is the dedicated ISA² funding programme, that has a dedicated governance structure composed of committees and working groups. Other relevant, but more general, funding programmes for public administrations are the Connecting Europe Facility (CEF) and the Digital Europe Programme.

In the healthcare sector, a voluntary "eHealth Network" was established based on requirements from Directive 2011/24/EU to connect the relevant national authorities. The network is responsible to enhance the cross-border exchange of health data and improve the interoperability of national eHealth systems. Other relevant expert groups that interact with the EC include the permanent eHealth Stakeholder Group and a temporary eHealth Task Force.

Tools and knowledge sharing

In the electricity sector, an important actor is the Horizon Europe BRIDGE initiative by the EC[29]. BRIGE is active in the provision of tools and organisation of events that support knowledge sharing among European RD&I projects. BRIDGE has also set up common tools such as a use case repository. More recently, a Coordination and Support Action has been funded under the Horizon Europe programme, that focuses on the creation of an "interoperability community."[30]

In the public administration sector, several tools have been developed to facilitate the cooperation among public administrations: The European Interoperability Reference Architecture (EIRA) defines a set of architectural building blocks for the benefit of building interoperable e-government systems and facilitating the delivery of cross-border public services.[31] The European Interoperability Cartography (EIC) is a repository of interoperability solutions.[32] The Joinup platform is a collaborative environment set up by the EC to facilitate experience sharing among Member States.[33]

[28] Note that IHE is not an EU-level initiative, but several IHE profiles were recognised by the European Commission to be used in public procurement.
[29] See https://bridge-smart-grid-storage-systems-digital-projects.ec.europa.eu/
[30] See https://intnet-project.eu/
[31] See https://joinup.ec.europa.eu/collection/european-interoperability-reference-architecture-eira/about
[32] See https://joinup.ec.europa.eu/collection/cartography/solution/european-interoperability-cartography-eic
[33] See https://joinup.ec.europa.eu/

In the healthcare sector, European RD&I projects such as epSOS and Antilope have contributed significantly to creating the building blocks for cross-border health exchange and facilitating knowledge exchange among Member States.[34]

Standardisation initiatives

Standardisation activities are relevant for all interoperability levels. On the technical levels, they support the harmonisation of requirements for devices and systems. On the higher levels, standards help to document business processes in a common way across organisations.

In the electricity sector, a relevant initiative was the standardisation mandate M/490, which resulted in the development of the SGAM (see also section 5.1.1).

In the public administration sector, the annual Rolling Plan for ICT Standardisation provides an overview of ICT standardisation priorities.[35] The Plan does not cover exclusively public administration, but also lists priorities in sectors such as energy and health.

In the healthcare sector, the EC issued standardisation mandate M/403 to the ESOs, requiring them to agree on implementable standards, technical reports, guidelines and methods in the domain of eHealth.

Monitoring and reporting

In public administration sector, a comprehensive EU governance system for monitoring and reporting national progress with interoperability exists. National administrative structures have evolved in different ways and there is not one authority that is responsible for setting digital public administration and interoperability policies. To ensure alignment in this heterogeneous landscape, the EC developed the European Interoperability Framework (EIF), a framework to organise concepts and terminology relevant for interoperability issues.[36] Based on the EIF, Member States are required to develop national interoperability frameworks and strategies. A National Interoperability Framework Observatory (NIFO) serves to facilitate the monitoring, evaluation and reporting on the implementation by the EC.[37]

Interoperability profiling and testing

Communication standards are an important building block for interoperability. However, a multitude of standards exist that may be relevant for a specific use case. At the same time, a standard might be rather general and not specific enough to (alone) support a specific implementation.

One solution has been developed in the health sector. The private non-profit organisation Integrating the Healthcare Enterprise (IHE) has set up a structured process for the selection and implementation of standards for specific use cases.[38] They have also implemented a specific governance structure that brings together users and developers of healthcare information technology on a voluntary basis with the aim of achieving interoperability of healthcare systems.[39]

CROSS-SECTORAL ASPECTS OF INTEROPERABILITY (AT THE NATIONAL LEVEL)

As described in Subsection 5.1.2, the EU-level discussions around interoperability and data sharing are increasingly seeing cross-sectoral aspects. The EC is working to implement a European single market for data to avoid uncoordinated approaches to regulating data exchanges at the national level. This includes a governance framework composed of horizontal cross-sectoral structures and vertical, domain-specific European data spaces, including in energy, health and public services. (EC, 2020b)

[34] See https://digital-strategy.ec.europa.eu/en/news/cross-border-health-project-epsos-what-has-it-achieved and https://www.antilope-project.eu/front/index.html
[35] See https://digital-strategy.ec.europa.eu/en/policies/rolling-plan-ict-standardisation
[36] See https://joinup.ec.europa.eu/collection/nifo-national-interoperability-framework-observatory/european-interoperability-framework-detail
[37] See for example https://joinup.ec.europa.eu/collection/nifo-national-interoperability-framework-observatory/digital-public-administration-and-interoperability-national-level
[38] See https://www.ihe.net/
[39] https://www.ihe-europe.net/.

The implementation at EU level could be inspired by ongoing national initiatives. In the following, the Netherlands and the UK serve as examples to describe concrete efforts to implement cross-sectoral interoperability and data sharing.

The example of The Netherlands

The Netherlands has a data governance programme to enable energy sector-specific and cross-sectoral data sharing and data-driven services. It serves to implement the requirements of the Clean Energy Package in terms of interoperability and data sharing, and to facilitate the building of a more general digital economy based on data sharing and re-use. Organisational structures and process for both the cross-sector and the energy-specific dimensions are being set up.

The cross-sectoral dimension is covered by the ministry-facilitated collaborative 'data sharing coalition'[40] which aims to enable cross-sector and cross-domain data sharing and re-use by combining existing and new sector-specific data sharing initiatives. Interoperability between these initiatives is enabled by the use of agreements that are adopted in an iterative use-case based process. The agreements can cover, for example, technical standards, data semantics, legal issues or digital identities. As a final aim, these agreements should be captured in a generic trust framework, and governed by a common governing body. One of the first cross-sectoral use cases brings together the energy and financial sectors to develop a concept for green mortgages.

The energy sector-specific dimension is covered by the new Dutch Energy Act. A new data exchange entity is set up that shall be responsible for data exchange within the energy sector. It shall also federate with the data sharing coalition on cross-sector data exchanges. TSOs and DSOs will collectively share the responsibility to operate this new legal entity, but operations should be separate from their existing grid operator business. In a first phase, the focus shall be on use cases that cover data needs for energy market facilitation processes.

The example of the UK

The UK national data strategy aims to make the UK a world-leading data economy and brings together the many data-related actions that have been initiated across government. Smart Data initiatives exist in multiple sectors to enable the secure sharing of customer data with authorised third-party providers based on customer consent. It is the aim of the government to expand Smart Data to several regulated sectors including energy. Synergies between sectoral initiatives should be leveraged to avoid a lack of interoperability and address common challenges such as the development of consent mechanisms. To facilitate the efforts and enhance the coordination across the sectoral initiative, a new “smart data working group” will be composed of experts from multiple sectors and types of profession.

Regarding standardisation, the British Standards Institution is implementing several activities to avoid duplications and redundant initiatives when it comes to standards relevant for demand side response, EV charging (points) and other smart appliances. It aims to facilitate better collaboration between relevant stakeholders to support the manufacture and use of secure and interoperable smart energy appliances.

POLICY RECOMMENDATIONS

As described in subsection 5.1.2, the implementing acts on interoperability and data access are at the centre of the policy and regulatory debate at EU level. The implementing acts are an EU level solution to tackle interoperability issues related to smart electricity metering via the definition of technical and procedural rules and requirements. Other solutions exist that could complement, or be integrated into, these acts. This work has shown that a change of perspective can help mobilise the full range of solutions, which can be inspired by progress in other sectors or at the national level. In the following, we formulate three policy recommendations based on our research.

[40] See https://datasharingcoalition.eu/

The first recommendation is to switch from a narrow to a broad interoperability perspective. Interoperability can be defined at the level of devices (narrow perspective), like in the case of smart electricity metering. It can also be determined at a higher level that considers the perspectives of individual users, teams or entire organisations (broad perspective), like in the electromobility and buildings ecosystems. The definition of interoperability as included in Directive (EU) 2019/944 has a narrow, rather technical focus. There is a risk that such a definition neglects the necessity of agreements at all levels, including between businesses/organisations and at policy, legislative and regulatory levels, to reach full interoperability of energy services. It also risks to lock-in a narrow understanding of interoperability that exacerbates the lack of academic works on the non-technical levels of interoperability in the electricity sector. Smart metering interoperability comes with challenges that reach beyond technicalities. Agreements need to be reached on all interoperability levels from business objectives and processes to functions, information exchange and models, and communication protocols and components. Policymakers should consider broadening the definition of interoperability used for smart electricity metering. The new definition should reflect the multi-level characteristics of interoperability. It should also acknowledge that the interoperability of devices is a prerequisite for the interoperability of organisations, which in turn is essential to achieving both the sector-specific and cross-sectoral objectives of the green and digital twin transition and a future integrated energy system.

The second recommendation is to take inspiration from successful interoperability solutions applied in other sectors such as public administration or healthcare. The energy sector is not the only one that wants to implement a more consumer-centric approach, and is also not the only one that is facing interoperability challenges on the way. Our research showed that EU-level solutions to interoperability issues are often similar, despite different issues across sectors. We do not suggest copying the approaches used in the public administration and healthcare sectors, but we do suggest taking inspiration where relevant. One example is to set up an EU monitoring and reporting scheme for national interoperability progress in the energy sector, in alignment with the activities conducted under the implementing acts. This can be inspired by the monitoring framework that has been set up in the public administration sector. Another example is to create a scheme for different types of interoperability testing. This can be inspired by the approach developed in the healthcare sector, but it may need to be extended to cover additional testing approaches. The “interoperability” community created in the framework of Horizon Europe may facilitate the collaboration of relevant initiatives to implement these solutions.

The third recommendation is to take inspiration from developments at the national level, especially when it comes to cross-sectoral aspects of interoperability. Synergies between sectors should be exploited better to avoid redundant activities and pool the relevant resources and expertise. One example is to set up a governance framework for interoperability that covers cross-sectoral and sector-specific aspects. The already ongoing relevant EU activities under the Green Deal can be inspired by the Dutch experience of setting up such a double layer governance scheme. Another example is to enhance sector convergence in standardisation to avoid duplication of efforts. This can be inspired by the efforts in the UK to look for convergence in standardisation relevant for demand response, EV charging and smart appliances.

5.3 Relevant demonstrators’ results on interoperability and relevance for new European rules

In this section we highlight the relevant results of the INTERRFACE demonstration pilots for the development of the implementing acts on interoperability and data access. A description of the demos and the use cases addressed by them is provided in Section 3.

The majority of the demos focuses on the provision of congestion management and balancing services; some of them address network investment deferral and the provision of non-frequency ancillary services. These services are not of immanent relevance for the implementing act that is currently under development. As is described in Section 5.1.2, the first interoperability implementing act centres around the provision of validated historical and non-validated near-real time metering and consumption data in the context of data sharing services. Demand-side flexibility is likely the focus of a second implementing act on interoperability to be developed in close alignment with the network code (or guideline) on demand response. However, several inputs from the demos have been identified as relevant for the overall debate on interoperability in the energy sector.

The **Italian pilot "DSO and Consumer Alliance"** provides insight into the use of different smart meters (electricity, water and heating) for demand response programs. It aims at exploiting synergies at municipal scale and in a multi-energy microgrid (including the electricity natural gas, district heating and urban water distribution networks) for congestion management and balancing services. Most final users are equipped with smart meters:

- All the final users of electricity and DER plants have a *smart electric meter*
- All the final users (1300) of the district heating network have a *smart thermal energy meter***.** Only static thermal meters are used that communicate through a double protocol, an open metering system (OMS) and a proprietary protocol (R4) to guarantee a wider coverage distance.
- Several final users (1600) of the water distribution network have a *smart water meter*. Two types of smart water meters are used, ultra-sonic static and a volumetric ones. Both meters interact with the remote reading infrastructure in a unidirectional manner, i.e. they transmit but do not receive the signal and in the data transmission phase they communicate with two protocols, one open metering system (wireless M-bus OMS), and one proprietary protocol (M-bus R4).

The final users can easily access their data via a web or mobile application. To ease data handling, the data is presented in an understandable way.

Regarding water and heating, the multi-utility achieves a twofold goal: it detects on time energy losses and water leakages thus increase savings, and it raises the awareness of final users aware of their thermal energy and water consumption. The remote acquisition system of the smart meters allows managers to view real-time, log consumption, analysis and verification. The cloud of meters collects and stores in all data coming from both district heating and water networks. The data are stored in a web-based application, provided by the supplier of the smart meters, running as a service on an external high security data center. The portal provides all key features for efficient processing of metering data and easy administration of meter reading via Fixed Network or Walk-By/Drive-By. Accessing the application 24/7 from any place and operating system increases the flexibility of administering metering data, read out processes and the supply network.

Regarding electricity, those residential users' homes participating in the "early stage" demand/response program were equipped with a monitoring system. The monitored data is sent to and stored within a cloud platform in order to make them available to the end user via a dedicated app. The final users were also able to interact with the local DSO through the app. The app and the web-based portal were developed with the aim of being simple and usable even by inexperienced people and, at the same time, will allow diving into the details of the measures. This helps to increase final users' awareness of their consumption and empowers them to participate in flexibility programs.

The results of the Italian pilot demonstrate the successful integration of multiple smart meters for the benefit of providing congestion management and balancing services to the system operators. The demo also highlights the potential for smart meters beyond electricity, an area that deserves more attention in research projects as it can support the twin green and digital transition to a future integrated energy system.

The **Bulgarian Pilot "Intelligent Distribution Nodes"** provides insights into the usage of an intelligent system including an information hub to leverage the flexibility of a multi-storey building. The integrated intelligence helps to optimise the building's electricity consumption according to market prices and reduce the energy bill for the aggregated consumers in the building. The system has three modules:

- an *energy resource management system* that is responsible for optimising the operation of the building's energy assets while meeting customer demands. The building's assets portfolio consists of

PV generation, conventional demand, and a centralized battery electrical storage system, which usage is optimized according to market and operating conditions and to reduce consumption.

- a *Grid Services Management System*, whose objective is to increase overall income for the building's users by managing the assets portfolio to provide flexibility and ancillary services to grid operators. It calculates optimal bids to be offered to operators for congestion management and balancing services through corresponding service markets and/or agreements.
- an *Information Hub*, which sits at the core of the concept and contains artificial intelligence algorithms to analyse data, run neural networks to obtain predictions or clusters giving information to the users regarding the buying and selling of energy and services.

The three modules work independently of one another, but coordinate to optimise the overall operations of the Intelligent Distribution Nodes. The objective is to provide grid services to both DSO and TSO via the IEGSA platform. This pilot provides insights into the relevant capabilities of an innovative control system, notably the implemented information hub: data consolidation, data quality, data integration and data governance. It demonstrates the interoperability of Intelligent Distribution Node with other digital assets in the network and used IEGSA IT platform as a key resource to centralize information flow for all stakeholders involved.

The results of the Bulgarian demo are also relevant for the integration of buildings as active participants in the energy system. An analysis needs to be performed on the resources of the building, with the purpose of understanding the different processes and operational schedule for the different users. Specific algorithms are developed to predict the consumption and the behaviour in specific parts of the building. After the data collection exercise, the process of evaluating energy efficiency in buildings requires energy efficiency indicators that provide the level of energy consumption performance.

The **Baltic-Nordic pilot "Single Flexibility Platform"** provides insights for a future interoperability implementing act on demand-side flexibility and the implementation of interoperable flexibility market platform. The demo results show the implementation of novel technical solutions to manage grid and system limitations via coordinated procurement of distributed flexibilities and to operate efficient and interoperable market and data exchange platforms for distributed flexibility exchange between market parties.

The Baltic-Nordic pilot relies on the IEGSA / Single Flexibility Platform, which is comprise of four main modules: Flexibility Register, TSO/DSO coordination platform, Single Market Interface and Settlement Unit. The flexibility register is a component that manages the flexibility resources and grants them access to specific market products (portfolio management). The TSO-DSO coordination platform handles the qualification processes which ensure that market actions do not violate the technical limits of the network. The Single Market Interface enables a uniform information exchange interface towards systems communicating with IEGSA. The settlement unit identifies whether the traded flexibility was delivered as promised and communicates these results forward.

A key benefit of **IEGSA** is its platform that acts as a common architecture and enables the connection, data and information exchange across Europe between TSOs, DSOs, market operators, flexibility service providers, customers, and data hubs. The architecture is SGAM-based and essentially lies between the business and the component SGAM layers covering the function, information and communication layers. It enables the assets and systems that lie in the component layer to work together, to communicate and exchange information and data in a standardized manner (through the application of the Common Information Model), in order to perform the processes described in the Business Layer.

The blend of assets, datasets, tools, services, and market models optimizes operations and allows the introduction of standardized/harmonized services and market designs to cover the needs of more stakeholders of the energy value chain. The conceptual and logical architecture design of the IEGSA platform essentially allows the facilitation of cross-border interactions among system operators as well as cross-border trading.

The capabilities and governance of IEGSA are relevant for the interoperability discussion around future implementing acts on demand response as well as on a common European common data space for energy. The integration of IEGSA with several other marketplaces and platforms makes it a central hub which promotes data transparency and flexibility. The interoperability enables reusing modules, thus lower costs for its users.

6 Conclusions

In the following, we present the key findings of our research on demand-side flexibility and interoperability and data access.

DEMAND-SIDE FLEXIBILITY

The Clean Energy Package Electricity Directive (EU) 2019/944 called on the Member States to establish regulatory frameworks for the procurement of flexibility by DSOs, including incentives and adequate remuneration to recover reasonable corresponding costs (Art. 32). This aims to improve the efficiency of the operation and development of distribution systems. At the same time, the Electricity Regulation (EU) 2019/943 included demand response, including rules on aggregation, energy storage, and demand curtailment rules as an area for a new network code (or a guideline). This would bring more detailed technical rules to be applied by the Member States in a harmonised way.

An uncoordinated adoption of national rules for flexibility may lead to entry barriers for demand-side flexibility. This report contributes to the debate by addressing the identified issues, following the CEP introduction, based on the developed optimization models and the lessons learnt from the demonstrators of the INTERRFACE project. Our findings are divided into two parts. The first part covers the long-term flexibility use case of network investment deferral, with results coming from our own research and simulation work. The second part covers the short-term flexibility use cases of congestion management and balancing, with results coming from the INTERRFACE demonstrators.

For the long-term use case of flexibility, i.e. network investment deferral, our simulation of the interaction between the DSO and residential consumers showed that there are different regulatory choices that could impact the potential of demand-side flexibility. The key related findings are:

- The cost-reflectivity of distribution network tariffs: We find that introducing explicit demand-side flexibility schemes in combination with cost-reflective capacity-based network tariffs lead to higher welfare gains than when combined with partly cost-reflective demand-side flexibility.
- The compensation levels: The results obtained through the developed models underline that it is difficult for the regulator or the DSO to set the correct level of compensation in the presence of active and passive consumers. For low compensation levels, passive consumers will be only partly compensated for the electricity load curtailment. However, for high levels of compensation, it becomes too attractive for prosumers who will game it and use their DERs against the system needs to increase their individual welfares.
- Voluntary versus mandatory demand-side flexibility: We compared these two schemes based on their potential for realizing welfare gains. The results suggest that regulators and DSOs should consider introducing a mandatory scheme for demand-side flexibility, i.e., mandatory demand-side connection agreements for its customers. The realized welfare gains are higher than when the customers opt voluntarily for such schemes. The applied load reductions take place only during the non-frequent high consumption events and represent a small fraction of the consumers' annual electricity demand.

For the short-term use cases of flexibility, i.e. congestion management, balancing or voltage control purposes, the results of the INTERRFACE demos projects shed the light on some important regulatory aspects to consider:

- Product definition and harmonisation: With the multitude of technologies and their related technical parameters, the experiences from the demos recognise that product definition and harmonisation are difficult tasks, especially when residential users are involved. However, such processes are key to enable the wide participation of actors in flexibility markets.
- The coordination and data exchange between system operators and FSPs: The demos results show that such coordination, which was embedded in grid qualification processes, could help to mitigate

congestion. This aims to ensure operational stability between TSO and DSO networks through evaluating the FSP resources using network information directly from the system operators. On data exchange, the demos results highlight the importance of utilising grid data as part of the flexibility trading to handle network constraints and flexibility needs.

- Flexibility resource register: Such register which collects all the significant data/information of flexibility resource, including spatial information, is crucial to enable TSOs' and DSOs' flexibility procurement from the right locations. The demo results highlight the importance of such register, for example, in the prequalification processes. However, several challenges and open issues have also been identified during the project. These are related to the future scale and functionalities of the register, as well as the proper definition and allocation of related roles and responsibilities.

INTEROPERABILITY AND DATA ACCESS

The recast of the Electricity Directive (EU) 2019/944 in the Clean Energy Package entitles the European Commission to adopt implementing acts specifying interoperability requirements and non-discriminatory and transparent procedures for access to metering and consumption data as well as data required for customer switching, demand response and other services. This aims to promote competition in retail markets and to avoid excessive administrative costs for the eligible parties. The development of the first of a series of implementing acts has already started. With the publication of the Fit for 55 Package, the scope of the debate was expanded to increasingly cover cross-sectoral aspects in light of a future energy system integrated with sectors such as buildings or electromobility.

This report contributes to the debate by analysing existing interoperability experiences within and beyond the electricity sector, including in the context of the INTERRFACE demonstrators, and providing a number of policy recommendations.

To contribute to the policy and regulatory debate surrounding the implementing acts on interoperability and data access, we have analysed interoperability frameworks and existing interoperability experiences in the electricity and healthcare sectors. The key findings are:

- The EU implementing acts on interoperability and data access should be ambitious in addressing the multiple dimensions of interoperability. Different multi-dimensional interoperability frameworks exist. While they agree that full interoperability can only be achieved if all dimensions are addressed, they do not agree on either the number of dimensions or on labelling them. We identified commonalities across the frameworks that need to be addressed to achieve full interoperability of energy services within the EU. These are regulation and policy, business processes, information models, data format and communication protocols, use of standards, and interoperability testing.
- Inspiration can be drawn from existing experience with interoperability in the electricity and the healthcare sectors. The experiences of the North American Green Button initiative with utility customer data and of ENTSO-E with network code requirements for the exchange of market and network data show that different use cases can inspire different solutions. Moreover, experience with interoperability in healthcare is very advanced and can serve as an inspiration for energy, especially regarding interoperability testing and governance.
- Governance is a key issue in achieving interoperability. The existing governance mainly covers stakeholder dialogue and European standardisation. We provided ideas on how to use the EU implementing acts on interoperability and data access to step up these efforts. In addition, we think governance should be extended to include formalisation of best practices, implementation monitoring and reporting, and interoperability testing. We reflected that this governance could be taken on by a new EU entity.

To contribute to the policy and regulatory debate around cross-sectoral interoperability in the context of a future energy system integrated with sectors such as buildings and electro mobility, we have analysed experiences in different ecosystems (smart electricity metering, electromobility and buildings), different sectors (smart electricity metering, healthcare and public administration) and at the national level (The Netherlands, and the UK). The key related findings are:

- The definition of interoperability depends on the context and reflects a narrow (at the level od devices and systems) or broad (at the level or organisations) perspective. The elements included in a definition give an indication as to open interoperability issues in a specific sector or ecosystem. We recommend broadening the definition of interoperability that is used for smart electricity metering. The new definition should consider the multiple levels of interoperability and acknowledge the interoperability of devices as prerequisite for the interoperability of organisations.
- Despite differences in the specific interoperability issues a sector faces, the solutions applied at EU level are often similar across various sectors. More advanced sectors such as healthcare and public administration can serve as a basis for the further development of interoperability solutions for smart electricity metering. One example is to set up an EU monitoring and reporting scheme for national interoperability progress in the energy sector, in alignment with the activities conducted under the implementing acts for interoperability and data access. Another example is to create a scheme for different types of interoperability testing. The "interoperability" community created in the framework of Horizon Europe may facilitate the collaboration of relevant initiatives to implement these solutions.
- Synergies between sectors should be better exploited to avoid redundant activities and pool the relevant resources and expertise. Inspiration can be drawn from developments at the national level, especially when it comes to cross-sectoral aspects of interoperability. One example is to set up a governance framework for interoperability that covers cross-sectoral and sector-specific aspects, in line with the ongoing EU activities in the context of the Green Deal. Another example is to enhance sector convergence in standardisation to avoid duplication of efforts, for example in the areas of demand response, EV charging and smart appliances.

Some of the elements that we have discussed in our research have recently been taken up in one way or another at the EU level. As described in subsection 5.1.2, the draft implementing acts published by the European Commission in mid-2022 are taking account of the various interoperability layers that exist (EC, 2022a). They also require the establishment of a common repository of national practices to collect information on how the reference model is implemented in the Member States and make it publicly available. It is foreseen that ENTSO-E and the EU DSO Entity take on this task as a shared responsibility and based on the existing responsibilities of the two bodies related to data management and data interoperability.

The Digitalisation of Energy Action Plan published by the European Commission in October 2022 aims to strengthen stakeholder dialogue (EC, 2022b). The action plan foresees that the Smart Grids Task Force will be formally re-established as Smart Energy Expert Group, which will have greater responsibilities and involve all Member States and additional stakeholders. In addition, the European Commission will set up a Data for Energy Working Group to bring together the Commission, the Member States and the relevant public and private stakeholders for contributing to building the European framework for sharing energy-related data. The working group will help strengthen the coordination at EU level on data exchanges for the energy sector, defining the driving principles and ensuring consistency across different data-sharing priorities and initiatives. The working group will focus its work on developing a portfolio of European high-level use cases for data exchanges in energy that are key to deliver on the objectives of the Green Deal and the Digital Decade, including, initially, flexibility services for the energy markets and grids, smart and bi-directional charging of electric vehicles, and smart and energy-efficient buildings.

We also analysed the results of the INTERRFACE demonstrators with regard to insights that may be relevant for the development of the EU implementing acts on interoperability and data access. However, the majority of the demos focuses on the provision of services (i.e. congestion management, frequency and non-frequency ancillary services, network investment deferral) that are not of immanent relevance for the implementing act that is currently under development. The first implementing act centres around the provision of validated historical and non-validated near-real time metering and consumption data in the context of data sharing services (EC, 2022a). Demand-side flexibility is likely the focus of a second implementing act on interoperability to be developed in close alignment with the new network code on demand response. However, several inputs from the demos have been identified as relevant for the overall debate on interoperability in the energy sector.

The results of the Italian pilot “DSO and Consumer Alliance” demonstrate the successful integration of multiple smart meters for the benefit of providing congestion management and balancing services to the system operators. The demo also highlights the potential for smart meters beyond electricity, an area that deserves more attention in research projects as it can support the twin green and digital transition to a future integrated energy system.

The results of the Bulgarian Pilot “Intelligent Distribution Nodes” demonstrate the usage of an intelligent system including an information hub to leverage the flexibility of a multi-storey building. The demo provides insights as to the relevant capabilities of an innovative control system, namely data consolidation, data quality, data integration and data governance. The results of the Bulgarian demo are relevant for the integration of buildings as active participants in the energy system.

The Baltic-Nordic pilot “Single Flexibility Platform” provides insights for a future interoperability implementing act on demand-side flexibility and the implementation of interoperable flexibility market platforms. The pilot relies on the IEGSA / Single Flexibility Platform. The capabilities and governance of IEGSA are relevant for the interoperability discussion around future implementing acts on demand response as well as on a common European common data space for energy. The integration of IEGSA with several other marketplaces and platforms promotes data transparency and flexibility. Its interoperable approach enables the reusing of modules, thus lower costs for its users.

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