FlexiGrid

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List of abbreviations

Abbreviation	Definition
FlexiGrid	Enabling flexibility for future distribution grid – FlexiGrid
DSO	Distribution system operator
TSO	Transmission system operator
RES	Renewable energy sources
DER	Distributed energy resources
P2P	Peer-to-peer
GHG	Greenhouse gases
V2G	Vehicle-to-Grid
LEM	Local energy market
LFM	Local flexibility market
FED-EM	Fossil-free Energy district- Energy market
EV	Electric vehicle
CPS	Cyber-Physical Systems

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Executive Summary

This report is written as the second deliverable of work package 2 of FlexiGrid project which aims to define the plausible future scenarios for local markets in distribution networks to set the scope of the research and the demonstrations for the project. Moreover, the general overview of the products and services that can be provided in local markets are elaborated, and the cyber-physical requirements for transacting such products are discussed.

The report presents a set of already established scenarios for the future of the grid in the partner countries of the FlexiGrid project: Sweden, the Netherlands, Bulgaria, and Turkey. The results show that in the analysed countries, distributed generation would be a considerable share of power production capacity within the horizon of 2030-2050. Moreover, the expected load from the electrification of transport would increase considerably in all the countries that are included in the assessment.

Furthermore, plausible scenarios for the future of the local energy and flexibility concept are developed based on scenario planning methodologies in the literature. The results from the scenario development for future of local energy and flexibility trading has shown that the highest expected impact and uncertainty are regarding the end-users' willingness for participation (active versus passive end-users), their level of digitalisation and automation (smart versus conventional end-users), and regulatory incentives for adoption of the local trading concept. Four plausible scenarios are developed (Figure 1) based on the uncertainties in the two following factors:

- The availability level of active and smart end-users
- Regulatory incentives for DSOs to adopt and promote local markets

Moreover, the results from the scenario planning show that an increase in grid reinforcement, availability of distributed generation, electrified heating and cooling, smart and digitalised grid monitoring and control tools, and high-resolution data have lower uncertainty but high impact on the future of the local trading concept.

The main services that are going to be examined in the project are peak reduction, congestion management, and voltage control. The products to procure these services are categorised in the report, and their possible attributes are discussed. The products in the flexibility market are classified into a reservation (capacity) based and activation (energy) based products. The reservation (capacity) based products are traded on a longer horizon to secure the availability of flexibility and incentivise investments in the smartness of end-users and distributed generation. On the other hand, energy-based products are used for periods closer to procurement and activation of flexibility. Furthermore, FlexiGrid will utilise, with modifications and improvements, the energy market and products developed as part of the FED project.

The report ends by introducing the requirements of the smart energy systems, considered as cyber-physical systems, for the FlexiGrid solutions. Computer-based algorithms are used for the process in cyber-physical systems. The functional and non-functional requirements of the FlexiGrid platform are introduced in the report. The functional requirements of the platform are listed from the perspective of the DSO, aggregator and the system administrator. The system requirements for the FlexiGrid platform, which is listed in the report, includes the graphical user interface requirements and the interoperability requirements. The security requirements of the FlexiGrid are also presented in the report. They

incorporate the concerns for communications, authentication, logging, data storage and caching, and access control.

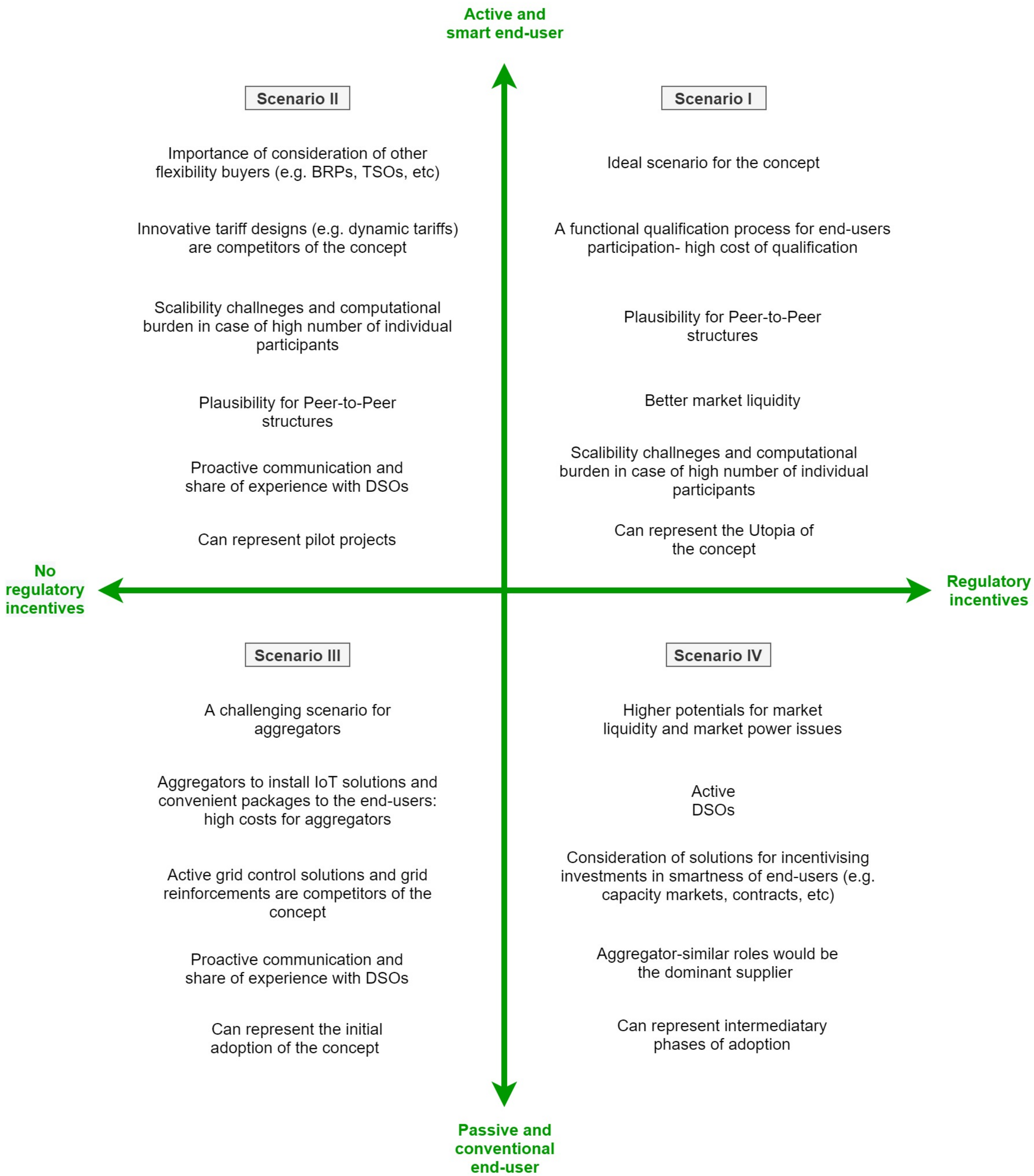

Figure 1 Plausible main scenarios for the future of local energy and flexibility trade

1 Introduction

Local flexibility resources could be used to manage the challenges related to the variable generation of distributed energy sources and the increased electrification. Trade of energy and services through local markets can support the operation of the distribution grids. The control, operation, and management of distribution networks have been influenced under the context of local markets. New solutions and innovative mechanisms are required to support the operation of the distribution grid, considering the supervision role of the Distribution System Operators (DSOs) and the economic consideration of the consumers/prosumers in providing the grid services.

1.1. The objective and scope

This deliverable reports on Task 2.2 “Scenarios, product design of grid services for local energy markets” of the FlexiGrid project, which aims at defining plausible future scenarios for local energy exchange in distribution networks to set the scope of the research and the demonstrations for the project. The services that the local customers can provide as grid services and the mechanisms used by the DSO to encourage more participation in the provision of grid services are elaborated. Moreover, insights are provided for the tradable products on the local markets, and their technical requirements are discussed. This study takes place at the initial stage of the FlexiGrid project and forms the link between the FlexiGrid market models and standardised products for grid services.

To reach the objectives of the task, a methodology was designed to develop the future scenarios for local energy and flexibility trading. Besides these scenarios, already established scenarios for the future of the grid were also analysed. The insights from both scenario analyses were used to identify their key impacts, appropriate tradable product designs in FlexiGrid local markets, and requirements for FlexiGrid solutions.

1.2. Context: local market for energy and flexibility

FlexiGrid will design a dynamically adaptive local market structure for energy and flexibility to allow active participation of all the related stakeholders, including end-users, aggregators, energy suppliers, DSOs, and the Transmission System Operator (TSO). End-users can participate in local trading either through an aggregator or directly. DSOs exploit the potential of local flexibility options to manage the local constraints in the grid at lower voltage levels. Many consumers are becoming well aware of the environmental impacts of energy consumption and climate change [1]. It is expected to have more active end-users in the future energy system. The end-users increasing awareness and the availability of the enabling technologies promote their transition towards more active players of the energy system, resulting in more investment in distributed renewable energy and storage sources. They could participate in local and wholesale markets directly or via an aggregator. An aggregator is a grouping of agents, such as consumers, producers, prosumers, or any mix of them, to participate in the retail or wholesale market or provide grid services as a single entity [2].

1.2.1. Flexibility

Flexibility is generally defined as the possibility of adjusting patterns of generation and consumption to a signal to provide different grid services [3]. The need for flexibility comes from the increasing penetration of renewable generation, which leads to more considerable uncertainty and variability of the net demand, and the need for ramping capacity increases in this situation [1]. Flexibility is technically defined as a power modification activated at a defined time for a specified duration at a specific location node within the distribution system [3]. Flexibility is deployed by the system operator to maintain system balance while satisfying the grid capacity constraints and guaranteeing the safe grid operation [4]. Flexibility is characterised by various attributes such as duration, rate of change, starting time and its trigger, duration, location, controllability, predictability, time availability, and delivery time.

1.2.2. Services and products

Grid supporting services at distribution levels are defined as the services provided to the DSOs to maintain the grid operation within acceptable limits to ensure the security of supply [4]. Grid service, such as balancing, congestion management, voltage control, and controlled islanding, is mainly delivered by third parties [5]. Grid services have opened up a new revenue stream for consumers [4].

The products should be designed following the needs and requirements of the DSOs [6]. Products with common characteristics are used for the exchange of grid services [4]. A product can contribute to the provision of one or more grid services. For instance, one product can be used for both balancing and congestion management [4]. Some product attributes need to be service-specific, e.g., the products for congestion management should include location information [4].

1.2.3. Procurement mechanisms

The mechanisms introduced in the literature or implemented in the pilot projects for the procurement of required flexibility volume fits into one of the three categories: rule-based mechanisms, tariff solutions, and market-based approaches [4]. The rule-based mechanism refers to the implementation of technical requirements and grid codes. The tariff solutions use the price signals to trigger the activation of flexibility for certain services [4]. Active distribution system management incorporates the key strategies and tools performed and used by the DSO for the secure management of the grid [5]. DSOs need the flexibility to manage the operation of their grids exactly at the instances that the demand for flexibility is high. Thus a mechanism should be used to coordinate flexibility [7]. The DSOs can consider flexibility when planning for grid expansion and reinforcement. Flexibility from the demand-side can be a cost-efficient alternative compared to grid reinforcement. The potential procurement mechanisms are regulation, a balancing market, bilateral agreement, and grid codes [7]. The procurement mechanism should ensure exact matching between the DSO needs and the system flexibility. To achieve this, information exchange among the DSO and other market players is critical [7]. A market-based approach could be used to obtain enough flexible volume to resolve the challenges and issues in the grid.

1.3. Deliverable structure

The remainder of this report is structured as follows: Chapter 2 introduces the methodology used for obtaining the objectives of the task. Chapter 3 reviews the state-of-the-art market designs and mechanisms proposed or implemented for unlocking the flexibility at the demand-side. Chapter 4 reviews the already established scenarios for the future of the grid and presents the results from scenarios development for the future of local markets. Chapter 5 provides an overview of tradable products on the local markets, including the different types of products and the potential attributes. Chapter 6 discusses the requirements of the FlexiGrid solutions, and in chapter 7, the reflections and conclusions from the task are presented.

2 Methodology

The methodology used for obtaining the objectives of the task is presented in this section. In the first section, the whole methodology is presented, and in the second part, the methodology used for scenario planning is discussed.

2.1 General overview

The general overview of the methodology is presented in Figure 2. The methodology is designed to obtain the outputs on the right-hand side of the figure. These outputs are:

- scenarios for the future of the grid,
- scenarios for the future of local energy and flexibility trading,
- impacts, characteristics, and relevant services from these scenarios
- FlexiGrid's local markets product design, and
- requirements for the designed products.

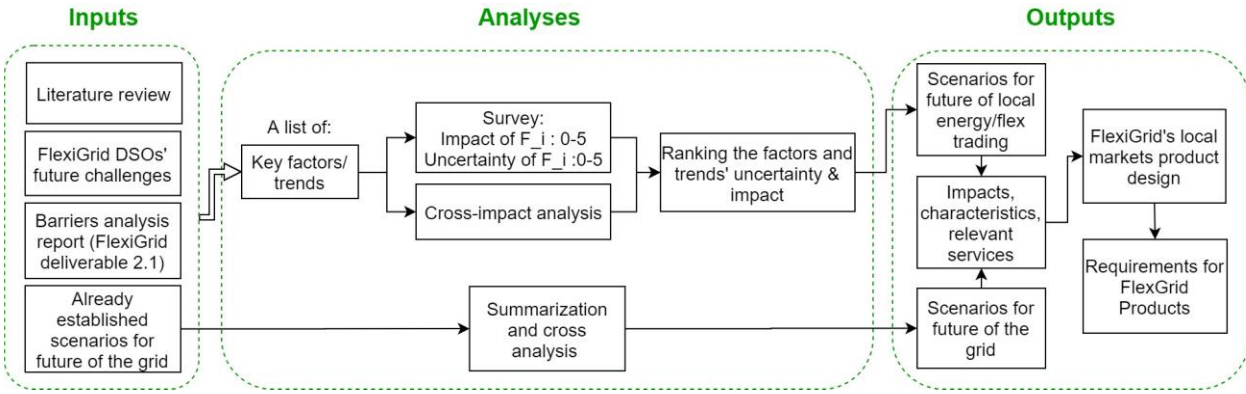

Figure 2 Methodology for task 2.2. T_i represents each key factor or trend.

The scenarios for the future of the grid are obtained by collecting the already established scenarios in various sources in each of the project partners' countries. These collected scenarios are then summarised and cross-analysed to provide further inputs for formulating the impacts and relevant grid services besides being available for further utilisation in other work packages and demonstrations.

Furthermore, a scenario development methodology is utilised to develop plausible scenarios for the future of local energy and flexibility trading. This scenario development methodology is obtained from scenario planning literature and briefly includes an environment scanning for finding the key factors/trends, a survey about uncertainty and impact of these factors/trends, a cross-impact analysis, and finally ranking of the factors/trends and scenario establishment. This methodology is further discussed in the section "scenario planning methodology".

After obtaining the scenarios for future of the grid and future of local energy and flexibility trading concept (called the concept from now on), the impacts and characteristics of these scenarios are defined, and relevant grid services are suggested accordingly.

The impacts, characteristics, and relevant services are then used to lead us in better product design for the local markets and defining the requirements for FlexiGrid solutions.

2.2 Scenario planning methodology

The development of the scenarios for the future of the concept is carried out to set the scope of the research and the demonstrations, analyse the impact of these scenarios on the future of the concept and provide guidelines for product design in the FlexiGrid project.

Scenarios are the possible forms of the future that provide narratives for the context and facilitate decision making [8]. Scenarios are not predictions of the future, but rather an exploration of the drivers of change and multiple plausible future situations to provide further insight for the participants in the scenario development process [8], [9]. Among these plausible future scenarios, some are probable, some are preferable, and some are not preferred (Figure 3). Considering the probable scenarios when designing the products for FlexiGrid and at the same time, acting proactively to reach the preferable scenarios can be helpful in achieving successful and implementable outcomes from the project.

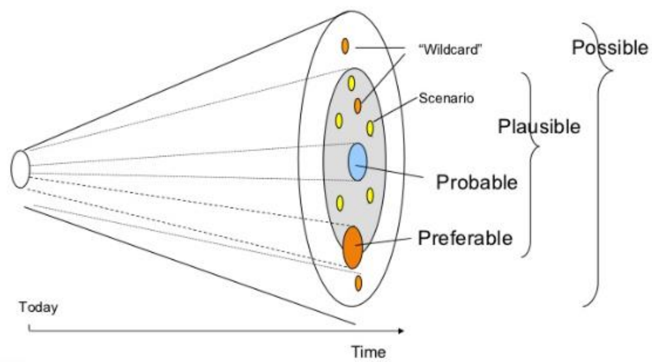

Figure 3 Types of futures [10]

There are three main schools of techniques for developing scenarios [11], [12]. These three schools are intuitive logics, probabilistic modified trends (PMT) methodology, and the French approach La prospective [11], [12]. Each of these techniques has been evolved in different institutes and with specific purposes. Among these, the intuitive logic school has been chosen for scenario analysis in this study because this technique matches the scope and the available resources of this task in the sense that it does not require complex computer-based modelling and analysis [11] while matching the expected deliverables from the task. This method is one of the most dominating methods for scenario development in many countries and has gotten a lot of attention in the literature for scenario planning [11].

The intuitive logic method was originally used by Pierre Wack at Shell in the 1960s [11]. The purpose of this method is to make sense of situations and developing strategies, while it can be an ongoing learning activity as well [11]. The output is a set of plausible qualitative scenarios, including implications and early warning signals [11], which can be used as input for product design in the FlexiGrid project. Scenario development approaches (models) for Intuitive logic method are varied in the literature, ranging from five to fifteen steps or more depending on what features of the scenarios are included [11], [12]. The approach used in this study is a seven-step process by Conway [10]. This approach is a more generic form of approaches proposed by Schwartz [13] and Stanford Research Institute International (SRI) [14], [15].

These approaches are among the most popular and frequently used approaches in intuitive logic school [12], [16].

The seven steps proposed by Conway are as follow:

1. Identify the focal question
2. Environmental scanning- internal and external
3. Selecting drivers of change and ranking them
4. Building the scenario matrix
5. Developing the scenarios
6. Presenting the scenarios
7. Considering the strategic implications

In step one, the focal question needs to be identified. In task 2.2, two of the focal questions are:

- What are the plausible scenarios for the future of the local energy and flexibility trading concept?
- What would be the impact of these scenarios on the project?
- Accordingly, what needs to be considered while designing the services and products of the project?

In step two, the environment scanning was carried out by literature review, experiences from similar projects, inputs from the DSOs in the project, and previous reports and discussions in the project.

In step three, the key driving factors and trends were identified based on the above-mentioned inputs in step two and iterated between five experts in the group to finalise the core key factors. The ranking of these key factors was done by two means. A survey was designed to rank the impact and uncertainty of the factors (Appendix 1), and a cross-impact matrix (Figure 4) was designed to identify the dynamics between these factors and finding the most impactful factors (the matrix designed for the project is available in Appendix 1). The survey was distributed among the project partners and external experts who are expected to have a background and understanding of the concept of local energy and flexibility trade. The cross-impact matrix was distributed among a smaller group of experts since it was more time consuming and more challenging to be distributed in a wider circle.

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	Active Score
T1		3	3	3	2	3	3	2	1	2	22
T2	0		3	0	3	0	2	0	1	2	11
T3	1	1		0	0	0	2	1	0	0	4
T4	2	2	3		3	2	3	1	1	2	16
T5	0	2	3	0		0	2	1	1	3	13
T6	2	1	3	1	1		1	0	1	2	13
T7	1	2	2	2	2	1		3	2	3	18
T8	2	3	3	1	1	0	3		1	2	16
T9	2	1	0	2	1	2	2	2		1	13
T10	3	3	3	3	3	0	2	2	1		20
Passive Score	15	18	23	12	16	8	20	12	9	17	

Active: T1 T7 T10
Passive: T2 T3 T7

0 Independent
1 Slight impact
2 Dependent
3 Strong driver

Figure 4 An example of cross-impact matrix [17]*. The factors/trends with the highest horizontal score (active score) represent the impactful factors.*

In step four, the scenario matrix (four-quadrant matrix) is built based on the available ranking from step three. To build the scenario matrix, two most uncertain and impactful factors must be chosen. This was done through the ranking based on the results from the survey (Figure 5) and further narrowed down by considering the obtained scores from the cross-impact analysis [18]. These two most uncertain and impactful factors made the two axes of the scenario matrix (Figure 6).

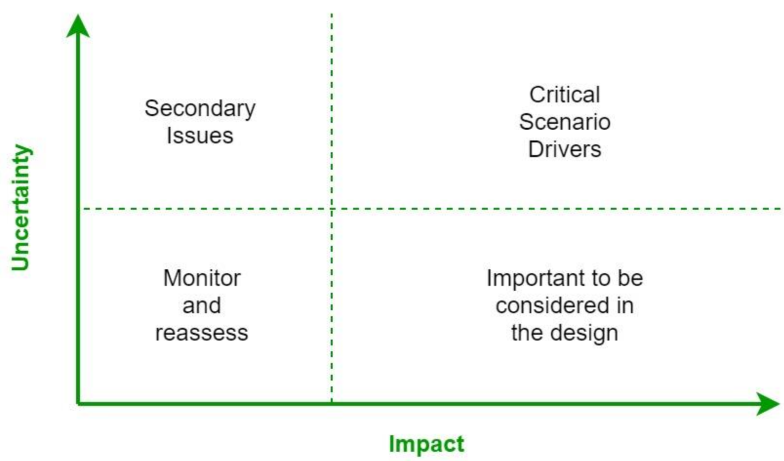

Figure 5 Uncertainty-impact ranking (modified figure from [10], [16]*). The most impactful and uncertain factors are used for the formation of the scenarios, most impactful but less uncertain factors are highly suggested to be considered while designing the project outputs, factors with high uncertainty but low impact are secondary issues, and less impactful, and less uncertain factors are just to monitor and reassess in case of need.*

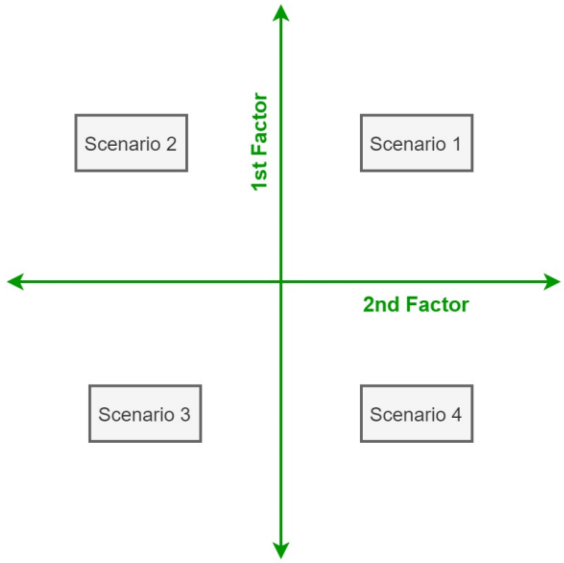

Figure 6 Scenario matrix is built based on the two most uncertain and impactful factors

In the fifth step, the four different worlds (scenarios) from step four were further assessed and described to build a narrative and check if they make sense to the group.

In step six, the results were formed in a presentable format, and finally in step seven the implications from each of these scenarios were identified. The implications were identified for the concept of local energy and flexibility trade, and it was tried to describe the impacts and characteristics of each scenario accordingly.

3 State of the art for flexibility exploitation

This section reviews the state-of-the-art market designs and mechanisms proposed or implemented for unlocking the flexibility at the demand-side. DSOs are seeking market tools to enable active management and control of the distribution system to face the emerging operational challenges in distribution networks using the potential flexibility in the demand-side [3]. The operational challenges are caused due to the increasing penetration of renewable energy sources and unpredictable loads, such as electric vehicles and heat pumps.

3.1 Local energy markets

Growing distributed generation induce the development of local marketplaces for local "sources" or provision of local supply to communities. The concept is rather new, and a unified definition is lacking [19]. Various business models have been developed for the purpose of utilising these different local resources. The way they distinguish from general electricity markets is that they are only open to assets within a limited local area with resources such as distributed generation, storage and demand-side response providers. The sales can be both locally (e.g. through peer-to-peer (P2P) markets or to local distribution companies) or aggregated and sold further in national-level markets.

Local marketplaces can be designed to enable access for consumers, prosumers, aggregators, suppliers, TSOs and DSOs to allow the trade of both energy and flexibility. Some key design features are shown in Table 1 [20].

Table 1 Key features of local markets

FEATURE	OPTIONS
WHAT IS TRADED	Flexibility (change in energy generation or consumption) Energy (kWhs) Network capacity (in future)
MARKET FUNCTION	Network management – purchasing local energy services with the aim of reducing network management costs, or avoiding/deferring network capacity investment Local portfolio balancing – using local energy marketplace to hedge short-term variation in generation/supply for small-scale asset owners Local trade – enabling local energy exchange
PROCURERS	TSO DSO (buying flexibility) Aggregators Suppliers (buying energy for local portfolio balancing; local energy supply)
SELLERS	Local generation and storage asset owners Community/domestic prosumers (small-scale generation, Storage, DSR) Large energy users
MARKET LINKS	Local resources <-> con-/prosumers P2P trading) Local resources <-> DSO (DSO market for flexibility) Local resources <-> DSO <-> TSO (DSO-TSO platform(s) for flexibility) Local resources <-> TSO (aggregators)

Research during recent years has provided some insights in opportunities and benefits with local energy markets, as well as highlighted some risks and existing hinders for development. These are described shortly in Table 2 [21]–[26].

Table 2 Opportunities and risks with local markets

Perspective	Benefits/Opportunities	Barriers/Risks
Consumer/ Prosumer	• The higher level of energy independence and source control are often motivators for prosumers to enter into local energy markets • Other motivations include reducing greenhouse gases (GHG), reduce costs and become more self-sufficient, all of which is possible to accomplish with local energy markets • Strengthening the customers' position and create an active role and more involvement in the electricity market, often connected with P2P trading of electricity • Engagement and active involvement raise awareness of efficient energy usage and provide a better departure point for involvement in innovative demand-side management • Enables aggregated prosumers to engage in wholesale markets, which otherwise would not have been possible • Microgrid design of local energy markets enhances the security of supply and lower costs with potential outages • Implementation of local energy markets drive further innovation and disruption in the energy sector and make traditional companies develop more consumer-oriented approaches to be able to stay in the competition from the transitioning sector.	• Local energy market (LEM) requires active participants and consumers that are not used to these activities • The success depends on the LEM project developer's ability to engage their customers actively – otherwise is the risk of resistance overwhelming • High upfront costs • Split incentive problems with benefits and investments • Difficult to establish secure and transparent local trading platforms • Blockchain technologies have been suggested, but meet challenges with scalability, complexity in technical protocols and implementation with current elements • Preservation of privacy in blockchain-based architectures • Secure data handling and risk for cyberattacks
DSO/TSO	• Local energy markets bring prosumer owned distributed resources and can decrease the need to invest in new and reinforced distribution grids due to increased flexibility and balancing of renewable energy sources • Aggregation of both generation and demand from several prosumers can help grid operators to more efficiently balance the grid's demand and supply. • Local energy markets can efficiently provide support to grid operations • If designed as several microgrids, the local energy market can provide flexibility, reliability and responsiveness to the greater power grid and allow greater integration of DERs	• With a traditional DSO business model, revenues will decrease – comes down to the DSO ability to change the business model and innovate new services and activities to create value for their customers • The interconnection and seamless change between connected and island mode in microgrids are challenging when it comes to voltage and frequency controls. Also, DER synchronisation is part of this with additional complexity from intermittent generation sources • Standardisation issues with interconnections and communication in LEMs are becoming more present as different countries are at various stages in the smart grid roll-out.
Innovation	• Market development for providers in hardware and software solutions for LEMs. Innovations and economic growth	• Some DERs, which play a significant part in LEMs, need further development. Most prominent are storage technologies, where massive R&D is being undertaken,

		but many solutions are still years away from market implementation.
Regulatory		• Many legal barriers exist, due to the traditional market set up and years of evolving legislation in favour of the centralised market model. Barriers can stem from rules regarding: ○ Who can participate? ○ Who will operate the market? ○ What sales and between who can take place? ○ Are DSOs incentivised to use demand response over infrastructure investments? ○ Can inverters run in island mode, and how are the regulations for bi-directional energy flows at the stated point of common coupling? ○ Taxation rules for local energy generation and sharing ○ The absence of regulations may cause long administration processes and uncertainties ○ Building parallel networks which may cause conflicts of interest between DSO and prosumers. ○ Definitions of LEM and DER in legislations.

3.1.1 Examples of real projects

Local energy markets have been piloted in several areas. For this report, we choose to include some examples with important learnings to take into consideration for further developments. The chosen projects ([27]–[29]) are as follows:

- Cornwall and Isles of Scilly local energy markets Cornwall, UK [30]
- RENeW Nexus P2P local market Fremantle, Australia [31]
- FED Chalmers LEM third party platform Göteborg, Sweden [32]
- Quartierstrom P2P market Walenstadt, Switzerland [33]
- Vermont Green P2P local market Vermont, USA [34]

Cornwall

Being the part in Britain which have one of the sunniest and windiest locations, Cornwall has high numbers of solar PV and wind power installed, creating challenges for the local Cornish grid. Developer Centrica created a LEM platform where the local DSO and national TSO can place bids for flexibility from local generation and storage systems in 100 homes and additionally 125 local businesses. A clearing engine takes bids and offers and finds the optimal clearing solution, taking into account grid and asset constraints to ensure feasible contracts. This will enable the Cornish grid to utilise local generation for flexibility and more efficient use of intermittent sources in the grid, by offering fair rewards for flexible customers.

Crucially, the platform coordinates the transmission and distribution bids to avoid conflicting signals. Also, a trial of P2P trading is taking place, using blockchain technology and in collaboration with LO3 energy who developed that platform. The trial has run since 2018 and ended in the spring of 2020. In this project, the TSO (National Grid ESO) and the DSO (Western Power Distribution) tested the coordinated flexibility procurement through a common trading platform. The homes and the businesses provide flexibility to balance the grid or manage a local network constraint in return for a financial reward [35].

RENeW Nexus

Up to 40 Residents in the city of Fremantle in Western Australia, trailed a P2P market during 2018-2019. Participants traded surplus electricity from their solar PV plants on the existing electricity grid. According to the project leaders, it is the first time that traders can set their prices. The purpose of the trial was to see whether participants can gain more knowledge about their energy consumption and thereby make meaningful changes to their consumption based on available renewable energy. In addition, with the trading platform, the local utility Western Power who operates the grid, and the electricity retailer, Synergy, agreed to trial daily fixed supply charges to further enable the marketplace between the participants.

FED - Fossil free Energy Districts

At Chalmers university campus in Göteborg, Sweden, a local energy market has been created covering both electricity, heat and cooling. Rather than trading energy between private homes and commercial actors, the FED market includes 50 buildings which are located at the campus and connected via a digital marketplace. They are also connected with the outside grid and district heating network and can thus provide services for these external networks as well. The buildings are the actors in the digital marketplace, and it is between these, the trading takes place. What makes FED more than just an autonomous market between buildings is its connection to the main grids and possibilities for trading system services. In this way, the possibility to optimise the overall energy use in the FED system and reduce peak loads as well as reducing costs and fossil energy use is created. The project was running between 2016 and 2019. Concluding recommendations from the project toward policy and regulatory bodies are:

1. Strive for social acceptance

2. Make direct investments towards replication of FED through the European Investment Bank and the cities and direct incentives towards cities in order to reduce CO_2 emissions

3. Define the role of the city/municipality in decision-making processes and local energy plans

4. Enable the DSO to trade with flexibility

5. Enable the possibility to test, make demos and proof of concepts in several places

Quartierstrom Walenstadt

The Quartierstrom project in Walenstadt, Switzerland trialled a P2P market between 37 households using blockchain technology over the course of a year between January 2019 and January 2020. The households are located downstream a grid substation, and 27 of these households have installed solar PV with a total capacity of 280 kWp. All participants installed smart meters, and the market is based on a double auction model where both consumers and prosumers determine price limits, and the smart meters send bids containing these limits. The bids are collected in 15min intervals and determines which transactions are made. All excess bids which cannot be filled with local supply or demand, go to the local utility and are handled with existing tariffs. During the trial period, automatic pricing was also tested with prices automatically calculated depending on whether the solar power was in relatively scarce supply or in surplus. The conclusion was that with individual pricing, some local generation could not be sold locally since price requirements did not match between suppliers and consumers, but automatic pricing was more efficient in supplying local demand.

Some important learnings were:

- The P2P market led to significantly higher consumption of local generation
- Almost no one wanted to pay the premium
- Automatic pricing was more effective
- The trial effectively raised awareness among prosumers and consumers
- Some hardware problems occurred
- Private blockchain kept consumption for the transaction low, about 4% of the total volume of traded power in the trial

A follow-up project will continue the LEM with some modifications from these learnings. The prices will, for example, be set automatically, and hardware will be switched to series-produced equipment.

Vermont Green

A new LEM project has been launched in Vermont, giving the users a possibility to trade private generated solar with local commercial actors through an app called Vermont Green. It is a collaboration between the blockchain company LO3 energy and the utility Green Mountain Power. 150 households and 50 business are the first participants in the pilot stage. They will trade something that is called Vermont green attributes, which is a local green energy credit. Via an auction platform provided by LO3, the businesses indicate the maximum amount that they are willing to pay for green energy and the platform conducts the auction which settles once per day for the previous day bids. The overall purpose is to provide a potential for the commercial actors to become 100% green in their electricity use, and to utilise locally generated electricity. The project is a first step with the ambition to involve more of the 265 000 residential and commercial customers the green mountain power serves.

3.2 Local flexibility markets

Several aspects should be considered in the design of the flexibility markets, such as the type of flexibility products, the providers of the service, the procurers, and the metrics [1]. Local flexibility market (LFM) prepare the distributed energy sources to provide their flexibility in demand or production for the operation of the grid in the form of services. They enable the trade of flexibility supplied by consumers and producers at distribution levels and provide a support tool for the DSOs and a value stream for the energy suppliers [36].

3.2.1 Examples of real projects

Research on optimal market design can be successful when market mechanisms are tested under real conditions because the interaction between market players and the adjustments needed could only be assessed under actual implementations [37]. Therefore, in this section, some examples of projects with pilot tests are presented. Several pilot projects are initiated in Europe to find out how to utilise flexibility through local flexibility markets and TSO-DSO coordination to resolve the grid issues and manage the operation of the power system. Although the projects differ in size and scope, they all share a common objective, which is to unlock the flexibility potential through market solutions at the local level and the need for the TSO-DSO coordination to resolve the local issues [38].

INTERFACE

INTERFACE aims to create a common architecture that connects market platforms to use flexibility for balancing and congestion management. IoT solutions are implemented to enable TSO-DSO coordination. TSO-DSO coordination facilitates the provision of flexibility from different market platforms and ensures that the flexibility activation will not cause operational problems in other networks [39].

As part of this project, a survey was conducted to explore the current European landscape from the grid and market stakeholders' point of view [40]. The survey had a special focus on currently used platforms and their functions, flexibility, and target market. Four options were suggested in the questionnaire to overcome the functional problems of local markets, such as market fragmentation, lack of transparency, and coordination problems between different market processes (e.g., double activation). Around 41% of the energy stakeholders believed that developing a limited/regulated number of fully integrated markets would be the best way to overcome the flexibility market design problem.

EMPOWER

EMPOWER H2020 [41] developed a local market concept with three basic types of market platforms for local electricity trading, local flexibility trading, and other services. The EMPOWER concept aimed to encourage the citizens that produce and consume energy to participate actively in the electrical systems. The market concept developed in this project is supported by novel ICT technologies. It promotes an integrated marketplace where energy, flexibility, energy services and combination of them is traded in different ways. The proposed trade model supports the interactions with the DSO to enable the trade via different flexibility contracts, including instant peak shaving, emergency support, “valley filling” and containment of local surplus [42].

UNITED-GRID

UNITED-GRID [43] aims to secure and optimise the operation of intelligent distribution networks, considering the new distributed market actors along with emerging technologies such as renewable generation, energy storage systems and demand response programs. The project provides integrated cyber-physical solutions to benefit from the opportunities provided by the new actors and innovative technologies. UNITED-GRID aims to develop a toolbox that could be plugged into the existing distribution management system via a cross-platform for advanced energy management, grid-level control and protection. In this project, the DSOs will be equipped with a market-based tool to holistically manage congestion and voltage issues in the grid.

Enera project

Enera project investigates the local dimension of the European power market by launching a local market platform for flexibility sources together with the system operators. EPEX SPOT and EWE will develop a transparent market mechanism for flexibility providers who participate in market-based congestion management [44]. The flexibility providers are the power plants, aggregators, virtual power plants, storage units, and renewables. The demand for flexibility also comes from the TSO, mid-voltage DSOs, and low-voltage DSOs. This market is open for all types of technologies, e.g., thermal or renewable energy sources, storage units, and flexible loads to provide upward or downward flexibility. The EPEX spot is considered as the flexibility market operator [44].

PARITY

PARITY [45] seeks, identifies, and analyses the adoption and implementation of IoT, blockchain, and smart contracts in local flexibility markets. PARITY investigates the automated flexibility exchange, in a framework that flexibility is rewarded in a cost-reflective and symmetric manner. PARITY solution includes novel tools for active network management, such as innovative STATCOM and power quality monitoring device, which enables the DSO to enhance its management capabilities, grid observability, and hosting capacity of renewable energy sources. PARITY relies on grid services provided by storage units, the power to heat, and demand response programs.

CoordiNet

CoordiNet [46] aims to investigate the DSO-TSO coordination for the procurement of grid support services in a reliable and efficient manner and assess how the coordination will lead to more cost-efficient solutions for the electricity supply. Standardised products with related key parameters for grid services will be implemented in ten demonstration sites. The CoordiNet platform interfaces the DSO/TSO systems, data needs, market-clearing algorithms, and the forecast for generation and consumption. This project intends to create a framework to promote the participation of all agents in the ancillary service market, to provide flexibility services to DSOs to solve congestions, voltage, and islanding problems and TSO to solve congestions, voltage and balancing problems [46].

DOMINOES

DOMINOES [47] provides a transparent architecture for the local energy and flexibility market, where consumers can interact and exchange energy and flexibility in an effective manner using innovative demand response and grid management services.

In the DOMINOES suggested model, local market services are managed under a single supplier contract, which enables the participants in the local community to share energy and flexibility with each other, as well as with other local communities, while addressing grid costs. The grid costs could include time-based or power-based tariffs. The market settlement is established at the community grid connection point, where also supplier contracts, grid services and balance services are managed [48].

Norflex

Norflex [49] is a concept project that explores future power grids with flexible consumption. It investigates the following four aggregation methods for flexibility to be offered to the DSO, TSO and other market actors:

- From few to many providers of flexibility to verify technology- and market development
- From one to multiple grid locations to demonstrate how distributed flexibility can be used to handle grid challenges
- From one to multiple grid levels to test how distributed flexibility can be made available for both TSO and DSO without causing problems for each other
- From separate to interconnected grid locations by using a common marketplace for flexibility and geographical information

4 Scenario analysis

In this section, the plausible scenarios for the future of the grid and local energy and flexibility trade are presented, and their impacts are discussed.

The already established scenarios for the grids in four of the project partner countries (Sweden, Netherlands, Bulgaria, and Turkey) are discussed in the first section to provide a vision of how the grids could possibly look like in a time-horizon of 2030-2050. Then the results from the scenario development for the concept of local energy and flexibility trade are presented. In the last subsection, the impacts and key conclusions from the scenario analysis are discussed, and suggestions are provided based on the discussed impacts.

4.1 Scenarios for the future of grid

The already established scenarios for the future of the grid are a complementary source of knowledge to the scenarios for the future of local energy and flexibility trade. Insights over the future of the grid can be used to design more appropriate project outputs as well as in framing different test cases in the demonstration phase. The scenarios for the potential future of the grid were obtained from various sources in four of the partner countries of FlexGrid. These scenarios are summarised and compared in this section.

4.1.1 Sweden

The collected scenarios in Sweden are from various sources. These sources are presented in Table 3. The relevant parts of these scenarios are summarised and further explained below. While analysing the scenarios, the focus has been put on electrification and penetration level of distributed generation.

Table 3 Sources for future scenarios of the grid in Sweden

Organisation	Publication name and year	Notes	Reference
Elforsk	Future requirements for the electrical grid (2014)	- Scenarios for the year 2037 - Issues that may arise for DSOs - Three different scenarios: inner-city, outer-city, and rural scenario	[50]
Power Circle	Electric vehicles prognosis (2018)	- The prognosis for the number of electric vehicles expected in 2030	[51]
Sweco and Tranfikanalys	Assessment of the development in Swedish road vehicle fleet (2017)	- Scenarios for the share of electric vehicles expected in 2030	[52]
Svenska kraftnät	Long-term scenarios for the Swedish electric power system (2019)	- Scenarios for the future of electric power system in Sweden mainly for 2040 but some assessments for 2030 as well - Based on the investment and hourly dispatch models for the Swedish system - Nuclear phase-out is considered in the scenarios	[53]

Energiforsk	End-User Scenarios and Their Impact on Distribution System Operators (2018)	- No scenario development for a specific year, but rather two assumed scenarios of “realistic” and “extreme” - Based on the data from Herrljunga Elektriska AB which is a small DSO	[54]

Elforsk- Future requirements for the electrical grid

In this study, the future scenarios for the power grid in 2037 are analysed. Three scenarios have been developed as a result: an inner-city scenario, an outer city scenario, and a rural one.

In this study, the total electricity production from PVs is assumed to be 14.5 TWh which is taken from the North European Energy Perspective Project [55]. From this value, the share of the buildings which are expected to have solar PVs is calculated for each scenario. The results show that the range of PV penetration is between 25-45% of the customers (this value for apartments is 30%). Moreover, the PV generation is all distributed, and none is large-scale. The installed capacity is assumed to be 1kW per apartment, 5 kW per houses, 5-50 kW per business (depending on the size of the business).

Regarding electric cars, between 20-43% of the households would have electric cars in the year 2037. The Share of the household that has electric cars is increasing as we move from inner-city scenario to rural areas, and generally, the share of houses that have electric vehicles is higher than apartments.

Power Circle- Electric vehicles prognosis

In this study, the total number of electric vehicles are predicted to be 2.5 million in 2030 in Sweden. This includes 1.7 million battery electric vehicles (EVs) and 0.8 million plug-in hybrid vehicles. Considering 4.9 million personal cars in Sweden [56], 51% of the personal car fleet is forecasted to be electrical in 2030. Accordingly, the total annual energy need for these electric cars are expected to be 6 TWh which is approximately 5% of Sweden’s total electricity consumption. It worth mentioning that heavy-duty trucks or buses are not considered in this study.

Sweco and Trafikanalys- Assessment of the development in Swedish road vehicle fleet

The government agency Trafikanalys and the consulting company Sweco have made a scenario analysis for an expected share of electric vehicles in the year 2030 in Sweden. The results from the study show that EVs are expected to be 6% and plug-in hybrids 13% of the car fleet in Sweden. With the assumption of 4.9 million cars in Sweden [56], these percentages are corresponding to 0.3 million and 0.6 million cars respectively.

Svenska Kraftnät- Long-term scenarios for the Swedish electric power system

Svenska Kraftnät (Svk) is the TSO in Sweden, and it conducts long-term scenario studies for the Swedish electric power system regularly. This report is the latest report published by Svenksa Kraftnät.

In this report, the scenarios are mainly developed for Sweden. However, the northern European countries and the import/export flows are also explicitly modelled and considered. The modelling includes hourly dispatching for the chosen years and an investment model to define the generation mix. The models consider a different set of constraints such as politically defined limitations, assumptions for fuel and emission prices, and future transmission capacity. Moreover, year-to-year variation in weather conditions is considered for multiple calculations of the scenarios for each year. In this report, 2030 and 2040 are the scenario years; however, more focus has been put on the year 2040. In the scenarios for the year 2040, no nuclear power generation is included in the models.

From the results, the power production from PVs are expected to reach 4 TWh in 2030 and 7 TWh in 2040 (the production from PVs in 2017 was 0.23 TWh). Moreover, the electrified transportation load is to reach 4 TWh in 2030 and 9 TWh in 2040 (the load in 2017 was 2.6 TWh). The forecasted electric load for the industry is expected to become 58 TWh and 62 TWh in 2030 and 2040 (the corresponding load in 2017 was 49.8).

The generation capacity of the distributed generation for 2030 and 2040 are presented in Table 4.

Table 4 Generation capacity in Svk scenarios for Sweden

Indicator		2017		Svk 2030		Svk 2040	
		GW	% of total	GW	% of total	GW	% of total
Distributed Generation	PV	0.3	0.7%	4.0	9.0%	7.4	14.0%
	Wind onshore	6.7	17.2%	12.8	28.8%	22.2	42.0%
	Wind offshore			1.3	2.9%	2.5	4.8%

Energiforsk- End-User Scenarios and Their Impact on Distribution System Operators

In this study, no specific scenario development for a specific year is conducted. The study is mainly focused on analysing the impact of the adoption of PV panels and EVs on Herrljunga's DSO (Herrljunga Elektriska AB). The study is carried out based on the data from three small networks in Herrljunga, and for analysing the impacts, two scenarios of "realistic" and "extreme" were considered. As mentioned, these scenarios are not built based on scenario development; however, the values can be used comparatively for demonstrations. The assumptions for each of the scenarios are elaborated further in Table 5. The population of the area is 10000 people.

Table 5 Assumptions used in the scenarios for Energiforsk's study

Indicator		"Realistic" scenario	"Extreme" scenario
Distributed generation	Small scale PV	All customers have 5kW installed	All customers have 10kW installed
Electrification	EVs	All customers have an EV with a 3kW charger	All customers have an EV with a 10kW charger
	Heat pumps	All heating is HP based	All heating is HP based
Energy efficiency	Heat pumps' COP	Improved from 2 to 3	Improved from 2 to 4.5
	Building isolation	Improved by 20%	Improved by 50%
Flexibility	Indoor temperature	±2 ^oC	±5 ^oC
	Hot water temperature	±5 ^oC	±15 ^oC

4.1.2 Netherlands

The scenarios for the Netherlands are obtained from a study published in 2019 by Tennet (The Dutch TSO) in collaboration with Gasunie (a Dutch natural gas infrastructure and transportation company) for future of the energy system in Netherlands 2050 [57]. The study includes both the electricity and gas networks. The developed scenarios consist of three main scenarios of "local", "national", and "international". These scenarios are explained further below.

- The **“local”** scenario strongly aims for energy independence relying on centralised Renewable Energy Sources (RES) that is considered to be mostly distributed solar PV. In this scenario, no energy exchange with neighbouring countries is carried out, and strong support from Power-to-gas and batteries is considered.
- The **“national”** scenario aims for energy independence by mostly relying on centralised wind power production. Compared to the previous scenario, the limited energy exchange is allowed with neighbouring countries in this scenario and similarly to the previous scenario, strong support from Power-to-gas and battery storage is considered.
- The **“international”** scenario considers a global-oriented policy focusing on more international energy exchange. This scenario is the business-as-usual scenario with no extensive support of renewable energy supply. In this scenario, the Power-to-gas and battery storage are considerably lower compared to “local” and “national” scenarios.

The expected distributed generation and storage capacity in each of the scenarios are presented in Table 6.

Table 6 Generation and storage capacity in Dutch scenarios

<table>
<tr><th colspan="2" rowspan="2">Indicator</th><th colspan="2">2017</th><th colspan="2">Sc. local</th><th colspan="2">Sc. National</th><th colspan="2">Sc. international</th></tr>
<tr><th>GW</th><th>% of total</th><th>GW</th><th>% of total</th><th>GW</th><th>% of total</th><th>GW</th><th>% of total</th></tr>
<tr><td rowspan="3">Distributed Generation</td><td>PV</td><td>3.0</td><td>9.1</td><td>84</td><td>53.5</td><td>34</td><td>28.8</td><td>16</td><td>30.6</td></tr>
<tr><td>Wind onshore</td><td>3.0</td><td>9.1</td><td>16</td><td>16.6</td><td>14</td><td>11.9</td><td>5</td><td>10.2</td></tr>
<tr><td>Wind offshore</td><td>1.0</td><td>3.0</td><td>26</td><td>10.2</td><td>53</td><td>44.9</td><td>6</td><td>12.2</td></tr>
<tr><td rowspan="3">Storage</td><td>Battery</td><td>0.0</td><td>0</td><td>60</td><td>44.4</td><td>50</td><td>45.5</td><td>5</td><td>71.4</td></tr>
<tr><td>Thermal</td><td>0.0</td><td>0</td><td>0</td><td>0.0</td><td>0</td><td>0.0</td><td>0</td><td>0.0</td></tr>
<tr><td>Power to gas</td><td>0.0</td><td>0</td><td>75</td><td>55.6</td><td>60</td><td>54.5</td><td>2</td><td>28.6</td></tr>
</table>

Moreover, the consumption in different sectors is foreseen to shift from fossil-based fuels to electricity and hydrogen. In Table 7, the consumption of electricity, hydrogen, and methane in different sectors are presented for the year 2050. The hydrogen is assumed to be produced by Power-to-H_2 technologies, and the values shown for hydrogen are the final demand. Therefore, the actual electricity consumption is even more than the summed value of electricity and hydrogen. A generally observed trend is the increase in electricity and hydrogen, which is even more considerable considering the required electricity for hydrogen production.

Table 7 Dutch electricity, hydrogen, and methane consumption in different sectors for the year 2050.

<table>
<tr><th colspan="2" rowspan="2">Indicator</th><th colspan="2">2017</th><th colspan="2">Sc. local</th><th colspan="2">Sc. National</th><th colspan="2">Sc. international</th></tr>
<tr><th>TWh</th><th>%</th><th>TWh</th><th>%</th><th>TWh</th><th>%</th><th>TWh</th><th>%</th></tr>
<tr><td rowspan="4">Electrification</td><td>Transport</td><td>3</td><td>0,9</td><td>40</td><td>11,1</td><td>42</td><td>13,0</td><td>49</td><td>15,5</td></tr>
<tr><td>Electricity</td><td>2</td><td>0,6</td><td>25</td><td>6,9</td><td>19</td><td>5,9</td><td>13</td><td>4,1</td></tr>
<tr><td>Hydrogen</td><td>0</td><td>0,0</td><td>15</td><td>4,2</td><td>23</td><td>7,1</td><td>23</td><td>7,3</td></tr>
<tr><td>Methane</td><td>1</td><td>0,3</td><td>0</td><td>0,0</td><td>0</td><td>0,0</td><td>13</td><td>4,1</td></tr>
</table>

	Industry	**121**	**35,4**	**112**	**31,1**	**112**	**34,7**	**55**	**17,4**
	Electricity	30	8,8	50	13,9	50	15,5	23	7,3
	hydrogen	0	0,0	58	16,1	58	18,0	25	7,9
	Methane	91	26,6	4	1,1	4	1,2	7	2,2
	Households	**102**	**29,8**	**60**	**16,7**	**80**	**24,8**	**84**	**26,6**
	Electricity	23	6,7	40	11,1	32	9,9	31	9,8
	hydrogen	0	0,0	5	1,4	36	11,1	27	8,5
	Methane	79	23,1	15	4,2	12	3,7	26	8,2
	Service sector	**69**	**20,2**	**35**	**9,7**	**47**	**14,6**	**51**	**16,1**
	Electricity	33	9,6	32	8,9	32	9,9	32	10,1
	hydrogen	0	0,0	0	0,0	10	3,1	11	3,5
	Methane	36	10,5	3	0,8	5	1,5	8	2,5
	Agriculture	**23**	**6,7**	**11**	**3,1**	**11**	**3,4**	**11**	**3,5**
	Electricity	9	2,6	11	3,1	11	3,4	11	3,5
	hydrogen	0	0,0	0	0,0	0	0,0	0	0,0
	Methane	14	4,1	0	0,0	0	0,0	0	0,0
	Other demand	**24**	**7,0**	**102**	**28,3**	**31**	**9,6**	**66**	**20,9**
	Electricity	24	7,0	12	3,3	12	3,7	12	3,8
	hydrogen	0	0,0	4	1,1	1	0,3	5	1,6
	Methane	0	0,0	86	23,9	18	5,6	49	15,5
	Sum	**342**	**100,0**	**360**	**100,0**	**323**	**100,0**	**316**	**100,0**

Considering all the above-mentioned changes in the energy landscape of the Netherlands, the expected required investments in the energy infrastructure is presented in Table 8.

Table 8 Required investments in the Dutch scenarios for the year 2050

Investment	Sc.1 Local	Sc.2 National	Sc.3 International
	€ bln	€ bln	€ bln
LV network	19.08	23.02	1.46
LV MV transformer	4.17	5.03	0.32
MV net	14.27	17.39	0.74
MV HV transformer	5.17	6.3	0.27
HV net	23.38	19.09	0
Interconnection net	1.51	1.51	1.51
Offshore net	30.3	61.35	6.94
Total	**97.88**	**133.68**	**11.23**

4.1.3 Bulgaria

The future scenarios are taken from two different sources. One is 2030: National Energy and Climate Plans (NECP) that is based on the country's commitments and EU Green Deal, and the other one is obtained from South-East Europe Electricity Roadmap – SEERMAP project which is a model-based assessment that discusses three different scenarios of "no-target", "delayed", and "decarbonisation". These two sources are presented in Table 9.

Table 9 Sources for future scenarios of the grid in Bulgaria

Organisation	Publication name and year	Notes	Reference
Bulgarian Ministry of Energy	Integrated plan in the area of energy and climate of the Republic of Bulgaria 2021-2030, (2019)	- The national energy and climate plans for year 2030 - Plans are based on countries commitments and EU Green Deal	[58]
SEERMAP Project	SEERMAP: South East Europe Electricity Roadmap, Country report: Bulgaria (2017)	- Scenarios for different years up to 2050 - Three main scenarios of "no target", "decarbonisation", and "delayed	[59]

Bulgarian Ministry of Energy- National energy and climate plans for 2030 (NECP)

This national plan has set the goal of integrating RES by a share of 27.1% in the gross final energy consumption, 30.3% in the electricity sector, and 42.6% in thermal energy and cooling sector.

According to the national plan, PV panels capacity will reach 3.2 GW with a yearly energy production of 4.7 TWh in the year 2030. These indicators for wind are expected to be 0.95 GW wind and 2 TWh. To get a better perspective, the total generation capacity of Bulgaria in 2017 was reported 12.7 GW by ENTSO-E [60]. The generation capacity of the distributed generation is presented in Table 10. Moreover, the penetration of EV fleet is expected to be 0.5 million cars which is equivalent to 1.2 TWh per year.

Table 10 Generation capacity in NECP plan for Bulgaria

Indicator		2017		NECP 2030	
		GW	% of total	GW	% of total
Distributed Generation	PV	1	7.9%	3.2	25.3%
	Wind	0.7	5.5%	0.95	7.5%

SEERMAP

SEERMAP project develops scenarios up until 2050 in the electricity sector for south-east European region. The report for Bulgaria has been used for this section. The scenarios provided in SEERMAP are based on different policy pathways that can be taken for decarbonisation of the society. Accordingly, three different scenarios are provided:

- The **"no target"** scenario considers the implementation of current energy policy and no decarbonisation target for 2050;
- The **"decarbonisation"** scenario considers efforts and policies for significant carbon emission reductions to be aligned with long-term EU goal of 93-99% emission reductions in the electricity sector by the year 2050;
- The **"delayed"** scenario considers the current policies in place to the year 2035 and from then implementation of decarbonisation policies to reach the same goal as mentioned in "decarbonisation" scenario.

The installed capacity, electricity production, and demand for different scenarios in different years are presented in Figure 7 and Figure 8.

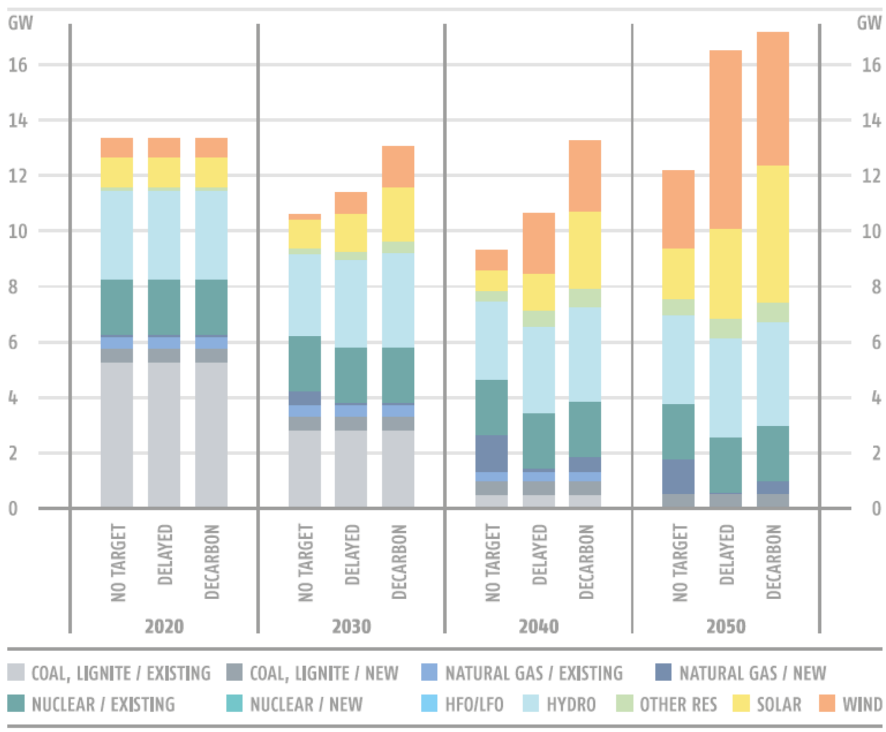

Figure 7 Expected installed generation capacity in Bulgaria for the three SEERMAP scenarios [23]

Approximate expected solar PV and wind generation capacity is summarised in Table 11.

Table 11 Generation capacity in SEERMAP scenarios

Indicator		2017		Sc. No target (2030)		Sc. Decarbonisation (2030)		Sc.3 delayed (2030)	
		GW	% of total	GW	% of total	GW	% of total	GW	% of total
Distributed Generation	PV	1	7.9%	1	9.5%	2	15.4%	1.2	10.4%
	Wind	0.7	5.5%	0.2	1.9%	1.5	11.5%	0.7	6.1%

According to the SEERMAP report, the decrease of wind generation capacity from 2017 to "no target" scenario in the year 2030 is due to the retirement of existing units and lack of further investments.

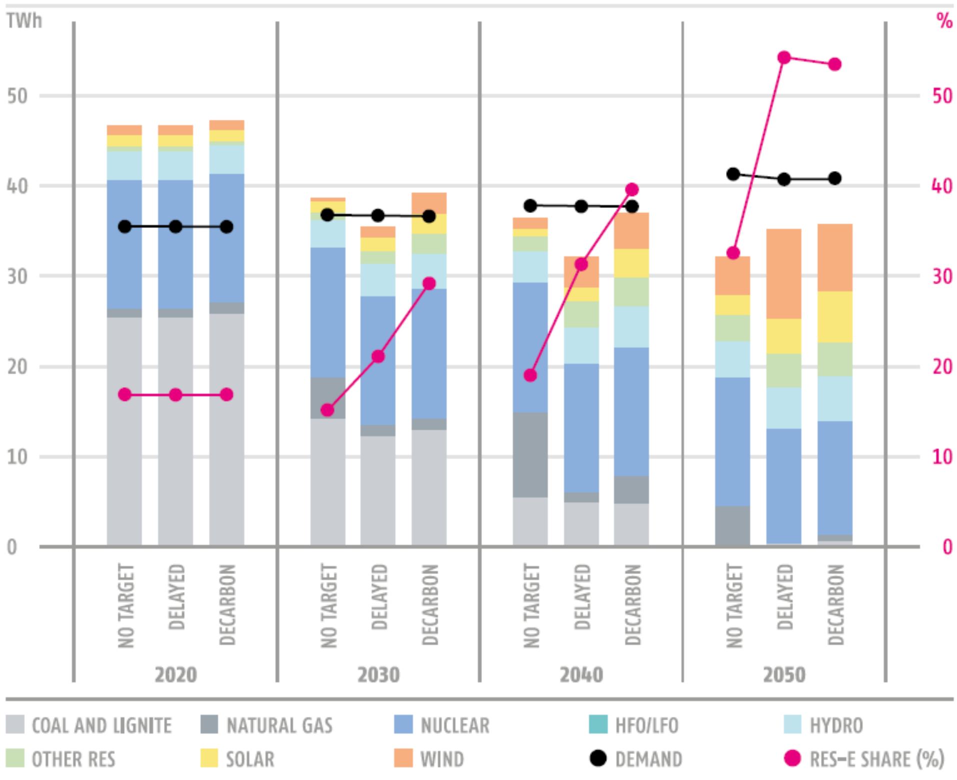

Figure 8 Expected electricity production from different sources of electricity demand in Bulgaria for the three SEERMAP scenarios [23]

4.1.4 Turkey

The Turkish scenarios are taken from a local DSO (Osmangazi Elektrik Dağıtım A.Ş- OEDAS [61]) in Turkey. The scenarios are developed for OEDAS's distribution grids in Eskişehir, Afyon, Kütahya, Uşak and Bilecik. These scenarios mainly discuss the gross electricity consumption and peak power demand in three different scenarios of "low", "base", and "high" cases. The time-horizon used for developing the scenarios is the year 2028, and the scenarios are developed for each year up until the year 2028. These scenarios do not include assessments on the penetration level of distributed generation.

The values for electricity demand and peak power production in the three different scenarios are presented in Table 12. The values for peak power demand are the average of summer and winter peak.

Table 12 Electricity consumption and peak power demand in Turkish scenarios for OEDAS network

Indicator		2019		Sc. low (2028)		Sc. base (2028)		Sc. high (2028)	
		GW	GWh	GW	GWh	GW	GWh	GW	GWh
Demand	Peak Power	1153	-	1509	-	1677	-	1845	-
	Electricity consumption	-	6969	-	8824	-	8983	-	9180

As can be seen in Table 12, the peak power demand shows an expected increase between 31-60% from the year 2019 to 2028. The same comparison for electricity consumption shows an expected increase of 27-32%. The yearly increase in the peak power demand is expected to be 4.3% on average while the forecasted yearly increase for electricity consumption is expected to be 2.9%. Moreover, the forecasts for the electricity consumption for EV charging stations are expected to be 0.034 GWh for a total of 818 planned charging stations in OEDAS network.

Since the elaborated scenarios for Turkey are not developed for the whole country, and they do not discuss the penetration level of distributed generation, conducting cross-country analysis and extracting conclusions faces difficulties. Therefore, these scenarios are not included in the cross-country analysis; however, the presented scenarios can be used directly for the design of demonstration in OEDAS network in work-package 8.

4.1.5 Cross-country analysis

In this section, we have tried to provide a comparison of the grid scenarios between different countries. However, it is worth mentioning that the results are intended to provide a general overview rather than to highlight the concrete differences between the future of the grid in different countries. The reason is due to the various assumptions and time horizons used in developing different scenarios. A scientific and concrete comparison requires the same assumptions and methodology for all the above countries and for the same time-horizon. The presented scenarios can be used separately in each country for a more compatible demonstration design to the future of that country. It worth mentioning that the Turkish scenarios are not included in the cross-country analysis because they are developed only for a specific region and not the whole country, which makes the comparison and drawing conclusions facing difficulties.

For the comparison, Svenska Kraftnät's scenarios for Sweden, Tennet's scenarios for the Netherlands, and the national energy and climate plan for Bulgaria are selected because they are provided by the TSOs or the energy ministry rather than individual studies. Moreover, individual studies are usually very specific and dependent on the status of each region and their distribution grids which can be misleading in providing a general, rough picture representing a country.

The distributed generation in these scenarios is presented in Figure 8. As can be seen, the percentage of PV penetration is the lowest in Sweden, and highest in the Netherlands and followed by Bulgaria. The wind generation is more dominating in Swedish scenarios and a "national" scenario of the Netherlands. It is worth mentioning that one of the reasons for the high penetration level of RES in the Netherlands can be due to the fact that the time-horizon in the Dutch scenarios is the year 2050.

The electricity needed for transportation is also presented as a share of total expected electricity demand in Figure 9. The share of transportation in electricity demand in the Dutch scenarios are calculated by adding up the need for hydrogen and electricity because it is assumed that the hydrogen is produced by electrolysis. As can be seen in the graph, the Dutch scenarios show to have a higher share of electricity need in transportation compared to Sweden and Bulgaria.

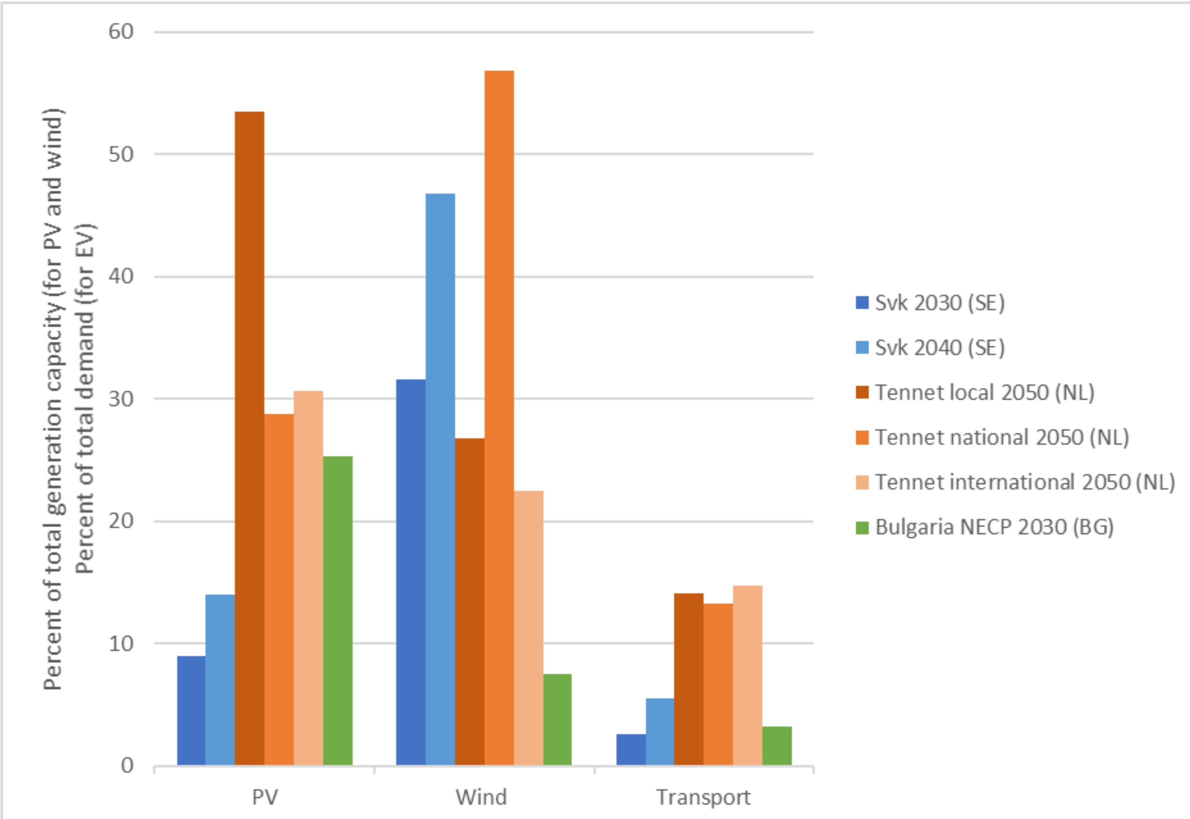

Figure 9 Comparison of distributed generation and transport as a share of total installed capacity or total electricity demand. SE: Sweden, NL: The Netherlands, BG: Bulgaria

Battery and heating storage have not been discussed in detail in any of the sources for the Swedish or the Bulgarian scenarios. However, batteries and power-to-gas technologies are playing an important role in Dutch scenarios.

4.2 Scenarios for the future of local energy and flexibility trade

In this section, the results for future scenarios of local energy and flexibility trade is provided. The results are the outcome of the scenario planning methodology that was explained in chapter 2.

The final trends and key factors for the future of local energy and flexibility trade that were selected based on the methodology (step 2 and 3) can be seen in Table 13. The uncertainty and impact of these factors were evaluated by 14 project partners from different stakeholders and the results of the survey for uncertainty and the impact of these factors are presented in Table 13.

The cross-impact of the same factors were analysed internally in the group with inputs from four experts on the topic. The results from the cross-impact analysis of these factors (as the average active scores for the factors) are sorted and can be seen in Table 14 (active score of a factor is the sum of the row corresponding to that factor). To see further details on the cross-impact of factors on each other, the full cross-impact matrix is available in Appendix 1.

Table 13 Analysed key factors/trends and their uncertainty, impact

#	Factor/trend	Average of uncertainty score	Average of impact score
1	**Availability of distributed generation (technical)** *Enough penetration level of distributed generation for participation in local energy/flex markets*	2,8	4,1
2	**Availability of distributed energy storage (technical)** *Enough penetration level of distributed generation for participation in local energy/flex markets*	3,4	3,6
3	**Availability of electrified transportation (technical)** *Enough level of electrification in transport sector that can affect Vehicle-to-Grid (V2G) capabilities or cause new peaks, congestions, etc in the grid*	3,2	3,9
4	**Availability of electrified heating and cooling (technical)** *Enough level of electrification in heating and cooling sectors that can affect the available flexible units in the system or cause new peaks, congestions, etc in the grid*	2,6	3,9
5	**Availability of electrified industries (technical)** *Enough level of electrification in the industries that can affect the available flexible units or cause new peaks, congestions, etc in the grid*	3,1	3,5
6	**Availability of high-resolution data from smart meters (technical)** *Availability of enough high-resolution data from smart meters which includes the accessibility of the data and enough deployment of smart grids*	2,2	4,6
7	**Availability of smart and digital grid monitoring and control (technical)** *Enough level of smart and digital grid monitoring and control for faster and more precise identification of the grid's status*	2,6	4,3
8	**Availability of smart and digital end-users (technical)** *Enough level of smart and digital end-users with automated, fast and precise control of load and distributed technologies like generation or storage units*	3,8	4,4
9	**Availability of relevant new competences in the energy industry (technical/social)** *Enough level of new competences (e.g. data, IoT, and statistics) in the energy industry can affect the implementation of local energy and flexibility trading solutions*	3,8	3,9
10	**Tendency of end-users for self-consumption (social)** *Tendency of end-users to become less dependent on the grid due to financial or life-style related reasons*	3,7	3,6
11	**Tendency of end-user's active participation (social)** *Active participation of end-users in the local energy/ flexibility trade*	4,1	4,0
12	**Number of end-users (social)** *Increase in the number of end-users due to general population growth or immigration to the cities can reach a level that might cause congestions and challenges in the distribution grid*	2,6	3,0
13	**Resistance from conservative culture of the energy industry (social)** *The conservative and risk conscious culture of the energy industry might cause resistances towards adoption of innovative solutions like local energy and flexibility trading instead of conventional solutions like grid reinforcements based on reasons such as safety and stability.*	3,2	3,5
14	**Positive changes in DSOs unbundling regulations (political)** *Current unbundling regulations in some countries prevent DSOs' ability to trade energy or own distributed energy technologies*	3,4	3,5
15	**Positive changes in regulatory incentives for DSOs (political)** *Currently, DSOs and TSOs are highly regulated in many countries. Depending on how these regulations are formulated, DSOs might or might not have the incentives to participate in local energy and flexibility trade*	3,6	4,1
16	**Increase of carbon taxes (prices) on local fossil-based generation (political)** *This increase can be a driver for promotion of local, clean distributed generation and storage*	3,0	3,3
17	**Increase of restrictions on end-user privacy (political/social)** *More restrictions on the end-users' privacy might affect the participants of local energy and flexibility trading regarding the data handling*	3,0	3,3
18	**Increase of investments in grid reinforcements (financial)** *The need for these investments can be a driver while being a competitor for the local energy and flexibility trade*	2,8	4,0

19	**Increase of wholesale electricity prices (financial)** *Increase of wholesale electricity prices might be driver for a higher local clean distributed generation and storage*	3,1	3,6
20	**Increase of grid tariffs (financial)** *This increase might affect the end-users or energy producers' behaviour and their willingness to participate in local energy or flexibility trading*	2,5	3,8

In Table 13, a higher score for impact or uncertainty indicates a higher uncertainty of impact expected from the factor/trend in the future of local energy or flexibility trade concept. In Table 14, a higher active score implies that the factor/trend has a higher cross-impact on the other factors/trends, and therefore it can be relatively more important.

To be able to develop the scenarios, we need to rank the factors to find the most uncertain and impactful elements. For ranking, the results from the survey are grouped into four groups based on Figure 5, and the results are presented in Figure 10. The separating lines are the average of all the scores for uncertainty or impact. The critical scenario drivers (in the up-right corner) are factor numbers 8, 11, 15, 9, and 3

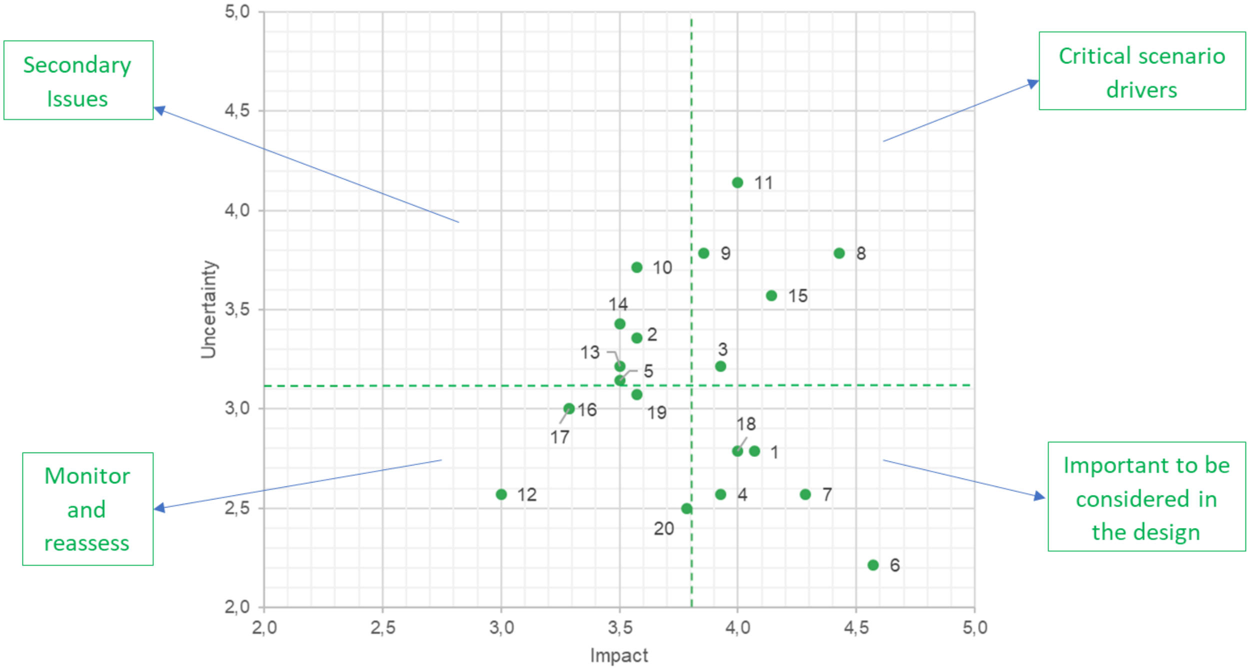

Figure 10 Results from uncertainty-impact ranking. The numbers for each point are the factor/trend number, and the separating lines are the average of all uncertainty or impact scores for all factors/trends.

To select the two axes of the scenario matrix (Figure 6), the active scores from the cross-impact analysis was used to filter further the critical scenario drivers. Among the critical scenario drivers of 8, 11, 15, 9, and 3, factor 11, 8, and 15 have the highest active scores of 32.7, 30, and 29.7.

Table 14 Cross-impact analysis (average active scores). A higher active score shows more impact from the factor on other factors

#	Factor/trend	Average active score
1	**Availability of distributed generation (technical)**	33.7

	Enough penetration level of distributed generation for participation in local energy/flex markets	
11	**Tendency of end-user's active participation (social)** *Active participation of end-users in the local energy/ flexibility trade*	32.7
7	**Availability of smart and digital grid monitoring and control (technical)** *Enough level of smart and digital grid monitoring and control for faster and more precise identification of the grid's status*	32.3
2	**Availability of distributed energy storage (technical)** *Enough penetration level of distributed generation for participation in local energy/flex markets*	30.7
10	**Tendency of end-users for self-consumption (social)** *Tendency of end-users to become less dependent on the grid due to financial or life-style related reasons*	30.7
8	**Availability of smart and digital end-users (technical)** *Enough level of smart and digital end-users with automated, fast and precise control of load and distributed technologies like generation or storage units*	30
15	**Positive changes in regulatory incentives for DSOs (political)** *Currently, DSOs and TSOs are highly regulated in many countries. Depending on how these regulations are formulated, DSOs might or might not have the incentives to participate in local energy and flexibility trade*	29.7
5	**Availability of electrified industries (technical)** *Enough level of electrification in the industries that can affect the available flexible units or cause new peaks, congestions, etc in the grid*	29.3
6	**Availability of high-resolution data from smart meters (technical)** *Availability of enough high-resolution data from smart meters which includes the accessibility of the data and enough deployment of smart grids*	29
20	**Increase of grid tariffs (financial)** *This increase might affect the end-users or energy producers' behaviour and their willingness to participate in local energy or flexibility trading*	28.3
16	**Increase of carbon taxes (prices) on local fossil-based generation (political)** *This increase can be a driver for promotion of local, clean distributed generation and storage*	28
9	**Availability of relevant new competences in the energy industry (technical/social)** *Enough level of new competences (e.g data, IoT, and statistics) in the energy industry can affect the implementation of local energy and flexibility trading solutions*	26
14	**Positive changes in DSOs unbundling regulations (political)** *Current unbundling regulations in some countries prevent DSOs' ability to trade energy or own distributed energy technologies*	26
19	**Increase of wholesale electricity prices (financial)** *Increase of wholesale electricity prices might be driver for a higher local clean distributed generation and storage*	24.3
4	**Availability of electrified heating and cooling (technical)** *Enough level of electrification in heating and cooling sectors that can affect the available flexible units in the system or cause new peaks, congestions, etc in the grid*	23.3
3	**Availability of electrified transportation (technical)** *Enough level of electrification in transport sector that can affect V2G capabilities or cause new peaks, congestions, etc in the grid*	21.3
12	**Number of end-users (social)** *Increase in the number of end-users dues to general population growth or immigration to the cities can reach a level that might cause congestions and challenges in the distribution grid*	21.3
18	**Increase of investments in grid reinforcements (financial)** *The need for these investments can be a driver while being a competitor for the local energy and flexibility trade*	20.3
13	**Resistance from conservative culture of the energy industry (social)** *The conservative and risk conscious culture of the energy industry might cause resistances towards adoption of innovative solutions like local energy and flexibility trading instead of conventional solutions like grid reinforcements based on reasons such as safety and stability.*	17.7
17	**Increase of restrictions on end-user privacy (political/social)** *More restrictions on the end-user's privacy might affect the participants of local energy and flexibility trading regarding the data handling*	14

Since the active score of factors 8 and 15 are very close and factors 11 and 8 are directly related to end-users, the scenario matrix axes were decided to be merged and form one axis related to end-users activeness and smartness (factor 11 and 8). The second axis was chosen to be based on factor number 15, that is related to the regulatory incentives for the DSOs. Accordingly, the four scenarios for the future of the local energy and flexibility trade were developed, as shown in Figure 11.

In Figure 11, the Y-axis represents two characteristics of end-users. The first characteristic is whether end-users are willing to participate in local markets (being active or passive), and the second characteristic is if end-users are automated, digital, and can have a fast and precise control over their energy assets or not (being smart or not). The X-axis represents the existence of regulatory incentives for DSOs to promote the local trading concept. As a result of the impact and uncertainty of these two axes, four plausible scenarios for the future of local energy and flexibility trade and their characteristics are defined as follows:

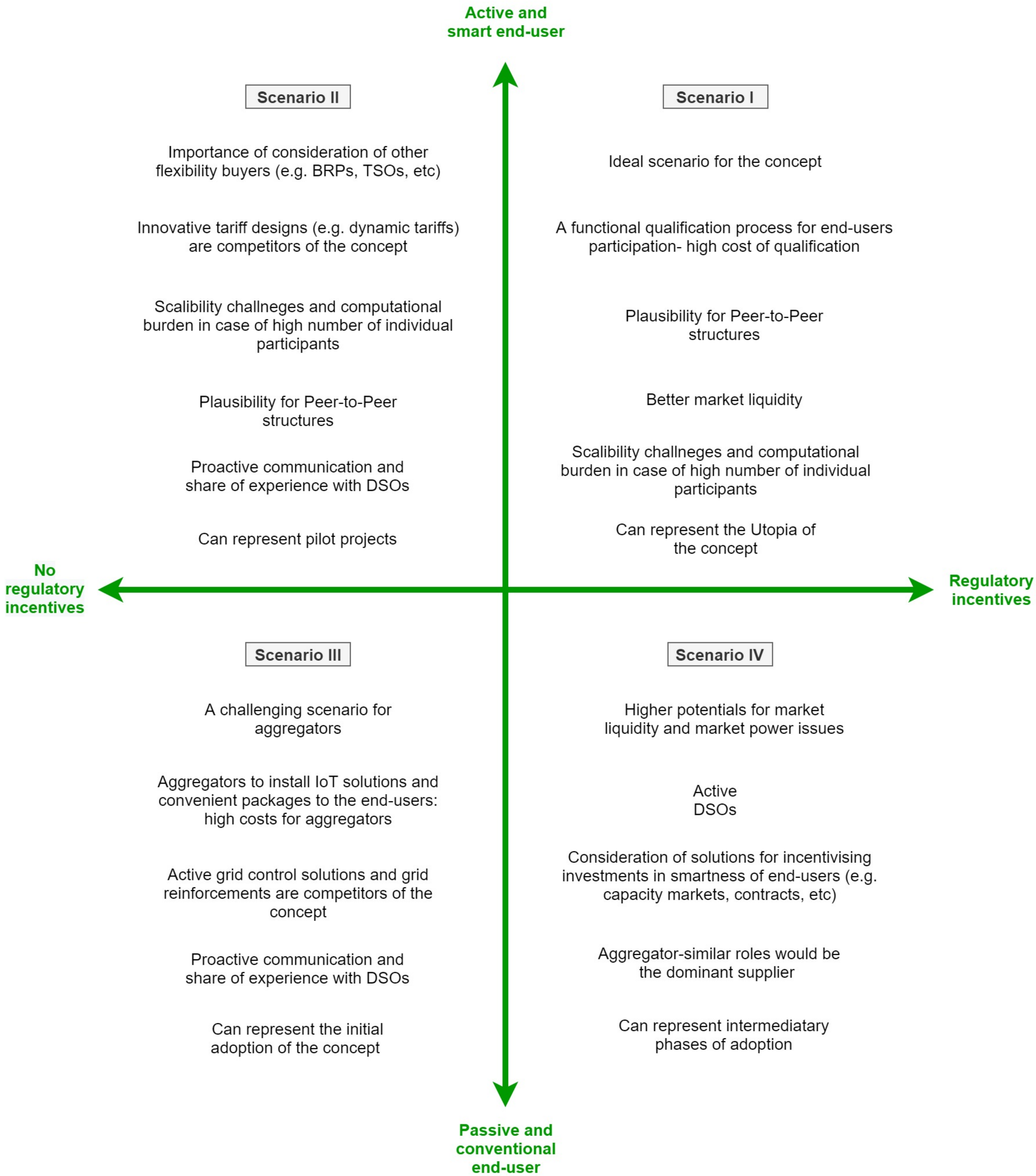

Figure 11 Scenario matrix for future of local energy and flexibility trade

Scenario I:

Scenario I is the preferable future for the local energy and flexibility trade. In this future, the end-users are digitalised and smart. They have automated, fast and precise control over their energy assets like distributed generation, batteries, heat pumps, and controllable loads, and they are willing to actively participate in the local markets. Furthermore, the cost-effectiveness and functionality of the concept of local energy and flexibility trade are communicated adequately with regulators and the involved stakeholders. As a result of this communication, regulatory incentives are in place for DSOs to participate and promote local markets.

Due to the willingness and smartness of the end-users, the recruitment of the participants is relatively easier. In this scenario, the number of participants is considerable. Thus, the concerns about market liquidity or market power exercises are less. This scenario can have good potentials for implementation of Peer-to-Peer structure for trading energy and flexibility.

On the other hand, because of the high number of participants which can be private individuals, a well-designed process is required for qualification of the participants to avoid issues such as inability to deliver the cleared flexibility or energy. This qualification process can be costly and complicated for market operators and participants. Moreover, because of the high number of small individual participants, the scalability and computational burdens from the high number of participants needs to be examined carefully.

Scenario II:

In this future, all the previous characteristics regarding the smartness and activeness of the end-users exist. However, there are no regulatory incentives for the DSOs to participate or promote the concept of local trade. Due to activeness and smartness of end-users, this scenario also has a good potential for implementation of peer-to-peer structures while the concerns regarding scalability, computational burden, and qualification procedures exist.

To be able to have a more implementable product in such a future, it is important to consider other possible consumers of flexibility/energy (e.g. Balancing Responsible Parties, TSOs, etc.) while designing the solution. Besides, proactive communication, the share of experience with DSOs plays an important role in reforming this scenario towards Scenario I.

In this scenario, dynamic tariffs and other new tariff designs are the competitors to the concept of the local market. This is because the end-users are smart and active and capable of reacting to such tariff designs and local markets do not have any regulatory superiority over the new tariff designs.

Scenario III:

This scenario is a challenging form of future for the concept of local markets. In this scenario, the end-users are passive and not willing to participate in the local trade. Moreover, the level of digitalisation, smartness and control is limited in the end-users. These characteristics of the end-users can also be translated to special regions or archetypes in a city, or the initial phase for implementation of local markets. Similar to scenario II, this scenario does not benefit from regulatory incentives for DSOs.

To be able to have a successful implementation of the concept in this scenario, end-users need to be digitalised while ease-of-use needs to be considered while recruiting participants. The aggregators and similar intermediary actors that facilitate the participation of end-users play an important role in this scenario. An example of providing smartness while recruiting end-users is Voltalis [62] in France. Voltalis provides end-users with a box that controls the heating in the apartment. The end-users can opt-out of participating by just pressing a button. The box, its installation, and its maintenance are free of charge. Such extra costs for aggregators might result in a higher price for flexibility/energy, which highlights the importance of developing cost-effective business plans and strategies for these actors. Moreover, due to the limitations in the number of participants/aggregators, the local markets might face other challenges regarding market liquidity and market power practices.

In this scenario where end-users are passive and conventional, and DSOs are not incentivised by regulations or policy, other solutions like active grid control methods or grid reinforcements are among the main competitors for the concept of local markets. Moreover, peer-to-peer solutions might face difficulties in implementation due to unwillingness or unavailability of smart end-users for participation.

Scenario IV:
The last scenario is a future where the DSOs are incentivised by regulations, but end-users are passive and conventional. In this projection of the future, DSOs can play an active role beside aggregators in digitalising and recruiting the end-users. Like the previous scenario, the end-users are not willing to participate actively in the market; therefore, the main supplier of the flexibility/energy would be aggregators or large industrial end-users.

As the DSOs are more willing to promote local markets in this scenario, instruments such as capacity markets, long-term contracts, or feed-in tariffs can be designed with the help of DSOs to provide incentives for investments in the smartness and digitalisation of end-users while affecting their willingness to participate in local energy and flexibility markets.

4.3 Key impacts and suggestions from scenario analysis

In this section, the key impacts and conclusions from the scenario analysis are discussed, and suggestions are provided based on the discussed impacts.

The results from the scenario analysis of the grid have shown that in the analysed countries, distributed generation would be a considerable share of power production capacity within the horizon of 2030-2050. Moreover, the expected load from the electrification of transport would increase considerably in all the countries that are included in the assessment.

Furthermore, the results from the scenario development for future of local energy and flexibility trading has shown that the highest expected impact and uncertainty are regarding the end-users' willingness for participation, their level of digitalisation and automation (smartness), and regulatory incentives for adoption of the local trading concept. Moreover, the results of the survey show that increase in grid-reinforcement, and availability distributed generation, electrified heating and cooling, smart and digitalised grid monitoring and control tools, and high-resolution data have lower uncertainty but high impact on the future of the local trading concept.

Considering the above-mentioned key results, distributed generation, EVs, and electrified heating and cooling would possibly be available at the end-user side. However, the key concern is related to whether these assets are accessible to be involved in the local markets or not. The key concern is arising from, first, the willingness of the end-users for participation and, second, the end-users' level of digitalisation and automated control regarding these assets. Therefore, considering different instruments for increasing the level of willingness and smartness of the end-users can be crucial for the successful implementation of the concept. Among others, the possibility of utilising incentivising instruments like capacity markets or long-term contracts, in addition to direct investments by aggregators or DSOs for providing smart switches and IoT platform for end-users are suggested to be considered. The incentivising instruments can be built between DSOs and end-users, DSOs and aggregators, or aggregators and end-users.

In addition, to further facilitate the recruitment of market participants, avoiding complex market structures, developing modular and API-based design for different system components and algorithms, developing user-friendly user-experience (UX) and automated designs for control systems at the end-user level are suggested. Besides, considering Key Performance Indicators (KPIs) that reflect upon ease-of-use and costs of digitalisation or automation of end-users are recommended for demonstrations.

Moreover, regulatory incentives to promote local markets has shown to have a great impact on the future of local markets. However, these incentives are accompanied with high uncertainty in whether they would be in place by the year 2030 or not. Therefore, proactive communication with system operators and regulators to share the experience and the results is highly encouraged. This communication can help to smoothen the adoption phase and leads to a faster transition from the worst scenario (scenario III) to the preferable scenario (scenario I).

According to the grid scenario and local market scenario assessments, distributed energy storage technologies are not discussed considerably in the established grid scenarios that were analysed. Besides, in the survey results, the impact from these technologies have rated low with high uncertainty in considerable penetration level for these technologies. Due to the intermittent essence of renewable distributed generation, and also a considerably high active score of distributed generation in the cross-impact analysis, it is important to further evaluate the role of distributed storage in local markets to obtain a better insight on the questionable impact and uncertain role of these technologies in local markets.

Regarding the impacts of the scenario I and II, the level of smartness and activeness of the end-users can impact the number of participants in the local markets. With a higher number of participants, better market liquidity can be obtained. However, the possible computational burden and possibly higher costs for qualification process can lead to scalability issues for the concept. Therefore, the computational burden and possible challenges in the qualification process are suggested to be considered while designing different modules of the system.

Finally, there are other solutions such as dynamic tariff designs, direct grid control, and grid reinforcements that can be used alongside or instead of local markets concept. To maximise the value for all stakeholders and the society as a whole, considering these other solutions is recommended for building comprehensive approaches to procure flexibility and resolve expected challenges in the grid.

5 FlexiGrid local markets' products design

In this section, an overview of the tradable products on local markets is presented. In the following section, the different types of products and their potential attributes are discussed separately for both local flexibility and energy markets.

5.1 Tradable products for a local flexibility market

In this section, the outline of flexibility products is defined. The details of the flexibility market's products are investigated in the market design (task 2.3), and it will be tuned closer to the demonstration phase and after the preparation phase of the demonstration sites is finalised.

General grid services that can be provided by flexibility markets are, among others, peak reduction, voltage control, congestion management, harmonics cancellation, balancing services and frequency control, black start, and controlled islanding [1], [63].

In this project peak reduction, voltage control, and congestion management services are going to be developed and demonstrated. These services are filtered based on the following reasoning. The characteristics of the network affect the level that the network can be impacted by the penetration of distributed generation or new electric loads. So, peak power reduction service has been chosen to be included as a general service to most of the networks as it can potentially reduce the operational costs by removing peak generation units with less dependency on the network characteristics. Voltage control and congestion management services have been mentioned as future challenges by the DSOs in the project. Therefore, they are included in the study to design better products based on the need of the market. The harmonics cancellation, balancing and frequency services, black start and controlled islanding, are not considered as a high priority due to the limitations in the demonstration site and availability of the relevant measurement or control systems at the demo sites.

The tradable products for providing the above grid services can be categorised into two main groups of reservation (capacity) based and activation (energy) based products [1], [4], [64]. Besides, according to the results from the scenario analysis, one of the possible challenges with the implementation of local markets is the availability of flexibility (i.e. available capacity, and active and smart end-users). This challenge can be addressed through different methods explained in the previous chapter. The tradable product in these methods can be categorised as reservation (capacity) based products which are traded in a more extended horizon before the activation time. On the other hand, activation (energy) based products are used for closer time-horizons to procurement time. These two categories of products are further explained below.

5.1.1 Reservation (capacity) based products

Capacity products can be activated through long-term markets, or contracts [64], [65]. United-Grid long-term market for services is an example of reservation-based products in which the flexibility providers bid a capacity volume and a reservation price to the long-term market, which takes place months ahead [64]. Moreover, an example of long-term capacity contracts is proposed by the French TSO RTE [65] where the contracts aim to reduce the peak power demand and incentivise investments in generation and demand response.

As mentioned in the scenario analysis, capacity-based products might not be needed in the pilot projects due to already available distributed technologies and active and smart participants. However, after the demonstrations and with the obtained results, further assessments such as investments models for replication, or studies for up-scaling can be done to make sure, firstly, if there would be enough penetration level for different types of technologies and secondly, if there would be enough level of active and smart end-users willing to provide flexibility or energy. From these results, the capacity products can be further tuned to match a specific site (e.g. a region) for replication.

In the FlexiGrid project, the mechanisms that were developed in United-Grid project are further improved, and capacity-based products are considered in the long-term market. In this market, a single-sided auction is developed in which the DSO is submitting a request (Table 15), then, flexibility providers can bid their flexibility volume and corresponding reservation price bid (Table 16). Moreover, an activation price can be bid along with the reservation price. The activation price is paid to the flexibility providers in case that their offered flexibility was activated later and closer to real-time when the service was required and activated. The activation (energy) based products are further explained in the next section.

Table 15 Example of a DSO request in the long-term market of United-Grid project (adapted from [64]*)*

Service Type	Timeline	Location	Nodes	Volume	Time & Duration	Timestamp	Market closure
e.g., active/reactive power up/down regulation	i.e., Long-term, Short-term, Real-time	e.g., the area	e.g., the nodes of interest	i.e., active or reactive power	i.e., the time of the incident and its duration	i.e., opening timestamp	i.e. the latest date and time for eligible bids

Table 16 Example of a flexibility provider's bid in long-term service market of United-Grid project (adapted from [64]*)*

Service ID	Aggregator ID	Nodes	Volume	Activation price (€/kWh)/ (€/kVarh)	Reservation price (€/kWh)/ (€/kVarh)	Timestamp
i.e., the reference ID of the DSO service request as appeared in the respective orderbook	i.e. The unique reference ID that distinguishes each aggregator	i.e., the node(s) to which the aggregator can provide flexibility	i.e., active or reactive power	i.e. The bid for activation price	i.e. The bid for reservation price. N/A for real-time services	i.e. submission timestamp

5.1.2 Activation (energy) based products

Activation or energy-based products are used directly to procure flexibility and provide the grid services. These products have different characteristics (Figure 12) such as preparation period, ramping period, full activation time, min and max activation quantity, min and max delivery period, and deactivation period [66]. Moreover, in case of activating flexibilities such as energy storages or demand response, rebound effects or payback effects can occur (Figure 12) as a result of depleting the storage or deferring tasks (loads) that might have to be paid back later [67]. Depletion of storage or shifting a load can solve an issue such as congestion in the grid; however, they can create another one during the payback time [68]. This rebound effect can be expressed as characteristics of energy products. Moreover, the above-mentioned characteristics can be added with other attributes or characteristics such as location, granularity, reservation price, activation price, payback period, etc.

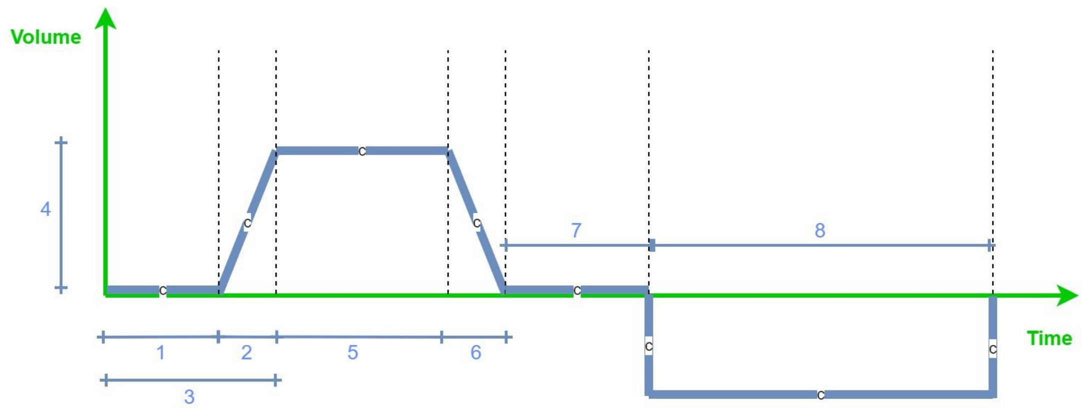

Figure 12 Energy product characteristics (modified figure from [66] *and* [69]*). 1: Preparation period, 2: Ramping period, 3: Full activation time, 4: Min and max activation quantity, 5: Min and max delivery period, 6: Deactivation period, 7: delay period, 8: payback period*

A list of these different attributes is presented in Table 17. The attributes in the table are originally defined for balancing purposes at TSO level; however, they can be modified and adapted to DSOs and flexibility markets [4]. These attributes are to be used as the basis for the further detailed design of flexibility products in FlexiGrid local flexibility market.

Table 17 Attributes of energy-based products for flexibility (modified table from [4]*)*

Characteristic	Definition	Source
Preparation period	The time between when the flexibility is requested to be activated until the unit starts the ramping phase.	[70]
Ramping period	The duration between the start of the ramping period until when the input and/or output of the power reaches the requested value.	[71]
Full activation time	The total duration between when the flexibility is requested to be activated until it reaches the full delivery level.	[70]
Minimum/maximum activation quantity	The power (or deviation in original plan) that is bided and is expected to be delivered at the end of the full activation time. The minimum quantity is the lower constraint on the quantity that can be provided.	[71]
Minimum/maximum duration of the delivery period	The max or min duration that the full quantity of the flexibility can be provided.	[70]
Deactivation period	The same as the ramping period, but for deactivation and going back to the power level before the activation request.	[70]
Granularity	The smallest increment in volume of a bid.	[71]
Validity period	The period that the bided flexibility can be provided by the flexibility provider. This period is defined by a start and end time.	[70]
Mode of activation	The mode can be automatic or manual depending on whether the flexibility is activated automatically or manually by the DSOs request.	[70]

Reservation price	Price for having the flexibility available (can be represented by € /MW/hour of availability).	
Activation price	Price for activation and delivery of the flexibility (can be represented by € /MWh).	
Divisibility	The possibility for partly using the offered flexibility. Division can be done in terms of power activation or time duration.	[70]
Locational information included	An attribute for determining the geographical location of a certain flexibility bid. It can be used in calculating the impact of flexibility on voltage control or congestion management.	
Recovery period	Minimum duration of the period after deactivation of the flexibility and the next activation.	[70]
Aggregation allowed	This attribute determines if the provided flexibility can be an aggregation of several units or not.	
Symmetric/asymmetric product	This attribute determines whether the offered flexibility should be symmetric (equal up and down-regulation), or asymmetric bids are also accepted.	[72]
Delay period	The delay period is the duration between the end of activation until the rebound effect starts.	[69]
Payback period	The payback period is the duration that the rebound effect takes place.	[69]
Minimum and maximum Payback quantity	Payback quantity is the same as activation quantity, but for the payback period.	[69]

Furthermore, based on the results from the scenario analysis, the energy-based products can be broken down into two different groups of simple products and more sophisticated products. This categorisation is due to the possible limitations in the availability of active and smart end-users. Simple on/off products include simple on/off switching of the loads such as thermostatic loads, turning off a fan in a ventilation system, or any other similar flexibility. Simple products can require less complex control systems (compared to sophisticated products), and therefore, they are easier and cheaper to install for non-smart end-users. More sophisticated products require a higher level of controllability and digitalisation. These products can include battery energy storage, reactive power control, or V2G technologies.

Implementing simple products in the project and demonstrations can be beneficial for more successful replication and upscaling. On the other hand, implementation of more sophisticated products provides the opportunity to evaluate the effectiveness (both technically and economically) of these products with research purposes and to result in a better insight over the impact of the technologies on the local market concept.

5.2 Tradable product for local energy market

In FlexiGrid project, a local energy market is planned to be in operation besides the local flexibility market, which is a modified and improved version of the local energy market developed in Fossil-free Energy District (FED) project [32]. In this section, the general characteristics of the FED energy market, and the designed products are presented, while the planned modifications are discussed.

5.2.1 General characteristics of FED market

The main characteristics of FED energy market (FED-EM) are as follows [73], [74]:

- **A pool-based double-sided auction:** the supply and demand bids are submitted to a centralised market at a specific time and in standard bidding formats. The cleared price is based on pay-as-cleared.
- **Multiple energy carriers:** In FED-EM, three different energy carriers of electricity, heating, and cooling are cleared in one market and at the same time. The clearing is carried out at the same time; however, the products in each energy carrier are balanced separately. To make the linkage between bids in different energy carriers, dependencies are considered between the bids which are explained further in the next section ("tradable products in FED-EM).
- **Rolling time-horizon:** In FED-EM, the bidding and clearing are done by a rolling time-horizon, to minimise the impact from forecast errors by clearing as close to the delivery time as possible. In the rolling time-horizon, the bids are cleared every hour and 10 next hours are submitted and cleared in each clearing. However, only the bids for the first hour are binding only for delivery in each clearing. Graphical expression of the rolling time-horizon is shown in Figure 13.
- **Network constraints:** The developed market takes into consideration the network capacity limitations when clearing the bids. These constraints include the energy flow limitations of the local distribution network.

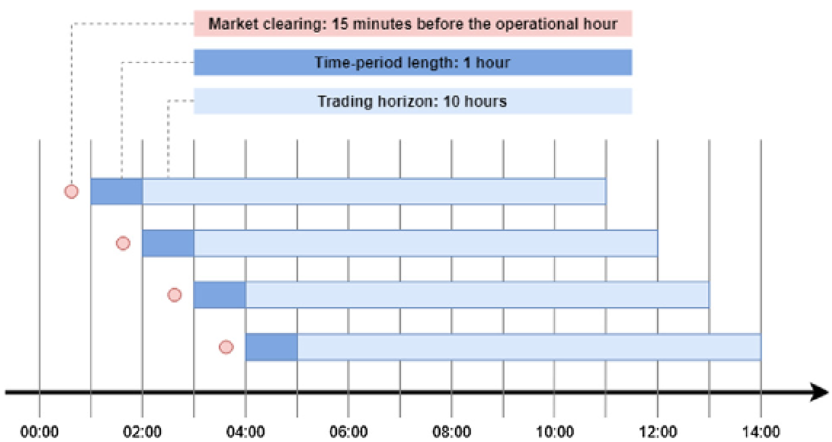

Figure 13 Rolling time-horizon clearing in FED-EM (adopted from [73]*)*

5.2.2 Tradable products in the FED-EM

The tradable products in FED energy market have different attributes. These attributes are presented in Table 18 [73].

Table 18 The product attributes in FED energy market

Attribute	Description
Energy carrier	If the bid is related to electricity, heating or cooling
Delivery-hour	Determining in which hour the bided quantity is going to be delivered or requested
Supply or demand	If the bid is for supply or demand
Location	The location in the network that the submitted quantity is going to be injected or withdrawn from.
Quantity	The amount of energy that is going to be injected or withdrawn within the delivery hour. It is usually expressed in kWh.
Price	The price corresponding to the bided energy. It is can be expressed in €/kWh.

Dependencies	Dependencies are for linking the different energy carriers. The dependencies are explained further below.

There are five different types of dependencies implemented in FED-EM [73]. These dependencies are:

- **AND-dependencies:** when the bids in the dependency should all be accepted or rejected
- **OR-dependencies:** when only one of the bids in the dependency can be accepted
- **Equality (EQ) dependencies:** when the sum of the accepted quantity of the bids in the dependency should be equal to a certain value
- **Less or equal (LE) dependencies:** when the sum of the accepted quantity of the bids in the dependency should be less or equal to a certain value
- **Greater or equal (GE) dependencies:** when the sum of the accepted bids in the dependency should be greater or equal to a certain value

The planned modifications and improvements on FED-EM include further development of the network constraints, design and implementation of coordination mechanisms between local energy market and local flexibility market. Moreover, since FlexiGrid project is focused on the electricity network, modifications are needed in the filtration of other energy carrier agents and their bids.

6 Requirements of the FlexiGrid solutions

The cyber-physical requirements and the needs for implementing the tradable products that are discussed in Section 5 are presented in this section. Trading these products and flexibility provision from the demand-side in energy systems requires a higher degree of automation and instrumentation at the end-user level. Its success depends on the level of automation and digitalisation being installed [75]. It is essential to enhance and improve the automation and intelligence level in distribution networks to facilitate the local transaction of flexibility. The cyber and physical systems are coupled together in smart energy systems to provide critical services, and thus, the smart energy systems could be considered as distributed Cyber-Physical Systems (CPS). The operation in energy systems depends on massive information obtained from the physical systems. The cyber system gathers the information and manages the operation by economic and remedial actions [76].

CPSs are based on integrating computation with physical processes. These processes are monitored and controlled by computer-based algorithms based on feedback loops in which physical processes affect computations and vice versa. In CPSs, physical components and software components are deeply intertwined. They can be operated on various spatial and temporal scales, illustrate multiple and distinct behavioural modalities, and interact with each other to change with context. Thus, CPS can be seen as a complex system that leads to difficulties in the requirements capture because requirements are also conflicting, redundant, and complex. The redundant and complex requirements increase the time and cost of developing the system.

The requirements for the cyber-physical system could be related to time. In the physical world, the passage of time is inexorable, and concurrency is intrinsic. Time is a crucial requirement for developing a CPS that leads to making the system deterministic and predictable. However, time cannot be exactly predictable due to the hardware configuration and programming language nature. The characteristics of the CPS from the demand-side are shown in Figure 14.

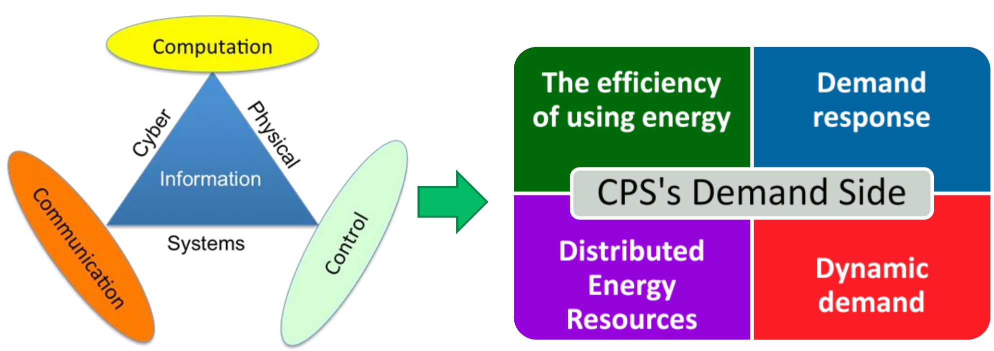

Figure 14 The characteristics of the CPS from the demand-side

- **The efficiency of using energy**: consuming less power to perform the same tasks. It relates to a permanent reducing of demand by using more efficient load-intensive appliances such as water heaters, refrigerators, or washing machines;
- **Demand response**: Actions to reduce, flatten or shift demand. It includes all intentional modifications to consumption patterns of electricity of end-user customers that are intended to alter the timing,

level of instantaneous demand, or the total electricity consumption. Moreover, demand response refers to a wide range of actions that can be taken at the customer side of the electricity meter in response to particular conditions within the electricity system (such as peak period network congestion or high prices);

- **Dynamic demand**: prolong or delay appliance operating cycles by a few seconds to increase the diversity factor of the set of loads. It means that by monitoring the load factor of the power grid, as well as their control parameters, individual, intermittent loads would switch on or off at optimal moments to balance the overall system load with the generation, reducing critical power mismatches. Because this switching would only prolong or delay the appliance operating cycle by a few seconds, it would be unnoticeable to the end-user;
- **Distributed Energy Resources**: distributed generation, also distributed energy, on-site generation, or district/decentralised energy is electrical generation and storage performed by a variety of small, grid-connected devices referred to as distributed energy resources (DER). Conventional power stations, such as coal-fired, gas, and nuclear-powered plants, as well as hydroelectric dams and large-scale solar power stations, are centralised power plants. Due to the fact that the supply outweighs the demand in nearby areas, electric energy to be transmitted over long distances. By contrast, DER systems are decentralised, modular, and more flexible technologies, that are located close to the load they serve. These systems can comprise multiple generations and storage components; in this case, they are referred to as hybrid power systems. DER systems typically use renewable energy sources, including small hydro, biomass, biogas, solar power, wind power, and geothermal power, and increasingly play an important role in the electric power distribution system. A grid-connected device for electricity storage can also be classified as a DER system and is often called a distributed energy storage system (DESS). By using an interface, DER systems can be managed and coordinated within a smart grid. Distributed generation and storage enable collecting of energy from many sources and may lower environmental impacts and improve the security of supply.

The requirements can also be divided into two types:

i. ***Functional***: The requirements described above fall into the functional group as each of the requirements will be a function (or feature) of the system;
ii. ***Non-functional***: It is also important to identify the following non-functional requirements at the elicitation phase for CPS:
    (a) **Dependability** refers to the property of a system to perform required functionalities during its operation without significant degradation in its function
    (b) **Reliability** refers to the degree of correctness which a system provides to perform its function;
    (c) **Predictability** refers to the degree of foreseeing of a system’s state/behaviour/functionality either qualitatively or quantitatively;
    (d) **Sustainability** means being capable of enduring without compromising requirements of the system while renewing the system’s resources and using them efficiently;
    (e) **Security** refers to the property of a system to control access to the system resources and protect sensitive information from unauthorised disclosures;
    (f) **Interoperability** refers to the ability of the systems/components to work together, exchange information, and use this information to provide specified services.

From the technical/implementation point of view, the following functional requirements were identified until now for the FlexiGrid platform. The requirements listed in Table 19-Table 22 will be enhanced during the project, based on the feedback received from the demo sites.

Table 19 Functional requirements for DSOs

ID	Category / Requirement
	Functional requirements for DSO (As a DSO I want to …)
	General
F001	Login to the system using a secured certificate, so that I can access all the available functionality
F002	Log out from the system, so that the resources are no longer used
F003	Have a dashboard, where the most important information (TBD) will be displayed. Also, the notifications and alerts be displayed there.
F004	Have the possibility to accept or to dismiss a notification or an alert
F005	Enter and store the data describing the topology of the distribution grid, so that it will be used by algorithms and presentation tools
F006	Enter and store the data describing the equipment in the distribution grid, so that it will be used by the optimisation, forecasting, or other algorithms
F007	Export data displayed in other formats (csv for data, pdf for graphs)
	Grid-related
FG001	Store the data from the distribution grid, so that the distribution grid can be monitored, and the forecasting algorithms have access to the training data
FG002	Display the data from the distribution grid in real-time, so that it is possible to see and intervene when necessary
FG003	Display historical data, for a specific period, with a specific time granularity (minutes, hours, days, weeks), so that predictions and future decision can be taken
FG004	Receive information about anomalies in the system in real-time, so that it will be possible to take the decision to put the system in normal functionality
FG005	Receive information about forecasted congestions, so that, a decision to optimise the grid can be taken
FG006	Accept or dismiss notifications about anomalies or forecasted congestions, so that the feedback can be used by the training algorithm and in future give more accurate information
FG007	Select a specific part of the grid, or the whole grid, for which processing is performed, so that the focus will be on the necessary elements
FG008	Be able to get the location of an anomaly or a forecasted congestion, so that it will be possible to take the appropriate action
FG009	Be able to see the probability of forecasted congestion, so that it will be possible to decide if taken into consideration
FG010	Be able to see the severity of an anomaly, so that it will be possible to decide if taken into consideration
FG011	Select the specific period, and a specific time granularity (minutes, hours, days, weeks) for a forecasting the grid, so that predictions and future decision can be taken
FG012	Run a what-if scenario for a selected period of time, with new entered parameters of the grid, so that it will be possible to run scenarios used to prepare future decisions
FG013	Select a specific part of the grid, or the whole grid, for which forecasting is performed, so that the focus will be on the necessary elements
FG014	Select the required accuracy for forecasting, so that it will be possible to adjust the balance between processing time and results obtained
FG015	Obtain the probability and the severity of the forecasting congestion, so that accurate decision can be taken
FG016	Display geographically (in the topology of the grid) and graphically (time series) data referring to forecasted congestions
FG017	Have the possibility to act on a congestion, so that the grid function in optimal parameters
FG018	Have the possibility to reconfigure the grid, to operate safely

	Photovoltaic
FP001	Setup voltage limits, so that the limit violations can be defined
FP002	Estimate the required flexibility so that the voltage limit violations can be addressed
FP003	Receive forecasts for voltage limit violations, so that required flexibility can be defined
FP004	Receive real-time voltage limit violations, so that immediate action can be ordered
FP005	Get calculations about operation points of the solar panels
FP006	Command the power converters of the solar panels, so that the grid can have optimal functionality
FP007	Monitor the operation points of the solar panels, so that immediate action can be taken if necessary
FP008	Store information received from operation points, so that training system can create good forecasting
FP009	Visualise the parameters registered from operation points of the solar panels, so that a clear view of the grid can be formed
FP010	Select area and time intervals for estimations about voltage limit violations
	Functional requirements for aggregators (As an aggregator I want to …)
FA001	Create the portfolio of providers
FA002	See the available flexibility in the grid topology and graphic way, so that I can decide on the next steps
FA003	Bid for a provider, to be able to optimise the grid
FA004	Get the optimal distribution of distribution points, so that the grid is optimally allocated
FA005	Control the controllable resources, so that the grid is working optimally
FA006	Get feedback on the new operating points and compare with different periods in the past
FA007	Run what-if scenario based on different configurations of the grid
	Functional Requirements for system administrator (as an administrator I want to…)
FD001	Store data about the topology of the grid, so that it is used in the processing algorithms
FD002	Store data about the equipment in the grid, so that data can be read, and controls can be sent
FD003	Register users and associate roles, so that they can access the right functionality
FD004	Register user certificates, so that they can login in a secured way
FD005	Monitor IoT platform functionality to offer users a good availability and performance
FD006	Audit IoT platform functionality, so that I can understand the events in the past
FD007	Receive notifications and alerts from the system, to be able to act when it behaves improperly
FD008	Delete data registered in the system, when it is not necessary

Table 20 General system requirements

SYS	System Requirements	
SYS-001	Support high-availability requirements	FlexiGrid must support high-availability requirements, operating without outages within certain periods, but still allowing for scheduled maintenance downtimes outside of committed hours.
SYS-002	Support backup and recovery operations	FlexiGrid must support copying and archiving data for restoring the original data after a data loss event.
SYS-003	Support both horizontal and vertical scalability scenarios	FlexiGrid must support both horizontal and vertical scalability for capacity expansion scenarios.
SYS-004	Support agreed workload and response time performance requirements	FlexiGrid must support agreed workload and response time performance requirements guaranteeing operation within considered time limits.

SYS-005	Support the agreed performance requirements with minimal hardware	FlexiGrid must support agreed performance requirements guaranteeing operation at considered peek workload with minimal hardware configuration.
SYS-006	Allow working on different hardware platforms (x64 compatible)	FlexiGrid must be designed to allow running server-side services on different hardware platforms (x64 compatible).
SYS-007	Support virtualisation options for hardware resources	FlexiGrid must support virtualisation options for hardware resources to allow optimal use of existing capacity, within budget constraints.
GUI	**Graphical User Interface Requirements**	
GUI-001	Provide common look-and-feel to the graphical user interface	FlexiGrid must provide a common look-and-feel through a portal-like user interface to guide the user to the underlying functionality of the internal components, such as a portal-like approach, which is a common practice for integrating distinct functional components and providing an integrated presentation layer.
GUI-002	Provide intuitive general navigation methods	FlexiGrid must provide intuitive general navigation methods.
GUI-003	Use unambiguous text to describe features	Text used for the FlexiGrid' user interface should be unambiguous. Typefaces and fonts used should be easily readable and should support international accents. Where symbols are used consider associating descriptive text as well. Beware of cultural differences related to naming and symbols.
GUI-004	Support localised texts for international end-users	FlexiGrid must support localised texts for international end-users, by using Unicode compliance for global text display, independent from a specific language/character set encoding, while also supporting right-to-left languages.
GUI-005	Use appropriate colours and contrast	FlexiGrid must use appropriate colours and contrast, avoiding conveying meaning by colour, as there may be cultural differences in interpreting colours between users of the system while making sure that information is comprehensible, even if the colours are absent.
GUI-006	Provide consistent labels for buttons and fields	FlexiGrid must provide consistent labels for buttons and fields. An explicit label must be provided for each form field. Each label must be placed close to the field to which it is attached. Group together related fields.
GUI-007	Indicate the size and format of documents available for download	FLEXIGRID must indicate the size and format of each document that can be downloaded. For each link that points to a document that can be downloaded, link text should include the document name, file format, and size.
GUI-008	Provide account authentication interface for user identification	FlexiGrid must provide a graphical interface for authenticating end-users. The interface should also allow system administrators to create user accounts, to configure appropriate roles and permissions authorisations, to activate and deactivate accounts, and to configure password reset intervals.
GUI-009	Provide adaptive user interface based on	FlexiGrid must provide an adaptive user interface based on authorisation access rights of the user, such as displaying only links/menus to activities and resources that the user has access to.

	authorisation access rights	
INT	**Interoperability Requirements**	
INT-001	Integrate components and external systems in a loosely coupled way	FlexiGrid must integrate internal components and external systems in a loosely coupled way; as such that each of its components has, or makes use of, little or no knowledge of the definitions of other separate components.
INT-002	System components expose and consume data in a standardised way	FlexiGrid components must expose and consume data in a standardised way.
INT-003	Publish and describe exposed interfaces towards other systems	FlexiGrid must publish and describe exposed interfaces towards other systems by managing a set of open APIs towards other systems, used both to develop the actual FlexiGrid system and to extend the system in the future if needed.
INT-004	Describe the syntax and format used for data exchange messages	FlexiGrid must describe the syntax and format used for data exchange messages, while also specifying the semantics of data fields. Standardisation of messages ensures that messages are robust, interoperable, and reusable.
INT-005	Leverage open standards to communicate with external systems	FlexiGrid must leverage open standards, where available, to communicate with external systems, as opposed to implementing custom means of data exchange.

Table 21 Security requirements

ID	Name	Category / Security Requirement
Communications		
COM-001	User Traffic	FlexiGrid must encrypt all communications between a user of the system. All web pages must be served over HTTPS.
COM-002	Module Traffic	All communications between modules must be encrypted. The use of TLS is recommended for HTTP based communications. All external communication must be conducted over HTTPS.
COM-003	Sensor Traffic	All communications to external devices and services must be encrypted. The use of TLS is recommended for HTTP based communications.
COM-004	Message Passing	All messages passed to and from the FlexiGrid message bus must be encrypted. Messages passed must avoid sending identifying information.
COM-005	Entry points	All entry points to the FlexiGrid system must be restricted in what functionality they expose. An endpoint should only expose the data that is needed.
COM-006	Data Authenticity	All data contained with the FlexiGrid system must be accompanied by a cryptographic signature. The originating module must sign the data with the modules own private key. Where modules receive data from other modules, they must check the signature against the sending module's private key and the data.
COM-007	Data Sanitisation	All modules in the FlexiGrid system must perform a basic level of input sanitisation, e.g. validating against a set data model or

		standard, such as JavaScript Object Notation (JSON). Where a standard structure is not defined, properties such as file size may be used to validate instead. A common attack vector is via injection, where raw queries/commands can be executed. All modules must not allow raw queries to be executed.
COM-008	Rate Limiting	Modules with exposed endpoints must implement rate limiting as protection against Denial of Service (DoS) caused by external attackers or malfunctioning modules.
Authentication		
AUTH-001	Internal Login	The FlexiGrid system must provide an interface to those users who are internal to the system. This interface must not be publicly accessible.
AUTH-002	External Login	The FlexiGrid system must provide an interface to those users who are external ('guests') to the system in order to authenticate themselves with the system. When users are authenticated with this interface, they should have restricted access to functionality and data. These restrictions should be configurable by access controls.
AUTH-003	Device Authentication	All devices must authenticate with the FlexiGrid system and modules using JWT tokens where possible.
AUTH-004	Multi-Factor Authentication	For users to authenticate with the FlexiGrid system, a Two-Factor (TFA) method must be used, for example One-Time use Passwords.
AUTH-005	Token Lifespan	All authentication tokens must have a finite lifespan. A recommended expiration period is 30 days.
AUTH-006	Token Revocation	The FlexiGrid system must have a centralised system to create, revoke and invalidate any tokens.
Logging		
LOG-001	Contents	Modules in production must not log any stack traces, domain data or, any other kind of information that may indicate how the module operates or what data it is currently processing. Log contents must be concise and only expose what is needed for debugging purposes.
LOG-001	Log Storage	The FlexiGrid system must provide a secure centralised location for the storage of logs from the system and individual modules. Modules are also responsible for providing secure storage for their own logs outside of the centralised system.
LOG-002	Log Accessibility	The FlexiGrid system must provide a method, such as a Graphical User Interface (GUI), that is accessible to the system administrators by which to view the logs of the system.
LOG-003	User Events	Each module must record any user events, such as user creation, password changes, new logins and failed logins.
LOG-004	Network Events	Each module must record any network related events such as new connections, connection failures.
LOG-005	Authentication Events	Each module must record any authentication success/failures; these include authentication events with accessing other modules and accesses from other modules.
LOG-006	Messages	Modules must keep logs of received events from the FlexiGrid message hub, including the topic and the originating module.
LOG-007	Data Events	Modules must keep logs of modifications to data, data validation errors and data verification errors. Modules must record CRUD operations performed on data, including the originating module.

Data Storage and Caching		
DS-001	Data Encryption	All data stored within the FlexiGrid system must be encrypted where possible. This includes and temporary data stores and caches.
DS-002	Data Lifetime	All data stored must be kept for a finite lifetime. When stored/cached data is no longer needed it must be securely deleted from data stores/caches.
DS-003	Key Store	Each module must incorporate a secure key storage system to hold any private keys, such as API keys, keys used for signing data and keys/tokens for authenticating with modules and services.
DS-004	Key Management	The FlexiGrid system must have the ability to create, revoke and invalidate any keys stored.
Access Control		
AC-001	Hierarchy of Access	The FlexiGrid system must provide a system by which features, and data can be restricted based on a role hierarchy (for example the 'admin' role grants the ability to edit system settings while a 'user' role would not). Access controls will be facilitated through
AC-002	Data Access Restrictions	Users of the system must be restricted to what data they can access based on role. Users should be restricted on a case level as well as by specific type of data. These access controls should be configurable base on the hierarchical role system.
AC-003	Physical Restrictions	The FlexiGrid system must have the ability to restrict access and functionality based on identifying features of a user's computer. This can be features such as IP address and MAC addresses.

Table 22 Additional requirements for the FlexiGrid solutions

ID	Name	Additional Recommendations
DEP-001	Examine dependency vulnerabilities	Partners should examine possible security vulnerabilities that may exist in libraries and external services used by their modules. Partners should avoid using versions of the library with known, high-risk security vulnerabilities.
DEP-002	Examine external dependency access	Partners should be aware of any external API calls an external library may perform, especially to third party services. It should be ensured that any data transmitted is sent securely and that only the minimal amount is transmitted. The transmission of sensitive data must be limited.
DEP-003	Do not store actual passwords in user stores	FlexiGrid shall not store the actual passwords, but one-way mathematical hashes of the passwords, to make possible validating a password without storing its value.
DEP-004	Assume all input is malicious	FlexiGrid shall not trust any input and should assume that all input may be malicious until proven otherwise. All input shall be validated first.
DEP-005	Verify the consistency and integrity of input data	FlexiGrid shall verify the consistency and integrity of input data, not relying on client-side validation, but perform validation also on the server-side. Data coming from application services should also be verified for consistency and integrity (e.g., using checksums).
DEP-006	Constrain, reject, and sanitise the end-users' inputs	FlexiGrid shall constrain, reject, and sanitise the end-users' inputs. Input validation strategy: (1) constrain acceptable input by validating data type, length, format, and range, (2) reject known bad input, and (3) sanitise input.
DEP-007	Do not store secrets if possible	FlexiGrid shall avoid or at least minimise storing secrets by using hashes wherever appropriate.

DEP-008	Do not store secrets in code	FlexiGrid shall not contain secrets stored in code (hard-coded).
DEP-009	Do not store database connections, passwords, or keys in plaintext	FlexiGrid shall not store sensitive data, such as database connections, passwords, or keys, in plaintext.
DEP-010	Retrieve sensitive data on demand	FlexiGrid shall retrieve sensitive data on-demand only when it is needed.
DEP-011	Do not use application implementation details to the client	FlexiGrid shall not use application implementation details to the client. For example, do not expose stack trace details that include function names and line numbers in deployment builds.
DEP-012	Log detailed error messages	FlexiGrid shall write detailed error messages into error logs while making sure that it does not log passwords or other sensitive data.
DEP-013	Catch and treat all exceptions	FlexiGrid shall catch and treat all exceptions, propagating exceptions internally within the application, while giving special consideration to what occurs at application boundaries.
DEP-014	Audit and log access across application tiers	FlexiGrid shall audit and log access across application tiers for non-repudiation. Use a combination of application-level logging and system-level auditing features where appropriate.
DEP-015	Audit and log all key events	FlexiGrid shall audit and log all key events, such as successful and failed login attempts, data modification and retrieval, network communications, and administrative functions such as the enabling or disabling of logging.
DEP-016	Secure and restrict access to log files	FlexiGrid shall secure and restrict access to the log files. Authorise access only to highly trusted accounts such as system administrators.
DEP-017	Backup and analyse log files regularly	FlexiGrid shall backup and analyse log files regularly.

7 Conclusions and next steps

This deliverable was meant to provide inputs for the other tasks and work packages regarding state of the art for local energy and flexibility markets, plausible future scenarios for local markets, local markets' products design, and their cyber-physical requirements. The report is to provide insights in setting the scope of the research and demonstrations in other tasks and work packages.

In the previous chapters, the following were discussed in detail:

- State of the art for local energy and flexibility markets,
- The already established scenarios for the future of the grid in the partner countries of the project (Sweden, the Netherlands, Bulgaria, and Turkey) within the time-horizon of 2030-2050,
- The plausible future scenarios for local energy and flexibility trade,
- The general overview of the products in the local energy and flexibility markets, and
- The requirements of the smarts energy systems, considered as cyber-physical systems, for FlexiGrid products

The scenarios for the future of the grid can be used in the next steps of the project in defining different tests in the demonstrations. The plausible future scenarios for local trading along with the developed methodology can provide input for work package 9 (which will elaborate on barriers to innovation, exploitation and deployment of FlexiGrid solutions) and task 2.4 (which will elaborate on the policy framework and business models for adoption of local markets). Furthermore, the provided overview for the local market products will be utilised in detailed product design in task 2.3, which is on designing the local flexibility markets. The requirements mentioned in Chapter 6 can also be used as the basis for the working task 4.1 and 4.2.

8 References

[1] J. Villar, R. Bessa, and M. Matos, "Flexibility products and markets: Literature review," *Electr. Power Syst. Res.*, vol. 154, pp. 329–340, Jan. 2018, doi: 10.1016/j.epsr.2017.09.005.

[2] J. Matevosyan *et al.*, *DEMAND-SIDE FLEXIBILITY FOR POWER SECTOR TRANSFORMATION Analytical Brief DEMAND-SIDE FLEXIBILITY FOR POWER SECTOR TRANSFORMATION*. 2019.

[3] X. Jin, Q. Wu, and H. Jia, "Local flexibility markets: Literature review on concepts, models and clearing methods," *Appl. Energy*, vol. 261, p. 114387, Mar. 2020, doi: 10.1016/j.apenergy.2019.114387.

[4] E. Union, "D1 . 3 – Definition of scenarios and products for the demonstration campaigns," 2020.

[5] N. S. Barnes, P. A. Brinster, and P. Fahey, "TSO-DSO report: An Integrated Approach to Active System Management," 2009. doi: 10.4219/gct-2005-161.

[6] N. S. Barnes, P. A. Brinster, and P. Fahey, "An Integrated Approach to Interpretation," *Gift. Child Today*, vol. 28, no. 1, pp. 24–29, 2005, doi: 10.4219/gct-2005-161.

[7] EDSO, "European Distribution System Operators for Smart Grids Flexibility: The role of DSOs in tomorrow's electricity market," 2014. [Online]. Available: http://www.edsoforsmartgrids.eu/wp-content/uploads/public/EDSO-views-on-Flexibility-FINAL-May-5th-2014.pdf.

[8] G. Ringland, *Scenarios in business*. Wiley, 2002.

[9] S. P. Schnaars, "How to develop and use scenarios," *Long Range Plann.*, vol. 20, no. 1, pp. 105–114, Feb. 1987, doi: 10.1016/0024-6301(87)90038-0.

[10] M. Conway, "An introduction to scenario planning," in *Foresight Methodologies Workshop*, 2003, p. 99.

[11] R. Bradfield, G. Wright, G. Burt, G. Cairns, and K. Van Der Heijden, "The origins and evolution of scenario techniques in long range business planning," *Futures*, vol. 37, no. 8, pp. 795–812, Oct. 2005, doi: 10.1016/j.futures.2005.01.003.

[12] M. Amer, T. U. Daim, and A. Jetter, "A review of scenario planning," *Futures*, vol. 46, pp. 23–40, Feb. 2013, doi: 10.1016/j.futures.2012.10.003.

[13] P. Schwartz, *The Art of the Long View: Paths to Strategic Insight for Yourself and Your Company*. Crown Business, 1991.

[14] W. R. Huss and E. J. Honton, "Scenario planning-What style should you use?," *Long Range Plann.*, vol. 20, no. 4, pp. 21–29, Aug. 1987, doi: 10.1016/0024-6301(87)90152-X.

[15] J. Ogilvy, T. Mandel, and O. Yu, *How to construct and use scenarios*. Menlo Park, California: SRI International, 1986.

[16] S. Kuiper, "The future of the DSO Enexis : a research on the strategic position of the DSO in 2030 using scenario and trend analysis," 2015.

[17] U. Pillkahn, *Using Trends and Scenarios as Tools for Strategy Development. Shaping the Future of Your Enterprise*. John Wiley & Sons, 2008.

[18] S. A. van ’t Klooster and M. B. A. van Asselt, “Practising the scenario-axes technique,” *Futures*, vol. 38, no. 1, pp. 15–30, Feb. 2006, doi: 10.1016/j.futures.2005.04.019.

[19] E. Mengelkamp, J. Diesing, and C. Weinhardt, “Tracing local energy markets: A literature review,” *IT - Inf. Technol.*, 2019, doi: 10.1515/itit-2019-0016.

[20] V. Ivanova, “The policy and regulatory context for new Local Energy Markets ERIS Elective Vilislava Ivanova, Arianna Griffa, Susanna Elks Markets, Policy and Regulation team The policy and regulatory context for new Local Energy Markets,” 2019.

[21] G. Mendes, S. Honkapuro, J. Nylund, O. Kilkki, S. Annala, and J. Segerstam, “Local Energy Markets: Opportunities, Benefits, and Barriers,” *CIRED Work.*, no. 0272, p. 5, 2018.

[22] F. Lezama, J. Soares, P. Hernandez-Leal, M. Kaisers, T. Pinto, and Z. Vale, “Local Energy Markets: Paving the Path Toward Fully Transactive Energy Systems,” *IEEE Trans. Power Syst.*, vol. 34, no. 5, pp. 4081–4088, 2019, doi: 10.1109/TPWRS.2018.2833959.

[23] E. Mengelkamp, B. Notheisen, C. Beer, D. Dauer, and C. Weinhardt, “A blockchain-based smart grid: towards sustainable local energy markets,” in *Computer Science - Research and Development*, Feb. 2018, vol. 33, no. 1–2, pp. 207–214, doi: 10.1007/s00450-017-0360-9.

[24] F. Teotia and R. Bhakar, “Local energy markets: Concept, design and operation,” *2016 Natl. Power Syst. Conf. NPSC 2016*, 2017, doi: 10.1109/NPSC.2016.7858975.

[25] R. Bray, B. Woodman, and P. Connor, “Policy and Regulatory Barriers to Local Energy Markets in Great Britain,” 2018. doi: 10.13140/RG.2.2.17562.08647.

[26] P. Siano, G. De Marco, A. Rolan, and V. Loia, “A Survey and Evaluation of the Potentials of Distributed Ledger Technology for Peer-to-Peer Transactive Energy Exchanges in Local Energy Markets,” *IEEE Syst. J.*, vol. 13, no. 3, pp. 3454–3466, 2019, doi: 10.1109/JSYST.2019.2903172.

[27] L. Ableitner, A. Meeuw, S. Schopfer, V. Tiefenbeck, F. Wortmann, and A. Wörner, “Quartierstrom -- Implementation of a real world prosumer centric local energy market in Walenstadt, Switzerland,” 2019. [Online]. Available: http://arxiv.org/abs/1905.07242.

[28] S. Wilkinson, K. Hojckova, C. Eon, G. M. Morrison, and B. Sandén, “Is peer-to-peer electricity trading empowering users? Evidence on motivations and roles in a prosumer business model trial in Australia,” *Energy Res. Soc. Sci.*, vol. 66, p. 101500, Aug. 2020, doi: 10.1016/j.erss.2020.101500.

[29] E. Judson *et al.*, “The centre cannot (always) hold: Examining pathways towards energy system de-centralisation,” *Renew. Sustain. Energy Rev.*, vol. 118, p. 109499, Feb. 2020, doi: 10.1016/j.rser.2019.109499.

[30] Centrica, “Cornwall Local Energy Market | Centrica plc,” 2017. https://www.centrica.com/innovation/cornwall-local-energy-market (accessed Dec. 09, 2018).

[31] “Synergy - Peer-to-peer Electricity Trading.” https://www.synergy.net.au/Our-energy/For-Tomorrow/RENeW-Nexus-Trial (accessed Jun. 18, 2020).

[32] FED Project, “Fossil-free Energy Districts.” https://www.uiainitiative.eu/en/uia-cities/gothenburg (accessed May 10, 2020).

[33] Quartier-strom, “Der erste lokale Strommarkt der Schweiz,” 2019. https://quartier-

strom.ch/index.php/en/homepage/ (accessed Jun. 18, 2020).

[34] "First US marketplace for locally produced clean energy launched by LO3 Energy and Green Mountain Power - LO3 Energy." ttps://lo3energy.com/first-us-marketplace-for-locally-produced-clean-energy-launched-by-lo3-energy-and-green-mountain-power/ (accessed Jun. 18, 2020).

[35] "ESO participates in Cornish Energy Market in world first project | National Grid ESO." https://www.nationalgrideso.com/news/eso-participates-cornish-energy-market-world-first-project (accessed Jul. 27, 2020).

[36] S. Minniti, N. Haque, P. Nguyen, and G. Pemen, "Local markets for flexibility trading: Key stages and enablers," *Energies*, vol. 11, no. 11, p. 3074, Nov. 2018, doi: 10.3390/en11113074.

[37] H. Sommer, "Local flexibility markets : beyond the status quo A truly European Power Exchange," no. April, 2020.

[38] Fingrid, "Local Flexibility Projects in the Nordics," 2020. https://www.fingrid.fi/en/pages/news/news/2020/local-flexibility-projects-in-the-nordics/.

[39] "Home | INTERRFACE." http://www.interrface.eu/ (accessed Jun. 19, 2020).

[40] M. Al-Saadi *et al.*, "Survey analysis on existing tools and services for grid and market stakeholders and requirements to improve TSO/DSO coordination," in *ISSE 2019 - 5th IEEE International Symposium on Systems Engineering, Proceedings*, Oct. 2019, doi: 10.1109/ISSE46696.2019.8984489.

[41] "The project – Empower," 2017. http://empowerh2020.eu/the-project/.

[42] "EMPOWER final project report (D1.5)," 2018. [Online]. Available: http://empowerh2020.eu/tag/deliverables/.

[43] United-Grid Project, "Solutions for intelligent distribution grids - UNITED-GRID." https://united-grid.eu/ (accessed Jun. 30, 2020).

[44] V. Diebels, "enera project: EWE and EPEX SPOT to create local market platform to relieve grid congestions | EWE AG," 2019. https://www.ewe.com/en/media/press-releases/2018/02/enera-project-ewe-and-epex-spot-to-create-local-market-platform-to-relieve-grid-congestions-ewe-ag.

[45] "Parity H2020 – Parity H2020," 2020. https://parity-h2020.eu/.

[46] "The CoordiNet Project." https://coordinet-project.eu/ (accessed Jun. 18, 2020).

[47] dominoes, "Smart Distribution Grid: a Market Driven Approach for the Next Generation of Advanced Operation Models and Services," 2020. http://dominoesproject.eu/.

[48] "DOMINOES-DELIVERABLE D1.1 Local market reference architecture and business requirements." [Online]. Available: http://dominoesproject.eu/wp-content/uploads/2020/01/D1.1_DOMINOES_LocalMarketReferenceArchitecture_v1.3_final.pdf.

[49] "NORFLEX | Enova." https://www.enova.no/om-enova/om-organisasjonen/teknologiportefoljen/norflex/.

[50] N. Damsgaard, K. Yuen, J. Helbrink, M. Andersson, P. Grahn, and J. Munkhammar, "Framtida krav på elnäten Framtida krav på elnäten," 2014.

[51] Power Circle, “Elbilsläget 2018,” 2018. https://infogram.com/elbilslaget-2018-1h1749rjvkrq4zj?live (accessed Jun. 12, 2020).

[52] M. Larson, F. Mohseni, H. Gåverud, and P. Hillbom, “Omvärldsanalys och bedömning av den svenska vägfordonsflottans utveckling,” 2017.

[53] Svenska kraftnät, “Långsiktig marknadsanalys 2018 - Långsiktsscenarier för elsystemets utveckling fram till år 2040,” 2019, Accessed: Jun. 12, 2020. [Online]. Available: https://www.svk.se/siteassets/om-oss/rapporter/2019/langsiktig-marknadsanalys-2018_sammanfattning.pdf?_t_id=1B2M2Y8AsgTpgAmY7PhCfg==&_t_q=energilagring&_t_tags=language:sv,siteid:40c776fe-7e5c-4838-841c-63d91e5a03c9&_t_ip=192.121.1.150&_t_hit.id=SVK_WebUI.

[54] C. Sandels and J. Widén, “End-user scenarios and their impact on distribution system operators. Report 2018:508,” 2018. [Online]. Available: https://energiforskmedia.blob.core.windows.net/media/24750/end-user-scenarios-and-their-impact-on-distribution-system-operators-energiforskrapport-2018-508.pdf.

[55] NEPP, “NEPP - North European Energy Perspectives Project.” http://www.nepp.se/index.htm (accessed Jun. 12, 2020).

[56] SCB, “Vehicle statistics,” *Transport Analysis*, 2017. https://www.trafa.se/en/road-traffic/vehicle-statistics/ (accessed Jun. 12, 2020).

[57] Gasunie and TenneT, “Infrastructure Outlook 2050,” 2019. Accessed: Jun. 12, 2020. [Online]. Available: https://www.tennet.eu/fileadmin/user_upload/Company/News/Dutch/2019/Infrastructure_Outlook_2050_appendices_190214.pdf.

[58] Ministry of Energy of the Republic of Bulgaria and Ministry of Environment and Water of the Republic of Bulgaria, “Integrated plan in the ares of energy and climate of the Republic of Bulgaria 2021-2030,” 2020. [Online]. Available: https://ec.europa.eu/info/energy-climate-change-environment/overall-targets/national-energy-and-climate-plans-necps_en.

[59] L. Szabo *et al.*, “South East Europe Electricity Roadmap (SEERMAP),” *International Conference on the European Energy Market, EEM*, 2018. https://rekk.org/analysis-details/238/south-east-europe-electricity-roadmap-seermap (accessed Jun. 17, 2020).

[60] ENTSO-E, “Installed Capacity per Production Type,” *ENTSO-E Transparency Platform*, 2020. https://transparency.entsoe.eu/generation/r2/installedGenerationCapacityAggregation/show (accessed Jun. 12, 2020).

[61] Osmangazi Elektrik Dağıtım AŞ, “Ana Sayfa | Osmangazi Elektrik Dağıtım AŞ.” http://www.osmangaziedas.com.tr/ (accessed Jun. 30, 2020).

[62] Voltalis, “Voltalis, first operator of Internet of Energy,” *Voltalis*. http://www.voltalis.com/individual (accessed Jun. 08, 2020).

[63] H. Hansen *et al.*, “Coordination of system needs and provision of services,” in *IET Conference Publications*, 2013, vol. 2013, no. 615 CP, pp. 0261–0261, doi: 10.1049/cp.2013.0640.

[64] UnitedGrid, “D4.4 A report on a design of a market framework for congestion management by the DSO,” 2021.

[65] RTE, *French Capacity Market: Report accompanying the draft rules*. Document released in April, 2014.

[66] ENTSO-E, “Electricity Balancing in Europe - An Overview of the European Balancing Market and Electricity Balancing Guideline,” 2018. Accessed: Jun. 19, 2020. [Online]. Available: https://docstore.entsoe.eu/Documents/Network codes documents/NC EB/entso-e_balancing_in_europe_report_Nov2018_web.pdf.

[67] E. A. Martínez Ceseña, N. Good, and P. Mancarella, “Electrical network capacity support from demand side response: Techno-economic assessment of potential business cases for small commercial and residential end-users,” *Energy Policy*, vol. 82, no. 1, pp. 222–232, Jul. 2015, doi: 10.1016/j.enpol.2015.03.012.

[68] A. Esmat, J. Usaola, and M. Á. Moreno, “Distribution-level flexibility market for congestion management,” *Energies*, vol. 11, no. 5, p. 1056, May 2018, doi: 10.3390/en11051056.

[69] E. Georges, B. Cornélusse, D. Ernst, V. Lemort, and S. Mathieu, “Residential heat pump as flexible load for direct control service with parametrized duration and rebound effect,” *Appl. Energy*, vol. 187, pp. 140–153, Feb. 2017, doi: 10.1016/j.apenergy.2016.11.012.

[70] The European Commission, “Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing,” *Off. J. Eur. Union*, vol. 2017, no. November, pp. 312/6-312/53, 2017, [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2017.312.01.0006.01.ENG&toc=OJ:L:2017:312:TOC#d1e2376-6-1.

[71] ENTSO-E, “Explanatory Document to All TSOs’ proposal for the implementation framework for a European platform for the imbalance netting process in accordance with Article 22 of Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on ele,” 2018. [Online]. Available: https://docstore.entsoe.eu/Documents/Network codes documents/NC EB/180618_ALL TSOs_INIF_explanatory_doc_final.pdf.

[72] ENTSO-E WGAS, “Survey on Ancillary services procurement, Balancing market design 2014,” 2015. [Online]. Available: https://www.entsoe.eu/Documents/Publications/Market Committee publications/150127_WGAS_Survey_2014.pdf.

[73] M. Brolin and H. Pihl, “Design of a local energy market with multiple energy carriers,” *Int. J. Electr. Power Energy Syst.*, vol. 118, p. 105739, Jun. 2020, doi: 10.1016/j.ijepes.2019.105739.

[74] M. Brolin and M. Thomten, “Deliverable D5.1.5 of Fossil Free Energy District project September 4, 2017.”

[75] Nordic Council of Ministers, “Demand side flexibility in the Nordic electricity market,” 2017, doi: 10.6027/TN2017-564.

[76] C.-C. Sun, C.-C. Liu, and J. Xie, “Cyber-Physical System Security of a Power Grid: State-of-the-Art,” *Electronics*, vol. 5, no. 4, p. 40, Jul. 2016, doi: 10.3390/electronics5030040.

Appendix 1

In this appendix the survey and the cross-impact matrix that were used in developing plausible scenarios for future of local energy and flexibility markets are provided.

Uncertainty-impact survey

The following factors and trends in this survey are extracted from various sources while searching for key drivers that can possibly form the future of local energy and flexibility trading. Among others, these trends and factors are extracted from literature review and resources and discussions from the FlexiGrid project.

To build the plausible future scenarios for future of local energy and flexibility trading, the uncertainty and impact of these trends need to be ranked.

With having your country in mind,

- **What level of uncertainty do you foresee regarding each of the following factors and trends? (consider the horizon up to year 2035)**
- **How impactful are the following factors and trends in your country on the future of local energy/ flexibility trading?**

The participants were asked to answer the above-mentioned questions for the list of factors and trends based on a Likert scale (from zero to five). Zero represents low uncertainty/impact and five represents high uncertainty/impact. The list of factors and trends are presented below:

1- Availability of distributed generation (technical)

Enough penetration level of distributed generation for participation in local energy/flex markets

2- Availability of distributed energy storage (technical)

Enough penetration level of distributed generation for participation in local energy/flex markets

3- Availability of electrified transportation (technical)

Enough level of electrification in transport sector that can affect V2G capabilities or cause new peaks, congestions, etc in the grid

4- Availability of electrified heating and cooling (technical)

Enough level of electrification in heating and cooling sectors that can affect the available flexible units in the system or cause new peaks, congestions, etc in the grid

5- Availability of electrified industries (technical)

Enough level of electrification in the industries that can affect the available flexible units or cause new peaks, congestions, etc in the grid

6- Availability of high-resolution data from smart meters (technical)

Availability of enough high-resolution data from smart meters which includes the accessibility of the data and enough deployment of smart grids

7- Availability of smart and digital grid monitoring and control (technical)

Enough level of smart and digital grid monitoring and control for faster and more precise identification of the grid's status

8- Availability of smart and digital end-users (technical)

Enough level of smart and digital end-users with automated, fast and precise control of load and distributed technologies like generation or storage units

9- Availability of relevant new competences in the energy industry (technical/social)

Enough level of new competences (e.g. data, IoT, and statistics) in the energy industry can affect the implementation of local energy and flexibility trading solutions

10- Tendency of end-users for self-consumption (Social)

Tendency of end-users to become less dependent on the grid due to financial or life-style related reasons

11- Tendency of end-user's active participation (Social)

Active participation of end-users in the local energy/ flexibility trade

12- Number of end-users (Social)

Increase in the number of end-users dues to general population growth or immigration to the cities can reach a level that might cause congestions and challenges in the distribution grid

13- Resistance from conservative culture of the energy industry (Social)

The conservative and risk conscious culture of the energy industry might cause resistances towards adoption of innovative solutions like local energy and flexibility trading instead of conventional solutions like grid reinforcements based on reasons such as safety and stability.

14- Positive changes in DSOs unbundling regulations (political)

Current unbundling regulations in some countries prevent DSOs' ability to trade energy or own distributed energy technologies

15- Positive changes in regulatory incentives for DSOs (political)

Currently, DSOs and TSOs are highly regulated in many countries. Depending on how these regulations are formulated, DSOs might or might not have the incentives to participate in local energy and flexibility trade

16- Increase of carbon taxes (prices) on local fossil-based generation (political)

This increase can be a driver for promotion of local, clean distributed generation and storage

17- Increase of restrictions on end-user privacy (political/social)

More restrictions on the end-user's privacy might affect the participants of local energy and flexibility trading regarding the data handling

18- Increase of investments in grid reinforcements (Economical)

The need for these investments can be a driver while being a competitor for the local energy and flexibility trade

19- Increase of wholesale electricity prices (Economical)

Increase of wholesale electricity prices might be driver for a higher local clean distributed generation and storage

20- Increase of grid tariffs (Economical)

This increase might affect the end-users or energy producers' behaviour and their willingness to participate in local energy or flexibility trading

Cross-impact matrix

The outline of the cross-impact matrix is presented in Figure 15 and the details of the scores for the cross-impact analysis are presented in Figure 16

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20	Sum
F1																					
F2																					
F3								*													
F4																					
F5																					
F6																					
F7																					
F8																					
F9																					
F10																					
F11																					
F12																					
F13																					
F14																					
F15																					
F16																					
F17																					
F18																					
F19																					
F20																					

Score the impact of each factor/trend on other factors/trends:	
0 Indipendent	1 Slight impact
2 Dependent	3 Strong driver

* The impact of F3 on F8

Figure 15 Cross-impact matrix. Each cell represents the level of impact of the row on the column. F1-20 are the factors/trends that were used in the survey.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20	Active Score	Normalized score
F1		2,67	1	1,67	1,67	1,33	1,67	2,33	1,67	3	2,33	0	1	1,33	1,67	2,33	1	2,67	2	2,33	33,7	1,00
F2	3		1,33	1	1,33	1,33	1,67	2,33	1,33	3	2,67	0	1	1,33	1,67	1,33	0,33	2,67	1,33	2	30,7	0,85
F3	1,67	1,33		0,33	0,33	0,67	1,33	1	1	0,67	1	0	1,33	1	1,67	1	0,33	2,67	1,33	2,67	21,3	0,37
F4	1,67	1,33	0,67		0,67	0,33	1,33	1	1	1,67	1,33	0	1	1	1,67	1	0,33	3	1,33	3	23,3	0,47
F5	2	1,67	0,33	1		1,33	1,67	1,67	1,67	2	1,33	0,33	1,33	1,67	1,67	1,67	1	2,67	1,67	2,67	29,3	0,78
F6	1,67	1,67	1,67	2	1,33		3	3	2,67	1	2	0	1,33	1,33	1	1	2	1	0,67	0,67	29,0	0,76
F7	2,67	2	2,33	2	2	2,33		2,33	2,33	1	2	0	2	1,33	1,33	0,67	1,33	1,67	1	2	32,3	0,93
F8	1,67	1,67	1,33	2,33	1,33	2,67	2,67		2	2,67	2,33	0	1,33	1	1	0,33	2,67	1	1	1	30,0	0,81
F9	1	1,33	1,33	1,33	1,33	1,67	2,67	2,67		1,33	1,67	0,67	1,67	1,67	1,67	0,33	0,67	1,33	0,67	1	26,0	0,61
F10	3	3	1	2,33	0,33	2,67	0,67	3	1		3	1,33	0,33	1,33	1	0,67	2,33	1	1	1,67	30,7	0,85
F11	2,67	2,67	1	2,33	1	2,33	1,33	3	1	3		1	0,67	1,33	2	1	2,67	1,33	0,67	1,67	32,7	0,95
F12	1	1	1,67	1,33	1	1	1,33	2	0,33	1	0,67		0,33	1,33	1	0,67	1	2	1,67	1	21,3	0,37
F13	1,33	0,67	0,67	1	1	1,33	1	0,67	1,33	0,33	0,67	0		1	1,67	0,33	2	1,33	0,33	1	17,7	0,19
F14	2	2	1	1,33	1,33	1	2	1,67	1,67	1	1,33	0,33	2		2,33	0,33	1	1,67	0,67	1,33	26,0	0,61
F15	1,67	1,67	1,33	1,33	1,67	1,67	2	1,67	2,33	1,33	2	0,33	2	2		0,67	1,33	2,33	1	1,33	29,7	0,80
F16	3	2,67	2	2,33	2,67	0,67	0,67	0,67	1	2	2	0,67	1	1	1		0,33	1	2	1,33	28,0	0,71
F17	0,33	0,33	0	0,33	0	2	2	1,33	0,67	0,67	2,33	0,33	1,33	0,33	1	0		0,33	0	0,67	14,0	0,00
F18	2,33	2	2	2	1,67	0	0,67	0,33	0,33	1,33	0,33	0,33	0,67	0,67	1,33	0,33	0,33		1,67	2	20,3	0,32
F19	3	2,33	2,33	2	2,33	0	0	1,33	0,67	2,33	2	0,33	0,33	0,33	1	0,67	0	1,67		1,67	24,3	0,53
F20	3	3	1,33	2	2	0,33	0,67	2	1,67	3	3	0,67	0,33	0,33	1	0,33	0,67	2	1		28,3	0,73

Figure 16 Details of the scores in the cross-impact analysis