edgeFLEX

D6.2

Comparative analysis of potential business impact

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Abstract
The goal of the edgeFLEX project is to advance the role of the VPP with the use of advanced grid management techniques, effective optimisation, flexibility provision and trading combined with enabling solutions such as Service Level Agreement Monitoring tools, edgePMU devices and 5G capabilities. Core to the advancement of this role is the development of business models and a method to assess them. This report presents two business scenarios that are based on two evolutions of the VPP, VPP1.1 and enhancement on the current implementation of the VPP and VPP2.0 a DSO centric VPP that engages community assets and details a process to assess them. This process involves actor targeted assessments that might be required to enable a widespread adoption of the VPP evolutions throughout industry. Both business scenarios are assessed and compared using the process. Finally, the report details the ongoing adoption of VPP2.0 within a real DSO and examines the barriers to adoption and the changes needed with in the DSO.

Keyword list
Aggregator business models, RES, energy storage, business impact, VPP, DSO, Multi Actor Assessment, Adoption

Disclaimer
All information provided reflects the status of the edgeFLEX project at the time of writing and may be subject to change.

Executive Summary

From the outset, the edgeFLEX project had the goal of evolving the role of the VPP beyond the traditional model, which was based on large assets, towards one that would involve energy communities and provide flexibility services for the System Operators so that they can maintain a stable grid. The work in this deliverable presents two evolutions, VPP1.1, a machine learning enhanced optimisation, and VPP2.0, which engages the assets owned with the energy communities in a way that they can solve local voltage problems for the DSO. While these two evolutions do not encompass the potential of the evolution from a technical perspective, they do provide a means to both assess forensically and take a comparative view of each.

This deliverable initially frames the evolution around two business scenarios, DSO centred (VPP2.0) and the aggregator centred (VPP1.1) and goes on to detail what changes to the sector are driving the evolution and how the solutions developed in edgeFLEX are facilitating it. It outlines the advancements of the energy sector, the technological solutions and how mobile communications and advancements in features offered by 5G underpin the evolution to the VPP and the smart grid in general.

The assessment of the business scenarios outlined in the deliverable are approached from the perspective of the organisation that would adopt them into their business. This assessment is not purely business focused as it also considers those with roles working in the energy sector who would typically manage, monitor, validate, install, assess, and financially benefit from the project. Therefore, the assessment involved engaging persons in the energy sector, from the CEO of a DSO to the Technical Operative that manages the physical assets in the field, to get a panoramic impression of the components and business scenarios. Given that the actors were of a multidisciplinary nature, the assessment covered not only the technicalities but also the market and regulatory elements of the business scenarios. This assessment led to technical improvements and enabled the discovery of the next steps for the solutions while getting a sense of the need for the components in industry.

The comparative analysis within the deliverable between these business scenarios was relatively small as it was identified through the assessments that they cannot be compared directly. However, they can be compared in terms of their relative ease adoption into industry, the barriers to adoption, technically, regulatory, socially and market.

To support the analysis and to place the DSO centred VPP2.0 business scenario in a real-world context, SWW developed a case study that aligns the VPP2.0 concept with their current situation as a DSO, their organisation specific implementation of the concept and the limitations and barriers that exist that may be overcome for them to fully implement and scale the concept.

This assessment is not exhaustive or comprehensive enough to categorically state that both business scenarios are fully fledged solutions for engaging flexibility at all levels of the sector, as each DSO, VPP Operator, Energy Community might have a different adoption timeline, whether through regional factors, company size, level of digitalisation or assessment process. However, the assessment process and its results could be a starting point for grid actors to base a complete assessment of new digital solutions or business scenarios, and the case study for a real-world implementation of VPP2.0 could serve as a blueprint for a grid actor that is looking to incrementally evolve towards utilising flexibility systematically.

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1 Introduction

From the outset, the edgeFLEX project had a vision of advancing the Virtual Power Plant (VPP) to manage a wider range of storage and generation assets, including energy communities. This vision places a systemic view of flexibility and edge-ready solutions that directly influence the local grid at its core. This system view of flexibility and the edge-ready solutions are geared towards offering the possibility of an incremental evolution towards a stable grid that is ICT rich for energy communities, System Operators and VPP Operators alike.

In the edgeFLEX project we framed this vision as a proposed VPP evolution from the traditional VPP 1.0 that uses large assets that are spread geographically which are grouped for management and trading purposes, to an enhancement of that concept with machine learning-based weather forecasting, market modelling and optimisation techniques in VPP1.1, to a VPP that comprises of small scale assets that are prosumer owned and those that can solve local problems for the grid operators in VPP2.0.

This deliverable describes both VPP evolutions by detailing the changing energy sector, the fundamental research, the solutions developed in edgeFLEX, the advancements in mobile communications and how they align and enable this incremental evolution. This deliverable looks at the two example business scenarios that represent a collection of the edgeFLEX components and align them to their application from a business context. Aside from placing the edgeFLEX tools and services in the business context, the business scenarios serve the purpose of developing, assessing, and comparing exploitation pathways for the edgeFLEX outputs.

In the first year of the edgeFLEX project, a broad view was taken of the edgeFLEX outputs, their business impact, and their relation to the energy sector, and the first version of this deliverable (D6.1) was centred on this broad view. Since then, as the edgeFLEX services, platform and the trials matured, focus has shifted towards a targeted comparison of two specific business cases that represent the **System Operator as the Aggregator (VPP2.0)** and the **VPP operator as the aggregator (VPP1.1)**. While the comparative analysis between these detailed in this document was eventually carried out, it was first necessary to develop a process under which they can assessed. This process is developed in a way that leads to transferability to other business models and scenarios and relies on asking targeted questions to the different levels of the business, from the field technician in the case of the DSO, to the CEO, and all levels in between.

The incremental evolution has begun in SWW, a small-scale DSO in Germany, and they have implemented VPP 2.0 in their trials and have also made the decision to proceed with the evolution in their business. They detail the reason why they are evolving and the edgeFLEX solutions that underpin the evolution, and highlight the benefits to their company, the grid, their customers, and society in general. This implementation and how SWW are evolving can serve as blueprint for other, similar grid operators to evolve.

This report details the changes in the energy sector that drive the need for the evolution of the VPP, provides an overview of the technical solutions and changes in the mobile communications sector that facilitate the evolution, the business models that foster adoption, the assessments that validate the solutions from an industry perspective and presents a real-world implementation in the operations of a DSO. Figure 1-1 illustrates the path of the edgeFLEX work from identifying the need to future adoption. The incremental evolution of the VPP can offer a systemic view of flexibility by offering new business opportunities to Energy Communities and providing an edge-ready solution that can help reduce the need for grid infrastructure investment for System Operators who aim to meet the challenges raised by RES deployment at a large scale and the electrification of heat and transport.

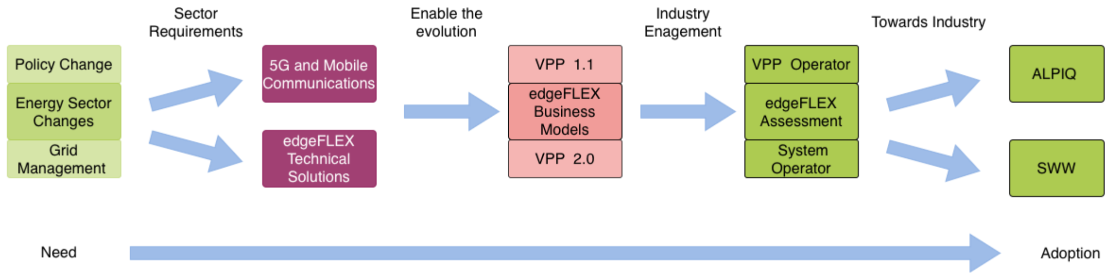

Figure 1-1: Path from Need to Adoption

1.1 Related Work

The precursor to this deliverable, **D6.1 Comparative Analysis of Potential Business Impact,** introduces the edgeFLEX approach to combine technological approaches with organisational structures to provide more flexibility in the European electrical network under the pressing need to mitigate fluctuation in power generation due to the increasing share of intermittent energies in the electrical mix in Europe. From a technological perspective the grid, VPP services, including the project work on 5G, are described in the WP1, WP2 and WP3 deliverables, and in the WP4 deliverables that describe the platform and the trial assessments, which are described in the WP5 deliverables. Figure 1-2 illustrates the linkage between the edgeFLEX tasks and the exploitation assessment and comparative analysis of the business impact of edgeFLEX. This deliverable to encompass the edgeFLEX project and link the technical assessments carried out in **D4.4 - Description of assessment of platform control service performance** with the business, regulatory and exploitation activities that have been ongoing throughout the project.

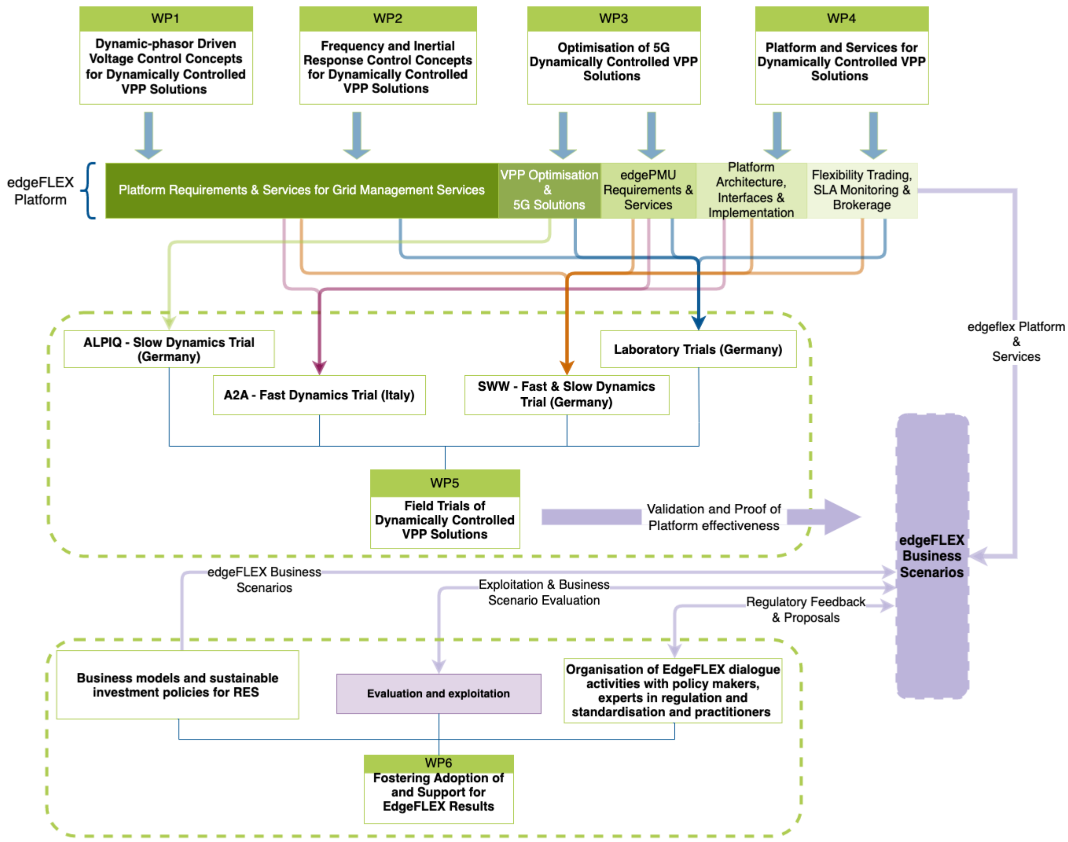

Figure 1-2: edgeFLEX Tasks and their business impact

1.2 Objectives of this Report

The main objective of this report is present how we analyse the edgeFLEX business impact and comparatively analyse two example business scenarios that frame the VPP evolution. Also, the objective is to provide the reader with an overview of the output of the edgeFLEX project and how it supports the VPP evolution.

1.3 Outline of this Report

This report provides an overview of the changes occurring within the energy sector and the technological advancements underpinning the edgeFLEX business scenarios. It will then describe two business scenarios that will involve the deployment of the edgeFLEX components in a DSO and an aggregator to facilitate the aggregation for power. These business models will be assessed at multiple levels of the business, from the CEO to the field technicians, the assessment process is described, and the results are presented. Lastly, the results of the two business scenarios are compared, and the conclusion will present the identified barriers to full adoption and the next steps towards exploiting the edgeFLEX solutions.

1.4 How to read this Document

This deliverable encapsulates a large portion of the work within edgeFLEX, as shown in Figure 1-1-1, and therefore to get a deeper understanding of the technical topics discussed, reading the deliverables in WP1 (Voltage Control), WP2 (Frequency Control and Inertia Estimation) , WP3 (VPP Optimisation and 5G) and WP4 (The edgeFLEX Architecture, Platform and Assessments) would be advisable.

2 edgeFLEX Solutions for the VPP evolution

From the beginning of edgeFLEX, the project envisioned the evolution of VPPs to play a larger role in grid control and to optimise it at a neighbourhood, regional and national level. To facilitate this, edgeFLEX developed a set of solutions underpinned by 5G that are supported by evolved regulations and that enable emerging Energy Communities and established energy System Operators to work together in a new market to meet the evolving expectations of society. As illustrated in Figure 2-1, we have developed the technical solutions and framed them under two evolutions of the current VPP1.0; VPP1.1 which centres on enhancing traditional portfolio management with AI-based optimisation techniques and VPP2.0 which centres on a new method of engagement between the Energy Community and the System Operator. The technical solutions developed in edgeFLEX are in line with the evolving need for grid actors to adapt to the ever-changing challenges posed by the higher penetration of RES, the electrification of heat and transport and the directives being put in place at a national and EU level.

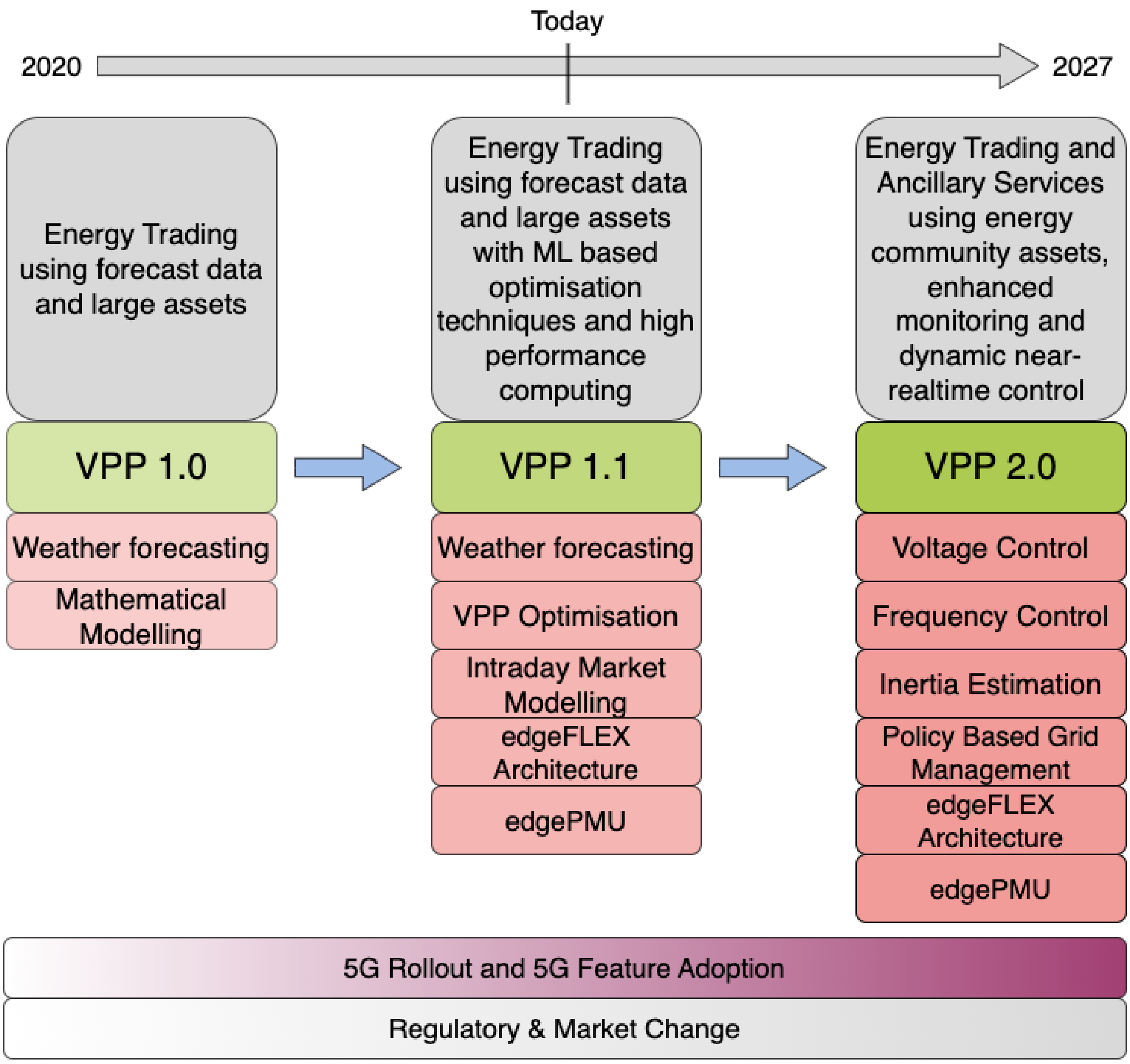

Figure 2-1: Evolution of the VPP

The concept of the VPP has gone through many evolutions since its inception in 1997 which are detailed in a paper by (Sarmiento-Vintimilla, Torres, Larruskain, & Pérez-Molina) from the VPPs role in Ancillary Services, into the research of the role EVs must play in the VPPs and to the newly researched Dynamic Virtual Power Plant (POSYTYF). As a result, the VPP has evolved from purely a market tool used to aggregate power that wasn't geographically collocated to one that involves advanced machine learning based tools and power management techniques that are driving this evolution. VPP 1.0 is the point of origin for the evolution edgeFLEX is proposing, and it can be described as a collection of Distributed Renewable Energy Sources (DRES) that are managed centrally and aggregated in a portfolio that aims to optimise them for trading on the day-ahead and intraday markets at a regional and national level. This portfolio traditionally consisted of large wind and solar assets and the optimisation would be typically based on mathematical modelling and weather forecasting techniques. Furthermore, very slow dynamics measurements are being carried out, meaning it participates in the secondary frequency reserve in the 15min+ range. The growing emergence of VPPs as drivers of the penetration of largescale variable RES in the energy system results in new solutions being developed to balance the volatile power generation of dispatchable RES in the slow dynamics timeframe. This saw the introduction of the intraday market to harness the flexibility available to mitigate the unpredictability of supply.

Although improvements have been made in recent years in forecasting and optimisation, there is still room for improvement. This improvement is coming in the wider range of VPP assets available, with dispatchable RES like biogas and battery storage beginning to play a larger role in providing a level of predictability, resulting in a need to factor storage into the modelling of assets. These improvements drive the evolution from VPP1.0 to VPP1.1 where more advanced mathematical modelling such as VPP Optimisation which incorporates dispatchable RES, models of the intraday market models and spatiotemporal wind forecasting, which uses a mix of weather forecasting and weather station data over large geographical areas, with the objective of minimising the costs of rebalancing the assets on the intraday markets. Therefore, the VPP Optimisation and the results reached are different from existing portfolio management in their method and scale. The number of power plants under management that can be optimised is around 200; this high figure can be reached mainly due to the battery setup. In addition, the optimisation is focused on high-speed computing, which is the key element leading to increased profits.

VPP2.0 takes a leap forward in terms of the role of the VPP; like the traditional VPP, VPP2.0 is a grouping of assets that are distributed, though these assets may not be typically large and may be prosumer owned. In this evolution, the VPP exists at a local level with a presence that typically connects to and impacts upon the DSO grid. The VPP2.0 assets would typically contain a mixture of microgeneration assets, such as solar PV, storage, and controllable load, such as electric heat pumps and electrical vehicle charging. Due to its variability, this mixture of assets would cause balancing and congestion issues for the DSO, where over- and under-voltage events would occur and poses a greater risk for system security due to its effects on the frequency variations.

edgeFLEX takes the VPP to a local level, involving the citizen by enabling them to directly interact with the DSO in a way that can help the DSO to solve problems on the grid autonomously. edgeFLEX seeks to make the locally based VPP a viable entity that can help solve the issues it creates for the DSO by providing it and the DSO with the tools and techniques to manage this imbalance by availing of the flexibilities available within the local VPP. This engagement is outside the curtailment model that can be enforced in areas of high-RES penetration and relies on using the surplus energy rather than curtailing the asset, or utilising the energy stored within the local VPP in the case of an energy deficient system at times of increased load.

VPP2.0 provides flexibility to the System Operators for the allocation of inertia and damping, with the objective of improving the dynamic performance of the system and ensuring its security. This allows VPPs to respond to fast frequency variations, i.e., system frequency variations in the first few seconds of any disturbance because of generation/load power variations or an event such as a short circuit or opening of a line. VPPs will respond to frequency variations by modifying their power output and provide fast (primary) frequency regulation towards the stability of the power system. This helps minimize the cost of frequency response provision for the VPP, ensures an optimized post-fault frequency dynamic response and allows for the charging of electric vehicles in large numbers without affecting the system stability by dynamically allocating the available power in an optimized way.

In edgeFLEX, we have developed tools and techniques to manage this locally such as Voltage Control, Frequency Control and Inertia Estimation that can measure the extent of the imbalances, provide fast resolution of them, predict the voltage system that the grid might need locally using model predictive control and use this as part of an engagement with the flexibility management systems in place with in the local VPP. This engagement is facilitated by using Policy Based Grid Management to monitor and validate the requests to the flexibility service, which is an implementation of the FlexOffer agent from the GOFLEX system. To facilitate this and to ensure that there is enough high-resolution data, the edgeFLEX project developed and deployed low cost edgePMUs that are edge computing compatible and that provide phasor measurements that feed accurate and high-resolution measurements to the grid management tools and services. Through this research, development, and innovation we have been able to trial our tools and techniques in both laboratory and field where we model the new VPP evolutions in certain scenarios. Engaging the energy community to solve a voltage issue for the DSO is one case where they alter their business to accommodate such interactions.

Alongside the tools and techniques, the VPP evolution is further advanced by mobile technologies like 4G, 5G and with research into 6G gathering momentum there is huge potential for it to play a role in further evolutions. As DER are becoming more commonplace, utilisation of the edge in new architectures being developed in the grid is becoming more commonplace also. As a result, there is a greater need for secure networks, low latency data transmission and edgeCloud capabilities which facilitate the deployment of our techniques close to the device in which IoT technologies play a larger role in the VPP evolution. Through the extension of the 5G features with prototypes like the 5G API and through testing of our techniques and tools with current features, like Ultra Reliable Low Latency Communications (URLLC), we have validated that current generations of mobile technologies will have a large role to play in future evolutions of the VPP and smart grid evolution in general. This is further validated by the acceptance of our contributions into the 5GPPP standards.

Core to the advancement of the energy sector is ensuring that the regulations change, or new regulations are introduced to ensure that pace is maintained with the technical advancements and the market need for change. In the edgeFLEX project we have identified the regulatory changes needed to facilitate this change and proposed amendments and additions to them to ensure that they are current with the market and the research. Furthermore, within edgeFLEX, we are cognisant of the business changes needed to facilitate this evolution, and the SWW business are changing to utilise VPP2.0 as a tool that can help their business evolve to incorporate the energy community while maintaining the integrity of their grid and ensuring that it is working within operational limits.

3 The changing energy sector and the advancements in techniques

In this chapter, we introduce trends and technology changes in both energy and mobile communication sectors and analyse the potential impact of this changes on the business scenarios and exploitation of the edgeFLEX results.

3.1 Changes in the energy sector and the evolution of VPPs

This section details the changes in the energy sector and the need for the edgeFLEX business scenarios.

3.1.1 Change in DSO responsibility towards grid management

3.1.1.1 RD2.0

Redispatch means, in essence, readjusting scheduled generation and consumption to be in line with the power grid's constraints. These are measures to host flexibility capabilities of the power system and to support congestion management. Until October 2020, redispatch was carried out in such manner that the TSO has had all responsibility to address bottlenecks in the responsibility area. In October 2020, the new and advanced scheme for re-dispatching, the so-called "ReDispatch 2.0", came into force. For its implementation, all grid operators must first collect extensive data to enable them to decide on the right redispatch measure for their own grid and upstream grid operators. In addition, all generation units with ≥100kW must participate in the new scheme, while smaller, remote-controlled units may participate as well. The DSOs are responsible for congestion events in their own grid.

3.1.1.2 Physical balancing

By means of assuming additional roles, if such responsibilities are enabled, DSOs can support local physical balancing measures to make sure consumption equals production, with consideration of tolerance boundaries. Assuming additional roles alongside the grid operator, the role of an aggregator, as well as retailer and RES owners, while being the local Balancing Responsible Party (BRP), allows the DSO to have more control on grid events and to address issues quicker and more efficiently.

3.1.1.3 Enhanced role for RES in system protection

Aggregated smaller generation units present the System Operators with the potential to control assets in cases of increased stress on the protection system of the grid. As protection systems always should address four fundamental key characteristics, namely selectivity (isolation of defected segment), reliability, reaction times and sensitivity, many smaller aggregated RES assets could actually allow System Operators to exploit the physical features of those assets, e.g. fast and cheap shut-on/off, and apply it on selected units instead of large SG assets.

3.1.2 Power Flexibilities

One of the aspects that has been investigated during the edgeFLEX project is the use of the flexibility for grid management. As described in D6.1, three different approaches for the harvesting of the distributed flexibility are defined:

- **DSO centred approach**, where the DSO is responsible for the collection of the flexibility from the assets.
- **Aggregation service provider centred**, where the "aggregators" provides flexibility in exchange of a service fee and entirely operates based on market signals.
- **Local energy community approach**, where the community itself has the role of collecting the flexibility of its members. The energy community responsible (ERC) or a

contracted third party is the manager of the services and eventually can also play the role of market operator.

In the context of the edgeFLEX project, the three approaches have been combined to collect flexibility from the local controllable assets present in the grid to cooperatively manage the distribution grid.

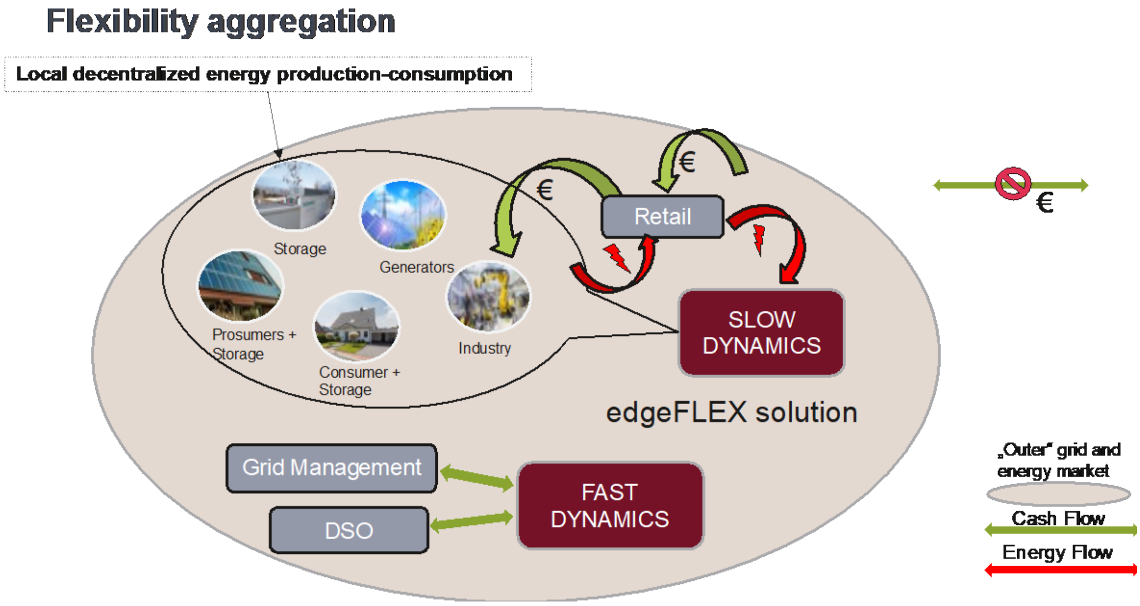

Figure 3-1: The edgeFLEX solution for collecting flexibility from the controllable assets

The idea behind this approach is that the DSO normally installs property assets in the distribution grid which can be used for the direct management of the grid. In this configuration, the fast dynamic control services, used for the grid management and hosted on the DSO platform, make use of this direct capability to control the flexibility of the resources. Moreover, the platform developed in edgeFLEX can be used to request and directly collect the flexibility from the assets. It is also responsibility of the DSO to host and manage the platforms and tools that enable the harvesting of the distributed flexibility. This first mechanism for collecting the flexibility is described in lower part of Figure 3-1.

On the other hand, DSO can also use the flexibility provided by the "aggregators" or directly by the energy community, as described in the upper part of Figure 3-1. In this case, due to the time required to calculate a market solution, the result of the flexibility trading can be applied only for control action that requires slower dynamics, as described in detail in Section 3.2.1.1.

The involvement of the "aggregators" and the energy community requires a change in the regulatory framework to define how the remuneration of the services performed by the customers can be actuated. This aspect not only represents a new business scenario, but also allows for the encouragement of customers' active participation in the management of the grid of which they are part. Moreover, this approach will reconsider the customer autarky towards a more communitarian share of the resources, rethinking the responsibility of the active customers towards the grid.

To practically implement the interaction between the DSO grid management services and "aggregators" or energy community, a regulation that specifies how the flexibility can be offered to the DSO must be defined. This regulatory process should describe the standard messages and control signals exchanged between the DSO and market platforms. It should identify time scales for the DSO to request flexibility and for the market entities to define an offer as a response signal. Besides, the sharing of data between the DSO and the "aggregators" or energy community represents a critical aspect linked to the privacy of customers' data and to the security of critical infrastructures' data. In this sense, defining criteria to protect the shared data while strengthening the way cybersecurity of energy system is defined is one of the key actions for the digitalisation of energy.

3.1.3 VPP Asset Portfolios & Energy Storage

The increasing penetration of RES throughout calls for a substantial increase of flexibility for the balancing of grid systems. Since there will likely be only limited growth in new hydro plants and flexible thermal assets, the capacity of storage systems needs to be increased dramatically. This also affects RES producers since the capture price of RES decreases with the increasing penetration of those sources in a system. Producers can balance their portfolios and increase their revenue using energy storage systems.

The optimisation work carried out as part of D5.2 has shown that integrating batteries in the VPP portfolio can increase profit. Whilst adding one battery produces this desired outcome, adding more batteries generates additional profit since it allows the further addition of biogas and wind asset units. The advantage of integrating batteries in a VPP is two-fold – not only can it benefit from the excess energy produced by the wind asset, it can also participate in the energy (intraday/day-ahead) and capacity markets (ancillary services).

Energy storage is also being developed at a high pace in colocation of distributed energy resources (DERs). It is expected that in the future, small-scale systems such as DERs will make up a part of the generation, with large growth coming from residential PVs. There will therefore also be a need for VPPs to access and manage this future capacity for flexibility. The individual asset owners can gain access to VPPs through an aggregator or through an Energy Community.

3.2 Technological Advances and Techniques

3.2.1 Advancement in Grid Management Techniques

In this subchapter, the advancements, and trends in the management of the electrical distribution grid are presented, particularly focusing on the new concepts related to the voltage (presented in D1.2, D1.3), frequency control and on the estimation of the inertia (presented in D2.1, D2.2, D2.3, D2.4 and D2.5). These concepts represent solutions to improve the ability of the grid operators to optimally manage the assets installed in the electrical system and react proactively to the events that occur in the grid.

3.2.1.1 Evolution and advancements of the control of the voltage in the electrical grid

The control of the voltage has always been a required aspect of the electrical system, given that the voltage is meant to be provided within a limit range in both Medium Voltage (MV) and Low Voltage (LV) levels. In recent years, the massive installation of RESs and ESSs has revolutionised the way the power grid was commonly conceived, showing an increase of voltage issues in sections of the electrical grid that were normally less monitored and controlled.

The first approach that has been used to solve such issues has been to invest in grid reinforcements, which consists of the updating the physical assets owned by the grid operator, typically transformers and cables. Although this approach reduces the voltage issues in the grid, it represents a high investment for the operator to solve events that normally happen during short periods during the day. Moreover, this approach is not flexible, given that it is realised for a specific condition of the electrical grid, which could change in the future.

A different approach has been included in the grid codes of different European countries in recent years. This technique consists in defining a curve that links the measured voltage with the injection and absorption of reactive power, so-called $Q(V)$, which is integrated in the local control algorithm of the RESs. Following this curve, the single RES can modify its injection of reactive power based on the voltage local measurement. This control solution, although very simple, can be insufficient to solve a voltage issue (Bolognani).

Conversely, edgeFLEX makes use of an advanced approach, where the voltage issue is not meant to be solved by grid reinforcements or by a single customer. This approach consists of finding a solution for the voltage issue using all the available resources in the grid, considering the voltage control problem from a system level perspective. This approach has the advantage that the whole set of installed RESs can support the control of the voltage, lowering the burden on the individual user. There is currently no regulatory framework covering such an advanced technique for controlling the distribution grid and few tests have been performed in the field. However, a new plan for digitalisation of the distribution grid to support the development of the renewables has been defined in (Commision, 2022). In particular, the document specifies the need for investments in the installation of smart IoT devices and meters and to define digital tools, powered by Cloud-edge computing servers, to optimise the use of the renewables.

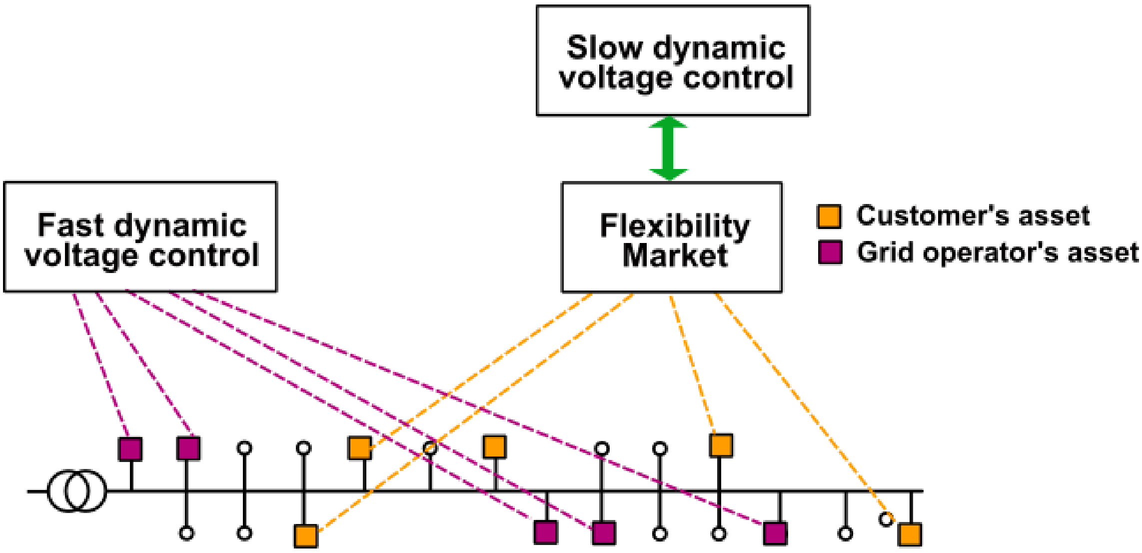

Figure 3-2: Voltage control actions with the different assets

In the concept developed in the project, two different control algorithms have been interfaced to give the possibility of controlling both the customers' and the grid operator's assets, as described in Figure 3-2. With this approach, the control actions can be separated into two different timescales. The slower control action is used to create the flexibility request for the flexibility market. The faster control action can directly steer the assets belonging to the operator and can be used to rapidly solve voltage issues. The interface with the flexibility market requires to wait for the market to calculate the offer before applying the set-points to the assets. In the edgeFLEX solution, for example, the control algorithm calculates an optimal request for a set of nodes and sends this request to the market. After the time requested by the market to calculate the offer, this is sent to the voltage control algorithm and applied to the assets. Consequently, if the voltage control issue has not been solved by means of the customer's assets, the fast timescale control is applied to the operator's assets.

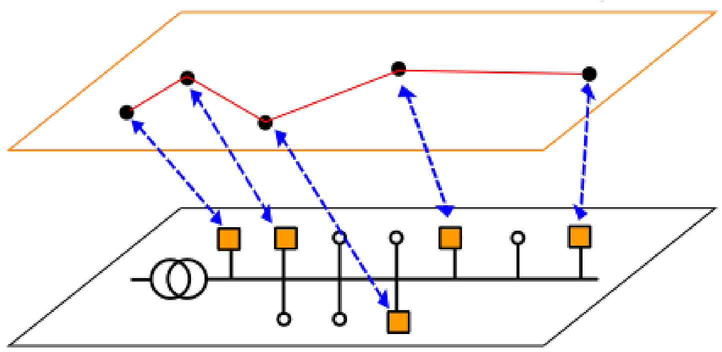

Figure 3-3: Configuration of a distributed control

In the instance of the slow dynamic Voltage Control scenario, the edgeFLEX Platform enables the interaction between the control service and flexibility market through the interfacing of edgeFLEX components with external systems. In operation, flexibility requests are made on behalf of the slow dynamic Voltage Control algorithm through the Policy Based Network Management (PBGM) system, which directly interacts with the flexibility market and returns the market calculation offer when available, or, as the generation of a FlexOffer is not necessarily immediate, a method for the algorithm to poll for the offer until such a time as it is generated. This interaction is described in Figure 3-4.

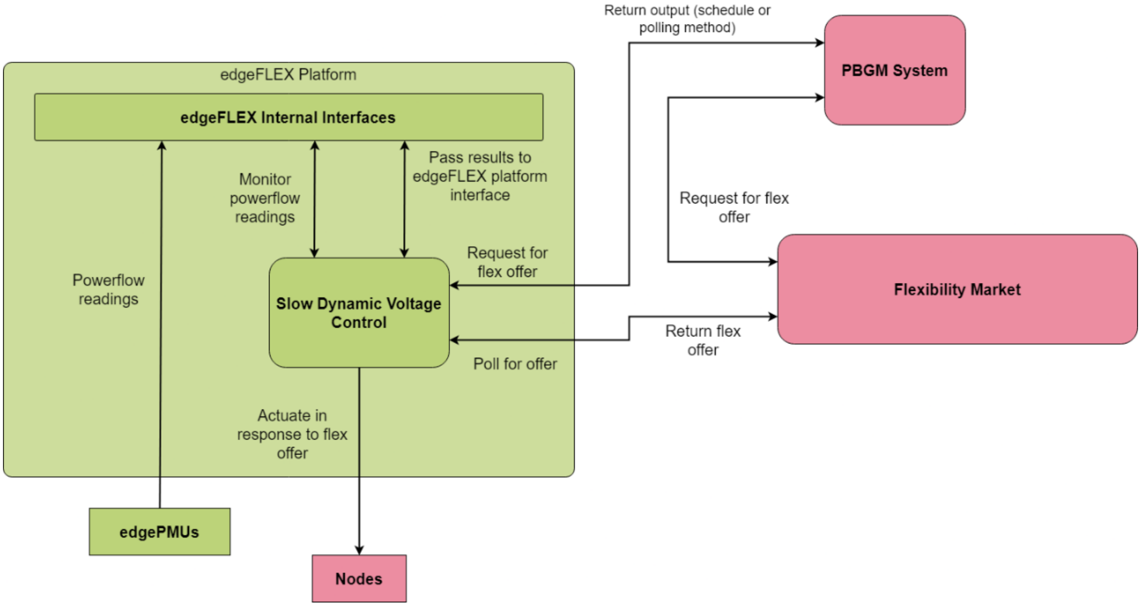

Figure 3-4: edgeFLEX Platform flexibility engagement interaction

In this way, the edgeFLEX Platform supports the move to more local control of assets and flexibility at the grid level, and by leveraging the capabilities of PBGM, allows System Operators a dynamic and fine level of control of the bounds and details of flexibility requests made by the PBGM system to the flexibility market.

More futuristic scenarios could consider the use of distributed solutions where each controllable asset solves a portion of the whole optimisation by exchanging data with a set of peers, as described in Figure 3-3 This configuration has the advantage that it does not represent a single point of failure, given that collection of data and computation are not concentrated in one point (E. De Din). Therefore, the fact that the private data are not centrally collected in a central control unit reduces the issues related to the privacy. This aspect has been defined by the European Commission in (Commision, 2022) as a key element for the development of the digital solutions and it is part of the EU action plan for the digitalisation of the energy sector.

3.2.1.2 Evolution and advancements of the inertia and frequency control related concepts in the electrical grid

The ongoing increase of penetration of Distributed Energy Resources (DERs) is leading to new challenges for maintaining the frequency stability of the power system (Sanniti). However, these challenges are also seen as opportunities for integrating DERs in electricity markets and ancillary services provision. VPPs have been introduced as a solution to realise the aggregated benefits of DERs. A VPP is a virtual entity that integrates multiple DERs and acts as a single unit in the electricity market. VPPs allow for the coordination and control of multiple DERs to provide various grid services, such as frequency regulation and peak shaving (Zhong W. e.). Although, VPPs have been introduced to realise the aggregated benefits of DERs, the role of VPPs has been limited to participation in energy markets and secondary frequency reserve ancillary services until now. The potential of VPPs to perform a wider range of tasks, such as providing primary frequency response remains untapped. The integration of such capabilities to VPPs can lead to significant improvements in the overall reliability, efficiency, and sustainability of the power system.

In the research community, the new concept of dynamically controlled VPPs has been introduced to extend the role of VPPs to provide fast dynamic services such as primary frequency control, fast frequency control and virtual inertia (Kim) (Zhong W. e.-l.). This will enable VPPs to provide fast and efficient services to meet the changing energy needs of the grid.

One of the key challenges in implementing dynamically controlled VPPs is ensuring that the available DERs are monitored and controlled effectively. This requires the development of new monitoring and control tools that can accurately track the performance of the DERs and respond quickly to changes in grid conditions. In edgeFLEX, six novel concepts have been developed to address this challenge and advance the role of VPPs in providing ancillary services. An overview of the different concepts related to inertia and frequency control is presented in Figure 3-5.

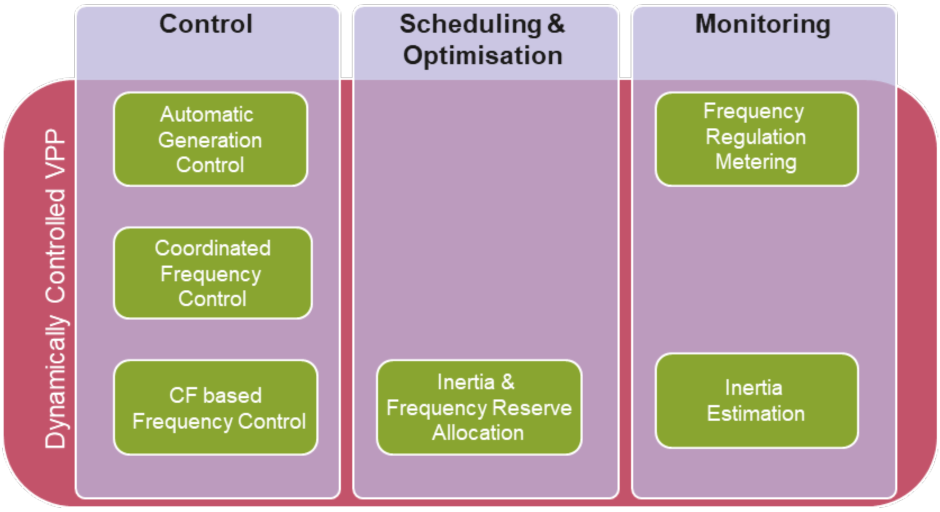

Figure 3-5: Inertia and Frequency Control Related Services

The concepts developed in edgeFLEX cover a wide range of frequency and inertia related control, monitoring, and optimisation topics. They are designed to provide improved performance and guarantee that VPPs can meet the changing needs of the grid. The concepts range from control strategies for DERs, to monitoring tools that can track the performance of the VPPs in real-time, to optimisation algorithms that can schedule the provision of ancillary services in an efficient and effective manner. Hence, the concepts together offer a comprehensive solution covering different time scales as illustrated in Figure 3-6.

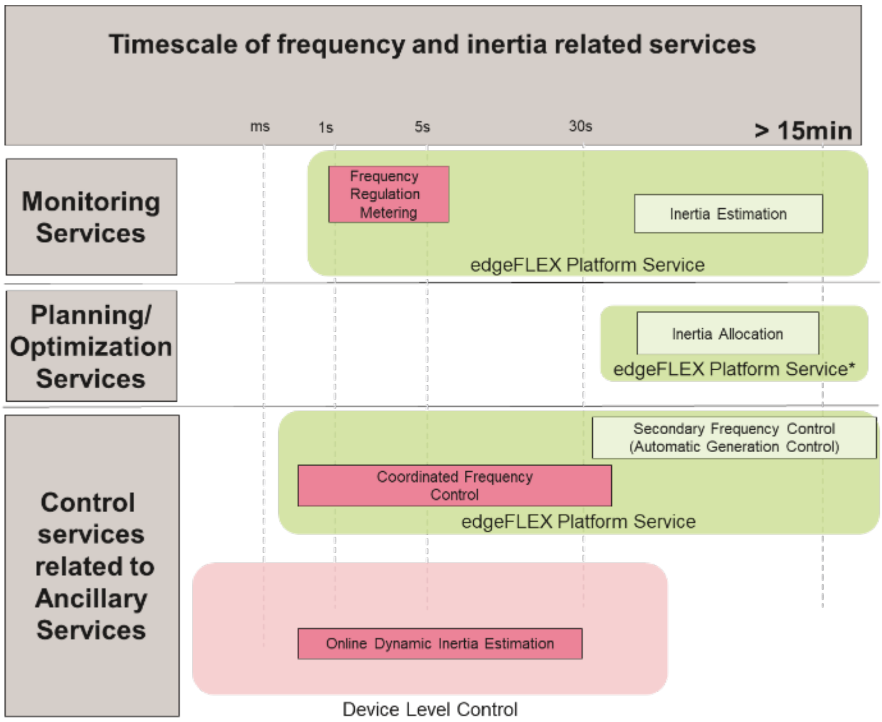

Figure 3-6: Timescale of Inertia and Frequency Control Related Services

Frequency Control Concepts:

The different frequency control concepts constitute the Automatic Generation Control (AGC), coordinated frequency control and the complex frequency-based frequency control. The AGC approach helps restore the grid frequency to the nominal value and keeps the VPP power injection at the scheduled value (Zhong W. G.).

The coordinated frequency control is intended for short-term frequency regulation; thus, it operates in the same timescale of primary frequency control of a few milliseconds to thirty seconds (Zhong W. C.). The coordinated frequency control combines the active power scheduling and frequency control to enhance the dynamic performance of VPP and minimise the stochastic variations in frequency during transients.

Finally, to extend the frequency control concepts to energy communities and future VPPs, a new theoretical concept, the Complex Frequency (CF), has been developed (Milano F.). The CF helps better understand and capture the frequency variations in a power network by representing the system frequency as a complex quantity. A combined voltage-frequency control scheme that efficiently utilises the active and reactive control loops of converter interfaced resources is then developed. This contrasts with existing practice, where frequency and voltage control are decoupled. Overall, the proposed scheme outperforms other possible control modes and provides a significant improvement to the dynamic response of the system.

Monitoring Concepts:

In edgeFLEX, two innovative monitoring concepts operating on different timescales have been developed to enhance the design and implementation of ancillary services markets. The first concept, frequency regulation metering, provides a practical and reliable criterion for distinguishing between devices that impact frequency and those that do not. This is achieved by using the Rate of Change of Power (RoCoP) as an index to differentiate between devices based on their effect on frequency at their point of connection (Milano F. a.). This information allows Transmission System Operators (TSOs) to accurately reward devices that provide meaningful frequency support, promoting the effectiveness of ancillary services markets.

The second concept, the inertia estimation algorithm, represents a major advancement in the ability of System Operators to accurately estimate inertia and damping at both the system level and device level (Nouti). Unlike existing methods that only estimate the effective inertia, this algorithm differentiates between inertial response and fast frequency response, providing a more accurate picture of the support that devices can provide to the system. Accurate estimation of system inertia enables TSOs to design ancillary services markets with a better understanding of frequency support needs, promoting the effectiveness of these markets.

Overall, these two monitoring concepts are critical tools for ensuring that ancillary services markets are designed and implemented effectively. They allow TSOs to make informed decisions about frequency support, promote effective ancillary services markets, and ensure that participants are properly rewarded for the services they provide.

Scheduling and Optimization Concept:

Mature technologies for DERs to provide ancillary services are already available. However, the cost for providing ancillary services must be economically viable for both the System Operators and VPPs. One of the key issues that must be considered is the cost of providing ancillary services, which must be balanced against the benefits that they provide to the grid. Moreover, physical constraints of generation systems and controllability must be considered. These constraints can significantly impact the ability of the VPPs to provide ancillary services, so it is important to consider them when developing solutions. To address these challenges, the inertia allocation algorithm has been developed. This algorithm offers a scheduling approach to optimally allocate inertia and frequency reserves among the resources that compose the VPP. In doing so, it provides an economically and technically optimised solution that can help to ensure that the VPPs are able to provide ancillary services in a cost-effective and efficient manner.

In conclusion, the novel control, monitoring, and optimisation concepts being developed in edgeFLEX will help to advance the role of VPPs and make it possible to provide fast and efficient ancillary services to meet the changing needs of the grid.

3.2.2 Advancement in VPP Portfolio management using Optimisation

A VPP optimised to maximise the revenues gained from the market price variations is generally referred to as a “Commercial VPP”. When the application of the optimised VPP is focused on the supply and demand balance of the grid, this is called a “Technical VPP”. However, a VPP can benefit from a more grid balanced portfolio through the ancillary services market, which could potentially render the distinction between those two types of VPP obsolete. Furthermore, if the assets and the asset owner or VPP aggregator are qualified for and have access to the energy (day-ahead, intra-day) and capacity (ancillary services) markets, the VPP could even benefit from increased revenue from both of those, with namely the intraday and day-ahead arbitrage as well as ancillary services revenue. Finally, the costs are reduced in such a system due to the lower balancing costs incurred by the asset owner of VPP aggregator.

Alpiq’s work on VPP optimisation, through the tasks completed in WP3 and WP5, features optimisation on the levels of Commercial and Technical VPP concepts combined, with the goal of maximising profits at the lowest cost. The following results have been achieved:

- Improvements in the computational speed of the optimisation algorithm can lead to increased profits – it allows the positions to be calculated at a speed that enables optimisation at the level of intraday trading (15 min time step).
- It has been shown that the addition of an energy storage system to a production-type portfolio increases profits; further additions lead to additional profitability since having more batteries in a VPP system leads to the possibility to integrate more production assets.
- Biogas plant asset owners could be incentivised to have their asset under such a multi-asset portfolio management since said plant can benefit from the excess energy produced by the wind farm.
- Measurement stations in closer proximity to production sites would allow more accurate day-ahead production forecasts – a portfolio effect was reached in that the weather fronts and movements from one power plant to another were modelled.

In relation to portfolio setup and capacity, there is a clear effect of economies of scale, where larger, more diverse portfolios can generate more revenue per unit of power. This is not only due to an optimised energy market trading but also due to the portion of fixed costs, which is quite high in the case of VPP aggregation. The increased returns of an optimised VPP setup and methods can be directed towards investments in the growth and diversification of the portfolio, thereby leading to further optimisation. Using the optimisation methods described above, it has been shown that increases in profit of about 2 % could be achieved through the participation of the VPP on both the energy and capacity markets. It is to be noted that the optimisation was carried out on as is applicable to a portfolio with a specific asset mix, namely biogas and a battery balancing a wind farm’s production.

Many other VPP optimisation studies have been completed with at least 65 methods to date, each developed with the application to a specific portfolio as well. In those other studies, the optimisation techniques presented rely on different levels of control methods (centralised, distributed), in which the aim remains the same – for the VPP to optimise the scheduling of the assets and thereby maximise profit. The flexible assets bring value in that they can benefit from the participation in the ancillary markets as well as contribute to reducing the balancing costs of the overall portfolio. The energy mix is bound to further evolve in the next few years. Whilst the systems will have to integrate and balance more RES, they will also see the emergence of an increased number of new sources of flexibility, such as non-lithium-ion batteries, long-duration energy storage (LDES) technologies, and hydrogen.

Moreover, despite the growing need expected in terms of LDES in the next decades, the participation of VPPs in the different capacity markets is expected to substantially increase due to the strong competition on those markets in the coming years. The optimisation of VPPs portfolio management is bound to evolve to reflect those changes. Indeed, with changing market environments and potentially decreasing time steps in trading, it is expected that VPP optimisation methods will have to be improved further by increasing the computational speed of optimisation algorithms or obtaining access to higher accuracy weather forecasts (Omelčenko). New methods, considering the specificities of the new types of portfolios, *i.e.,* more RES and new sources of flexibility as well as their resulting uncertainties, are expected to be developed. Finally, as illustrated by the below figure, it can be foreseen that the continuous evolution of VPP optimisation will also allow a further improvement of the integration not only in the number but also in the types of assets under management, thereby creating a positive feedback effect.

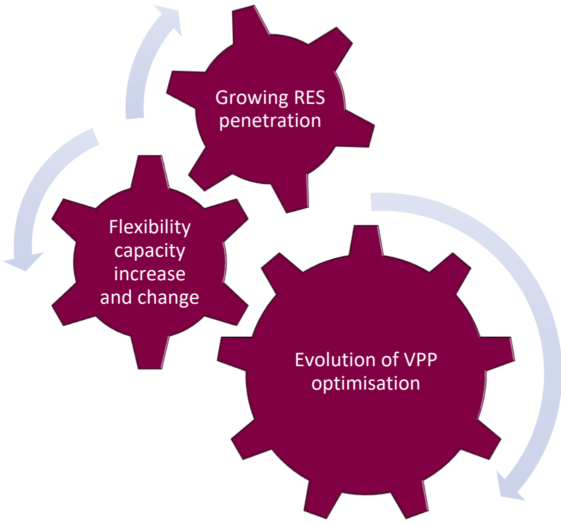

Figure 3-7: Evolution of VPP optimisation, driven by changes in flexibility and RES capacity

3.2.3 How Microservices Architectures and the Internet of Things support the VPP Evolution

As detailed in Section 2, the edgeFLEX projects proposes an evolution from the current VPP, referred to herein as VPP1.0, through to VPP2.0. In VPP1.0, a monolithic architecture may be sufficient as plant portfolios typically consisted of large-scale and centrally managed wind and solar plants. VPP1.1 introduces AI based VPP optimisation and advanced mathematical modelling to enable services such as weather forecasting. As VPP2.0 moves towards smaller and more distributed prosumer-owned assets, the operating conditions and requirements may differ on a case-by-case basis. A VPP operating at a smaller, more local level requires a different set of tools than a VPP operating around a centrally managed wind farm. This variability of use-cases creates a need to move away from a monolithic architecture towards a more modular approach.

The edgeFLEX platform was developed using a microservice architecture. This means that the overall platform is separated into several independent parts, each with its own, narrowly defined function. Each service is deployed to its own container, with a communications interface handling traffic between each container. These services are loosely coupled, meaning that it is possible to freely add or remove connections with other microservices.

Each of the services and interfaces within the edgeFLEX platform are containerised as part of a microservice architecture. The design was based on the H2020 SOGNO reference architecture, which was extended to incorporate the concept of flexibility trading developed as part of the H2020 GOFLEX project. The scale of the deployment of the platform may range from a single component to the entire suite of services and interfaces. Therefore, many of the services can be configured to work as a standalone application, or to interface with existing services within the System Operator's environment, introducing a degree of modularity and flexibility. For example, a System Operator may have a database service in place and may configure the edgeFLEX services to utilise the existing database in place of the edgeFLEX Persistence service. Given the modular nature of this microservice architecture, an opportunity is presented to make use of open-source software, as the edgeFLEX Databus is extended from the open source DockerMQTT project developed as part of H2020 RESERVE. This in turn creates an incentive to open-source additional components to support future projects where possible.

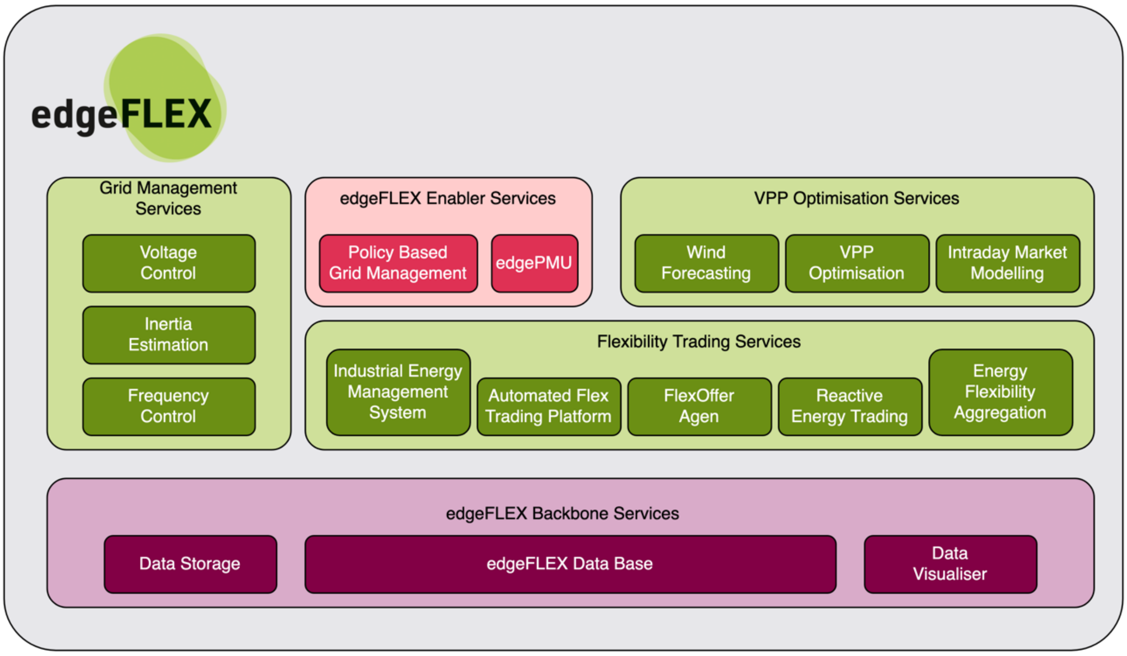

Figure 3-8: edgeFLEX Reference Architecture

This flexible approach is essential in the development of VPP2.0, where the operating conditions may be vastly different from one to another. To enable a wide range of use cases, several variations on the edgeFLEX deployment architecture have been explored in detail, which can be grouped under centralised, decentralised and hybrid architectures. A centralised configuration involves deploying each of the services to the same environment with limited external communication, minimising communication latency and security concerns from data being transmitted outside of the closed system. A decentralised architecture may be used if the services are deployed to a location with limited available processing, such as a substation or an on-pole device, with the data being returned to the central environment for processing. A flexible approach may be taken in the hybrid architecture where the edge cloud and 5G technology can be utilised to allow processing to be performed at the edge. This flexibility is afforded using microservices, as a monolithic architecture would not have the capability to support this array of use-cases.

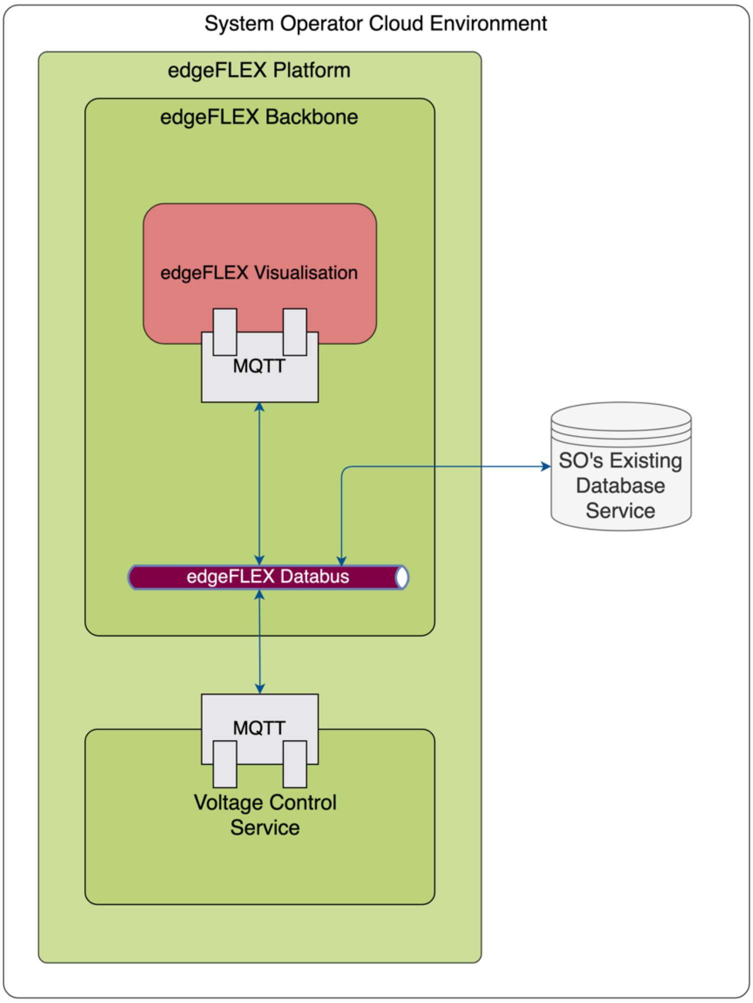

Figure 3-9: Example deployment of edgeFLEX platform and Voltage Control service

Developing the platform as a set of microservices allows it to be scalable into the future. VPP2.0 services such as frequency control, inertia estimation and voltage control functions can be developed and deployed independently of one another. Each of these services can be integrated seamlessly as no one service relies on any other specific service outside of its container. The services can be deployed rapidly, and any issues that arise can be addressed quickly and the services redeployed. Ease of testing is also facilitated, as each component can be validated in isolation. Utilising microservices allows System Operators to integrate the edgeFLEX platform into their existing infrastructure with a minimal level of disruption to day-to-day operations.

3.2.4 How cellular networks support VPP evolution

This section introduces trends and technology changes in the mobile communication sector, and comments on the potential use of existing and forthcoming features and deployments in the VPP generations.

Section 3.2.4.1 provides an overview of the edgeFLEX service requirements and mobile communications solutions and roadmaps for the evolution of the related global standards.

In Section 3.2.4.2, features and deployment scenarios of 4G and 5G mobile networks in their relations to the VPP generations are described.

3.2.4.1 edgeFLEX overview of communications requirements and solutions

This sub-section describes the requirements which the edgeFLEX services place on communications networks, followed by a description of the large-scale evolution of mobile systems as network generations, and concludes with a description of the general solution proposed by edgeFLEX to support the edgeFLEX energy services and the roadmap of the mobile communications sector global standards organisation, 3GPP.

3.2.4.1.1 edgeFLEX use case communication requirements

edgeFLEX use cases carry stringent requirements on wireless communications, the most important of which are very high reliability, availability, and security of communications, and low latency in several cases. In the first reporting period of the edgeFLEX project, the edgeFLEX project analysed the edgeFLEX research concepts and service implementations to define the requirements that are likely to be placed on communications networks when they are deployed in the energy infrastructure on a large scale. Accordingly, the likely communications network requirements have been estimated based on discussions with power sector and ICT sector organisations participating in edgeFLEX.

Figure 3-10 describes the requirements of the edgeFLEX services in the context of their current deployment in the energy infrastructures. As the management of the energy infrastructures evolves in coming years, these requirements are expected to become more stringent requiring the features of 5G-Advanced and 6G to fulfil them.

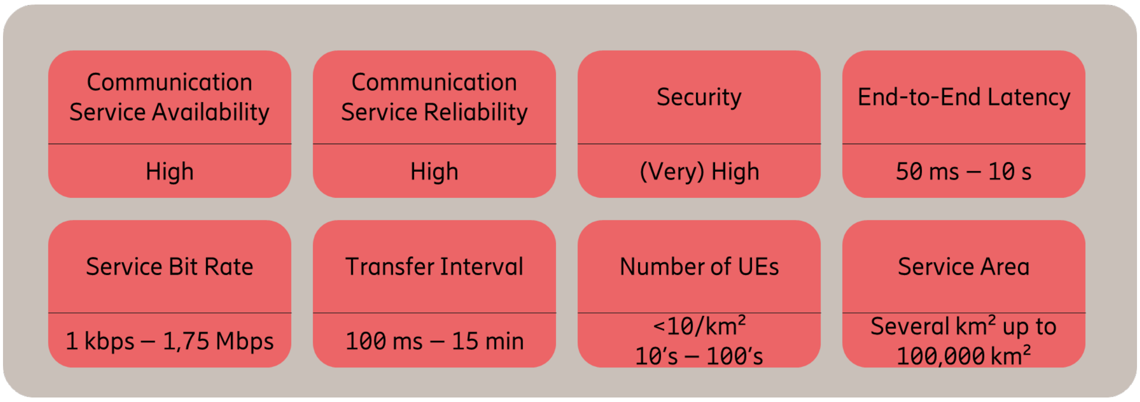

Figure 3-10: Communication requirements of edgeFLEX services

3.2.4.1.2 Evolution of generations of mobile systems

In Figure 3-11 below, the evolution of mobile systems is illustrated covering the timescale from the introduction of 1G, brought to market in 1980 to the introduction of 6G expected to come on the market around 2030.

1G was based on the use of different frequency bands in each country in Europe and required users to use different mobile phones and different SIM cards for each European country in which they travelled.

2G was the first mobile system for which the use of the same frequency bands throughout Europe was introduced. Additionally, users required only one SIM card for all European countries as roaming functionality was introduced.

3G introduced the large-scale use of data services with low bandwidth from mobile devices and roaming to Asia and the United States became practical.

4G, also known as LTE, introduced the first broadband data services with global standardisation deployed in the United States and widely in Asia.

5G expands the broadband capacity and provide specific capabilities not only for consumers but also for various industries as well as for society at large. The aim of 5G is to provide connectivity for any device and application that may benefit from being connected.

The forthcoming 6G mobile systems is expected to bring limitless connectivity with trustworthy systems enabling a sustainable world, and support for a digitalised programmable physical world and connected intelligent machines.

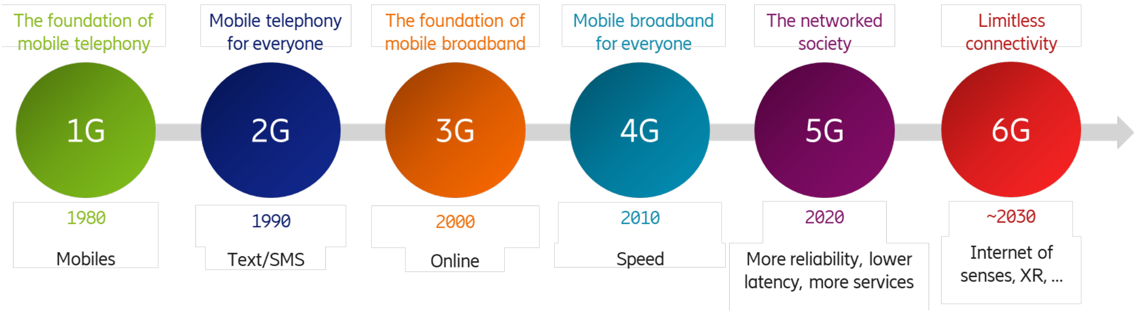

Figure 3-11: Generations of cellular communication technologies. Source: Ericsson

The work in edgeFLEX has focussed on exploring and enhancing the ability of 5G to support the edgeFLEX services. In our project work, we have highlighted the ability of 4G to support many of the edgeFLEX services as they would be deployed at present by utilities, and of 5G and concepts for 6G networks to support the future needs of the edgeFLEX services as the management of energy services becomes increasingly proactively managed using data-driven approaches and close to real-time communications optimising the efficiency of power generation, storage and use by energy network customers.

3.2.4.1.3 Cellular IoT functionality evolution

IoT applications supported by cellular communications have been widely adopted around the globe (Ericsson White Paper: Cellular IoT Evolution for Industry Digitalisastion, January 2019). 2G and 3G network connectivity have enabled early IoT applications. 4G has brought greater bandwidth, lower latency, and increased support for large volume of devices per cell that brings great benefit to IoT applications. These capabilities are further enhanced with arrival of 5G networks that will enable Ultra-Reliable Low Latency Communications (URLLC) that increasingly support critical IoT applications. Cellular IoT connectivity is required to support a wide range of requirements, from the massive number of device connections with relatively simple requirements to the stringent requirements of critical IoT applications.

Cellular IoT is based on 3GPP global standards supported by a rapidly increasing number of mobile network providers, and device, chipset, module and network infrastructure vendors. It offers better performance in terms of coverage, quality of service, security, scalability, and flexibility to manage a comprehensive range of use cases compared to other Low Power Wide Area (LPWA) network technologies. Ericsson defines four IoT segments – Massive IoT, Broadband IoT, Critical IoT and Industrial Automation IoT – based on connectivity requirements defined into market segments that are aligned with many use cases spanning different industries (Figure 3-12).

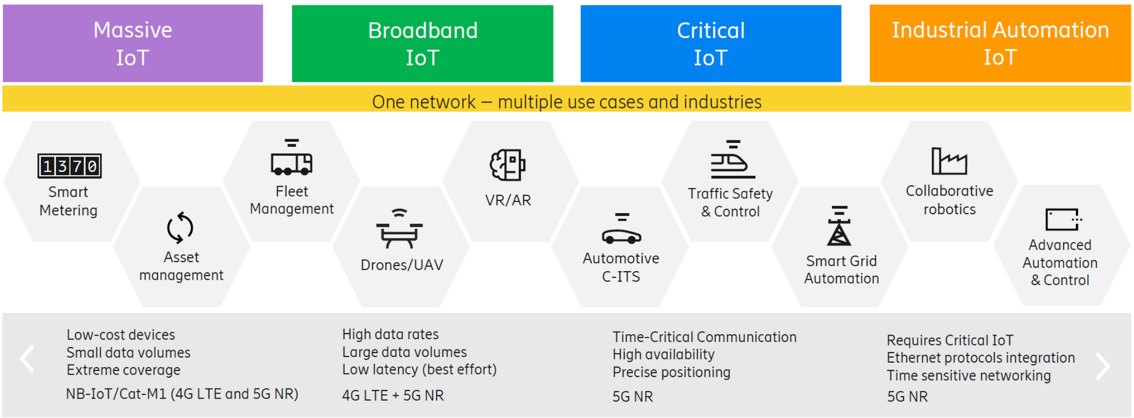

Figure 3-12: Cellular IoT functionality evolution

Note: Updated re-print by authors of white paper "Cellular IoT Evolution for Industry Digitalization" 2019, Ericsson white paper, p. 3. Copyright 2019 by Ericsson AB. Reprinted with permission of the authors.

3.2.4.1.4 General mobile communications solution for edgeFLEX services

The general 4G/5G solution supporting the edgeFLEX services is shown in Figure 3-4 below. Our research concepts, translated into energy services in power infrastructures, require that devices such as sensors, actuators and edgePMUs are installed in the infrastructures of power system and VPP operators, and of energy communities. These devices generate data such as the voltage, current, frequency and power measurements required as input to the edgeFLEX services. Measurement data is transmitted through the radio access network to the edge cloud infrastructure that hosts the virtualised edgeFLEX services. Virtualised edgeFLEX services for voltage and frequency control, inertia estimation and VPP optimisation require the use of edge infrastructure to improve the power system resilience and to minimise latency. The output of the virtualised services is transmitted via the mobile transport infrastructure to the energy management system (control centre) of the power System Operators, VPP operators and energy communities for visualisation. The communications connectivity is managed by the mobile core network.

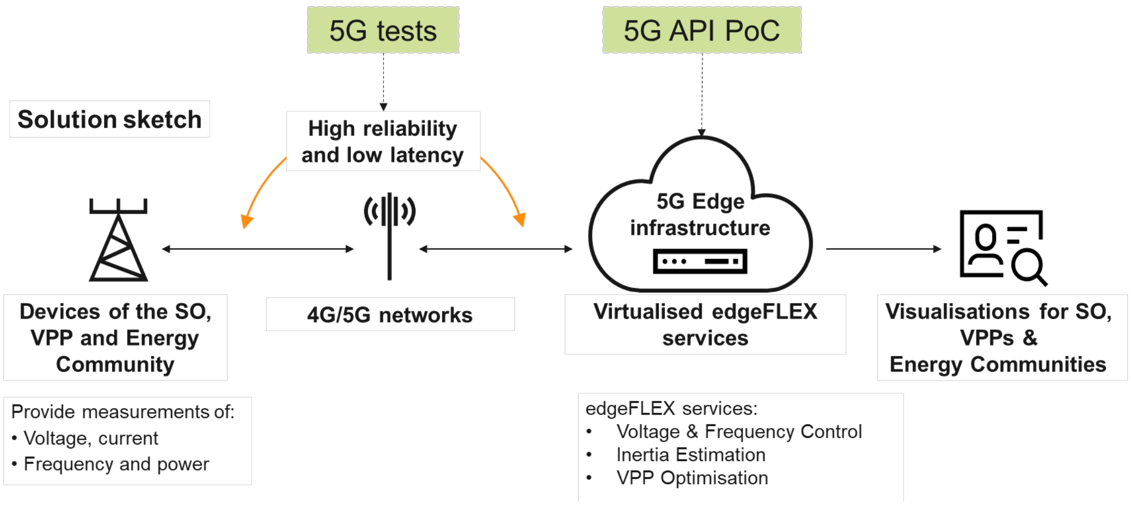

Figure 3-13 General 4G/5G solution supporting edgeFLEX services

The generalised solution illustrated in Figure 3-4 can be enhanced and adapted to meet a wide range of ownership and business model requirements which energy sector actors may wish to implement. The technical capabilities of the communications network can be enhanced with many new services being researched, implemented, standardised and brought to market for 4G and 5G networks. These new capabilities are described in the following sub-sections of this chapter.

3.2.4.1.5 3GPP releases time diagram

3GPP is the organisation responsible for the global standardisation of mobile systems. This organisation has prepared a 5G technology roadmap illustrating the key topics for standardisation supporting the segments of mobile broadband, critical IoT, massive IoT and cross-domain issues in Figure 3-14 below. As can be seen in the figure, the standardisation of new functionality is progressing along different timescales for the different technical topics. New releases of 5G are becoming available every one to two years, upgrading its functionality. The forthcoming releases 18 and 19 will include functionality to implement “5G-Advanced”, which is expected to be available on the market as 5G Rel-18 around 2024 with Rel-19 coming around 2025.

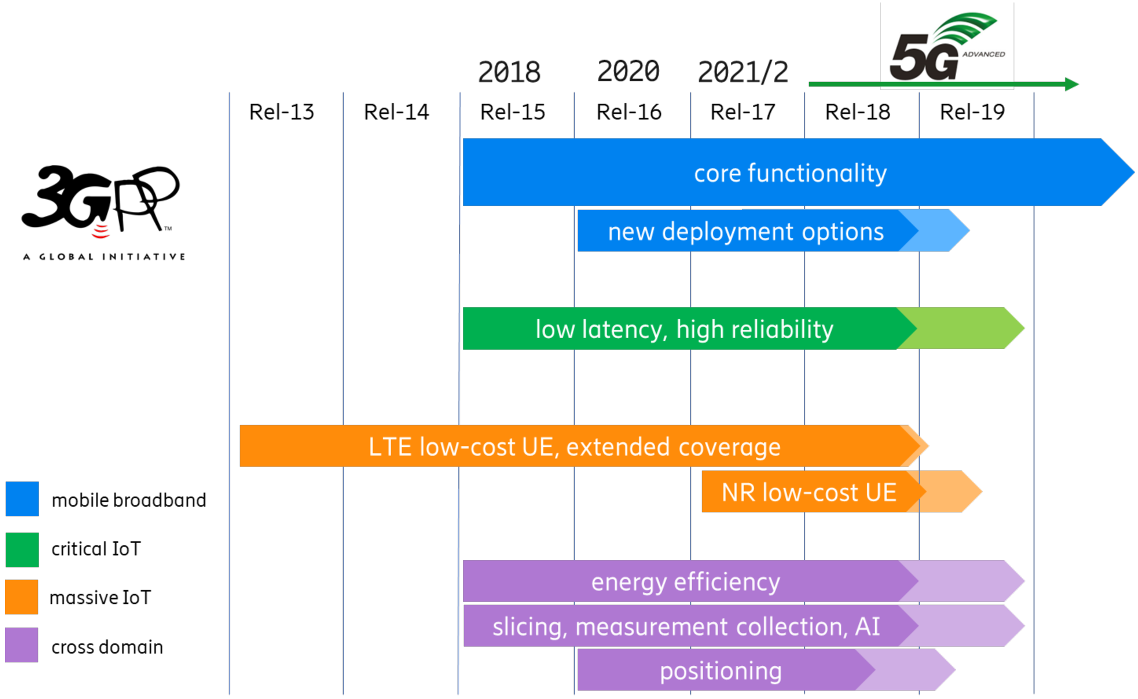

Figure 3-14 3GPP 5G RAN technology roadmap. Source: Ericsson

3.2.4.2 How mobile network features and deployments support edgeFLEX services

This sub-section provides a few examples how 4G and 5G network features and deployments can support edgeFLEX services in different VPP generations. For an overview of the extensive number of features and deployment options of 4G and 5G networks supporting edgeFLEX services, please refer to the Annex section.

How mobile network features support edgeFLEX services

Power system infrastructure assets are dispersed through geographical wide areas, and edgeFLEX services will often collect the data from high number of infrastructure assets dispersed throughout. They are often deployed in remote or less reachable places. In such cases, the functioning of the asset needs to be ensured for a period in the range of years. Mobile network solutions for massive IoT such as LTE-M and NB-IoT provides ideal solution in terms of extended coverage and support for low complexity devices, ensuring a long battery life. Furthermore, standardised modems such as Cat-M1 and NB-IoT have a future-proof evolution in 5G networks that can ensure a long lifespan for the assets. The introduction of 5G reduced capability devices is expected to result in further reductions to modem complexity and optimisation of the power consumption of devices.

Power infrastructure assets are exposed to high temperatures, humidity, or vibrations. Embedded Subscriber Identification Modules (eSIM) can be used in such circumstances. Assets integrating eSIM can be smaller and of higher quality than those using a physical SIM card. Furthermore, the selection, contracting and onboarding of a communication service provider is easier for the power system or VPP operator, as the operator does not need to look for communication providers. eSIM can choose a new local communication service provider to remotely provision and activate a new subscription to the asset over the air. Finally, it will guarantee seamless global connectivity services provided by communication service providers across the entire device life cycle.

Reliable and secure communications with guaranteed performance is a mandatory requirement for all edgeFLEX services. Mission critical mobile networks fulfil these requirements in all geographical areas even under extreme circumstances. Furthermore, they provide extendable coverage comparing to commercial mobile networks and resilience mechanisms significantly higher than by commercial networks, including power backup, redundant transmission and geo-redundant core network.

The mobile network slicing feature will ensure reliability and latency communications requested by edgeFLEX services in both private and public mobile networks, enabling flexibility and faster delivery of edgeFLEX services.

Mobile networks provide communications security by design, beginning with the first mobile network generations. Communication security is built through the key areas of standardisation, product development, deployment and operations of mobile networks.

Edge computing will host edgeFLEX services of voltage control, frequency control, and inertia estimation, as well as edgePMU device logic providing computing, network and storage execution resources close to devices. It will provide the low latency, high bandwidth, device processing, data offload and security functionalities requested by the edgeFLEX services. It will be possible to deploy the edgeFLEX service in an optimal location, i.e., an edge, regional or national site.

In the edgeFLEX project, we have integrated and tested the new, advanced 5G features such as 5G device management exposure and URLLC supporting edgeFLEX services on the standard 5G and the prototype URLLC networks in the laboratory. These features will be available to the market in the future. We have proved in the project laboratory test that enhanced 5G device management exposure can enable the edgeFLEX service user to manage the connectivity and devices in a simple manner. In this case, the interaction with the communication service provider is not needed. Furthermore, ultra-reliable and very low latency features can significantly improve quality of the edgeFLEX services supported by edgePMUs.

Energy efficiency of mobile networks has always been important for mobile network operators and will be important for the mobile network owner in the future due to significant costs. Energy consumption is responsible for 15-40 per cent of OPEX for the mobile network operator. Modernising the existing equipment contributes to reducing energy consumption of the mobile network. The test pilots show that 5G technology is up to 90 % more efficient than 4G in terms of energy consumption per unit of traffic.

How mobile network deployments and other aspects support edgeFLEX services

Here we describe different aspects how mobile networks can support edgeFLEX services such as 5G radio spectrum flexibility, communication service life cycle management and mobile network deployment options.

4G radio spectrum assets are mostly in the low bands (< 1 GHz) and mid bands (1 GHz - 6 GHz). These bands will continue to be used for wide-area coverage in the 5G era. Besides the use of high bands (24 GHz – 40 GHz), 5G can use the radio spectrum assets currently used by 4G either through spectrum sharing or refarming. The coverage provided by the low-band and mid-band spectrum assets will play a key role to enable edgeFLEX services in wide-area deployments. Additionally, new 5G spectrum assets in the mid bands around 3.5 GHz and in the high bands will provide increased communication capacity requested by certain edgeFLEX services and enablers such as edgePMU.

Communication services in energy infrastructures are expected to last for multiple decades, and mobile networks should address this requirement. Mobile networks under 3GPP standards support long lifecycle of energy infrastructures by enabling backward compatibility and providing comprehensive support for diverse communications services for each generation. It is worth mentioning a few prominent 5G features in this context:

- Dynamic Spectrum Sharing 5G feature enables parallel use of 4G and 5G in the same frequency band, enabling backward compatibility.
- 3GPP standardised LTE-M and NB-IoT technologies will continue evolving as part of 5G specifications. This means that mobile network owners can already leverage their investments in these technologies and will continue to as a part of the 5G evolution.
- New 5G networks will co-exist side-by-side with 4G ones for many years for reasons of practicality and efficiency. 5G New Radio is designed to work in coexistence with 4G networks operating in non-standalone mode.

The mobile network deployments options supporting edgeFLEX services can be categorised as public, non-public and hybrid mobile network deployments.

- The deployment of power grid and VPP System Operator devices often requires the establishment of communications to locations for which utilities do not already have privately owned communications links. In such cases, the use of public mobile networks provides communications to new devices without the high costs associated with deploying private cabled or wireless connections to the new locations.
- In contrast to public networks that offer mobile network services to the general public, 5G Non-Public Networks (NPN, also called private networks) offer mobile network services to a specific organisation or a group of organisations. The non-public network is based on 3GPP defined technologies, and provide high quality of service capabilities, high security, isolation from other networks and accountability.
- Combining a public and non-public network into a Hybrid Network can also offer a flexible solution supporting the communication requirements of edgeFLEX services. Hybrid networks can facilitate the control of critical infrastructure assets using geographically restricted, private networks complemented by public mobile network operator networks for controlling less important, dispersed, critical infrastructure assets.

3.2.4.3 Summary of how mobile network features support VPP evolution

In relation to mobile communications networks, we describe how the existing features of 4G and 5G describe the key requirements of the edgeFLEX services for reliability, availability, security, latency, and communications throughput. We placed special emphasis on the description of the support of differing mission critical requirements of the Critical-IoT and the Massive-IoT market segments as energy services often must play mission-critical roles in the energy infrastructure. The big differences in the requirements of these two major market segments mean that mobile networks must be able to support a wide range of capabilities and offer great flexibility of configuration and implementation options. We have described how the emerging features of 5G-Advanced and 6G will enhance the support of mobile networks for the edgeFLEX services.

The possibility to virtualise services in an edge, distributed or centralised cloud offers many advantages to the energy sector. Service resilience is increased, operation and maintenance are simplified, and flexibility in the deployment and management of services is increased.

5G reuses frequencies used by both 4G and 3G, and this has the benefit of increasing the energy efficiency of mobile networks, enabling higher bandwidth and throughput with lower latency and an overall greater energy efficiency in the use of the available spectrum than was possible with older networks. It also enables wider geographical network coverage than would be possible if the new 5G infrastructure was based entirely on the deployment of new 5G equipment at all locations.

We describe the wide range of ownership models supported by mobile networks including private, public and hybrid ownership models, and we relate them to specific network capabilities, such as network slicing, which offer energy sector actors enhanced control and security features. Hybrid networks enable privately owned networks in local or campus contexts to be complemented by regional and national infrastructures which may be publicly or privately owned.

We describe the standardisation of 5G and the expected future standardisation of 6G networks and provide the roadmaps defining the plans for future standardisation. Experience has shown that standardised mobile networks have been supported for over 30 years after they were brought to market. 2G and 3G networks are still in use in many parts of the world, and interoperability of their services with those of newer network generations is assured by the standardisation process, protecting the investment of the communication network owners and the network users. Global standardisation of mobile networks brings many advantages to energy providers in terms of the:

- Long-term support for products implementing the standards and launched on the global market.
- High levels of security and reliability of such solutions gained through the collaboration of and technical analysis undertaken by many manufacturers and system houses in the discussions in standardisation bodies.
- Reduced investment risk associated with purchasing and using globally standardised networks, implemented as products and services by many global suppliers.

3.3 Results from the BRIDGE Stakeholder Characterisation activities

The Stakeholder Characterization Survey was developed and is being conducted as part of the "Platone" and "edgeFLEX" research projects and the BRIDGE Topic Group "Stakeholder Characterization". This survey will capture and analyse the experiences of a wide variety of stakeholder types (>200) and their engagement in the flexible energy system. The survey has a duration of several months to collect sufficient responses for the intended holistic approach. The aim of the survey is to share the engagement experiences through an openly accessible European database. The insights gained should help future projects and ventures of all kinds to further develop their stakeholder engagement strategies, and to understand the relevant stakeholders better generally.

The survey is aimed at anyone who has been or is involved with the topic of flexible energy systems, as well as stakeholders currently active in the energy system, from industry and research to policymakers and individuals in Europe and beyond, as appropriate. The survey describes and categorizes experiences. No rating system is implemented. The observed quantitative results are evaluated qualitatively. Notable respondents will be additionally interviewed, if necessary, to learn more about their answers.

In the following, preliminary results will be presented and connected to edgeFLEX findings.

After approximately three months of the ongoing online survey, responses were observed in 128 cases, of which 61 were completed in full and were therefore valid. These valid responses are used for the following initial analysis. Respondents spent an average of 19 minutes (± 9 minutes) to complete the survey, with each respondent characterizing an average of 5 stakeholder types. Based on the number of stakeholders per respondent, we can conclude that most respondents had various interactions with stakeholders in the flexible energy system.

For simplicity, and because the survey is still ongoing, the initial analysis included only the five most frequently selected stakeholder types, as shown in the table below. For better understanding the stakeholder types were renamed (Original name (from survey) >> New name).

Original Name	New name	Number of responses
Electrical Distribution System Operator (DSO) -> Technical Position	DSO Technician	11
Natural person / private homeowner / tenant -> Residential consumer	Private home / Consumer	8
Natural person / private homeowner / tenant -> Residential prosumer	Private home / Prosumer	6

Energy community operator -> Energy community member	Energy community member	5
Local / regional Government -> Politician	Regional Politician	5

The following sections examine key drivers and incentives for participating in the energy transition and promoting flexibility, barriers, and difficulties in engaging with stakeholders, and a comparison between the current roles and future roles of the selected stakeholders. The percentages in parentheses correspond to the proportion of respondents who agreed with the statement/category.

DSO technicians: technical aspects are the motivating factors for technical positions in a DSO to actively support the energy transition and use of flexibilities, with "access to advanced technical functionality" (45% of respondents agree) and "contribution to technological infrastructure" (36%) being the most important. In general, DSO staff see "regulatory gaps" (36%) as the biggest barrier to stakeholder collaboration. DSO staff responsibilities currently include "power system operations" (73%), "power distribution" (55%), "technical support" (55%), and "rate setting" (27%) concerns. For the future, the DSO technician is assigned more tasks across a broader spectrum in the survey. "Electric grid operation" is gaining importance (82%), as is "electric power distribution" (73%). The two categories "Technical support" and "Tariff setting" have remained the same, while the two categories "ICT provider" (27 %) and "Provision of energy flexibility" (27 %) are new additions.

Private home / Consumer: When it comes to motivating factors for active participation in the energy transition, especially the “Potential to protect the environment” (63%), followed by “Economic incentive” (38%) and “Reputational benefits” (38%) stand out. "No economic interest" (38%), followed by "Lack of experience in this field" and "No compatibility of assets” (25% each) were the top responses to the question of barriers to greater engagement. “Energy consumption” (63%) and “Energy flexibility provision” (38%) are seen as the main tasks currently. This is not expected to change in future, though it is expected that the category “Electricity generation” (38%) will be added in future, transforming rather passive consumers to more active prosumers.

Private home / Prosumer: Like the consumer, the main motivation for prosumers is the “Potential to protect the environment” (67%), followed by the “Economic incentive” (50%) and “Allowing for self-supply / autarky” (33%). The major barriers for homeowning prosumers to take a more active role were “No economic interest” and the “Absence of digital tools” (each 33%). The current tasks are categorized as “Electricity generation” (50%), “Energy consumption” (50%), “Peer-to-peer trading” (50%) and “Energy flexibility provision” (50%). In future, it is expected that both “Energy consumption” and “Energy flexibility provision” grow to 63%.

Energy community member: The “Economic incentive” (80%) is a very high ranked motivation factor to participate in energy transmission and promoting flexibility. The drivers “Sense of ownership”, Affiliation or community action”, “Fostering local energy” and “Potential to protect the environment” were also important (all 40%). The major barriers for engagement for energy community members were “Bad/ non targeted communication” as well as “Lack of experience in the field” (each 40%).

Energy community members tasks are currently the following: “Energy consumption” (80%), “Electricity generation” (60%), “Energy flexibility provision” (40%) and “Energy services provision” (40%). In the future, respondents believe that energy community members will only participate in two tasks: “Energy consumption” (60%) and “Electricity generation” (40%). This is counter intuitive as the expectation would be that the role and importance of Energy Communities will grow. This rating will further be investigated as more replies to the survey are expected after the edgeFLEX project’s end.

Regional Politician: Here only “Fostering local energy” (60%) is shown as an important driver. The main hurdles to regional politicians mentioned were “Lack of experience in the field” and “No compatibility of assets” (both 40%). The fact that an asset was mentioned might imply that there is a lack of technical understanding or know-how rather than the missing compatibility of assets. This is a good example of the need for further investigation via in-depth interviews. In the survey replies, the regional politician is assigned with two tasks: “Policy and regulation” (80%) and “Awareness raising” (60%). It is the only stakeholder type with no categorisation changes for the future.

The preliminary findings of this stakeholder characterisation survey support the approach taken in the edgeFLEX project to assess questions and concerns of all stakeholders in detail, which is part of the process as documented in the following chapters of this deliverable. It is by no means given that they participate in leveraging flexibility and enabling this, due to diverse reasons.

4 edgeFLEX Business Scenarios

In the first version of this report, edgeFLEX examined how to increase the profitability of intermittent generation plants, which is often the case for RES assets. Organisational approaches (Energy Community) were considered, as well as investment structures with reduced risks (Risk separation in Power Purchase Agreement) and improved and new revenue opportunities for flexible plants or combinations of such (VPP optimisation, Ancillary service provision, Flexibility trading).

This chapter now describes the two business scenarios developed by edgeFLEX and how mobile communications networks can support the deployment of each scenario. The scenarios highlight the role of the system aggregator and how the type of organisation responsible for this key role impacts the social and economic features of each scenario.

In the corporate world, business plans are used to define the pathway for a product or idea towards market. These plans can often take a long time to write and given the nature of the corporate world it might not have the agility needed to facilitate the business scenarios proposed by edgeFLEX. The means by which we define these business scenarios and align them to a business model, given the changing electricity sector and the novelty of the edgeFLEX solutions, would need to be lightweight and agile. For this, the Lean Business Model Canvas, a tool that is used to analyse the key components that are needed to take an idea to the customer, was chosen.

The Lean Business Model Canvas explores the problem facing the potential customer and the alternatives available to them and aligns it to a solution with the unique value proposition that the product provides to support the solution placed at the centre. It details the customer segments and the early adopters that would be the target for the product, and the channels through which to reach them. Finally, it outlines the key metrics under which the product can be measured, the cost structure, both fixed and variable, and the revenue streams that the product will generate.

In the following sections, the business model canvases will be analysed and the illustrations in Figure 4-1 & Figure 4-2 provide a graphical view of the canvas which is normally a large table with cells assigned for each component. In the upper part, Problem, Solution, Unique Value Proposition and Customer Segments as well as identified Early Adopters and Channels to reach those are described. In the lower part of the diagram, Key Metrics, Cost Structure and Revenue Structure are shown.

4.1 System Operator as aggregator

This scenario is "set" in the low voltage grid where assets of residential and commercial consumers / prosumer are considered to be a VPP as they will be managed together. In this scenario, the DSO assumes the role of a VPP aggregator, operating edgeFLEX solutions which then enable the use of flexibility provided by the assets organised in a VPP structure owned by individuals or even in an Energy Community (EC). This business scenario is based on the technical VPP2.0 described earlier in Chapter 2 of this report, and Figure 4-1 shows the associated business model canvas for a VPP2.0

Problem
Technical problems that will be addressed such as, in the case of the DSO, a lack of insight into the grid due to a lack of high-resolution grid measurements at the edge, grid instability which is caused by the increasing share of RES generation, and demand through sector coupling in the low voltage grid. Among other things, this initially has economic consequences for the DSOs due to penalties they need to pay to customers experiencing outages, and to RES asset owners for curtailing their assets. Upon reinspection, those costs will eventually be flipped to end-customers in the energy system. An economic impact concerning the DSO will be customer satisfaction, which might decrease due to outages.

Solution
In edgeFLEX, several interdependent solutions were developed to address those problems. This includes tools to enable Energy Communities to offer their flexibility to the DSO for grid

management, specifically Voltage Control, as well as direct Voltage Control solutions for the DSO and low-cost edgePMUs for enhanced monitoring of grid parameters.

Customer Segments

In the analysis of the business scenario, several actors were identified as potential customers: Energy Communities and DSO as already discussed, but also individual prosumers, aggregators, and Energy Service Providers. Individual prosumers organised within an Energy Community and the roles of the aggregator are taken by the DSO.

Early adopters

DSOs who are willing to engage in leveraging and using local flexibilities for their grid management as well as Energy Communities are considered as early adopters of the edgeFLEX solutions.

Channels

Channels to reach those customer segments were identified, of which the FlexCommunity, BRIDGE, consultancy companies and engagement with DSO organisations are considered as the most promising ones.

Key Metrics

With the solutions proposed by edgeFLEX and analysed in this business model, it is expected that an increased penetration of RES connected to the DSO grid can be reached with regards to key metrics. In addition, positive effects on the voltage behaviour will be measured. Through online Voltage Control, a reduction in over and under voltage events would be considered a key metric. Use of MPC Voltage Control would aim to achieve a prolonged voltage imbalance (>15mins) given that it is based on predicting the quantity of power needed to resolve a prolonged event.

Cost Structure

There are two types of cost structure in the BM Canvas, variable and fixed. In this scenario, there is a large emphasis on the fixed costs, partly because there is a hardware component and there may be interaction directly with the asset. This means that there may be procurement or upgrading of assets to facilitate the implementation of the business scenario, but most of these changes would be up-front costs and would require investment. The variable costs in this case are fewer, by nature not up front, but will partly involve the cost in adding tasks to functions within the business. For example, an existing technical support team might need training to be able to support the maintenance of the edgePMU or the control centre operator might need training to be able to interpret the outputs of the Voltage Control.

Revenue Structure

The revenue structure is also split in two – business-to-business (B2B) and business-to-customer (B2C). On the B2B side, the DSO can generate revenue by selling flexibility that they do not need themselves for network management to the upstream DSO instead of buying some of the services related to network management from them. On the other hand, it has expenses because it buys flexibility from the aggregator or the energy community. This means that the revenue streams shift, at least in part, with the goal of reduced costs of flexibility for grid management by integrating local resources. If not organised as an Energy Community, the B2C revenue stream would be from the DSO buying flexibility from the individual prosumer.

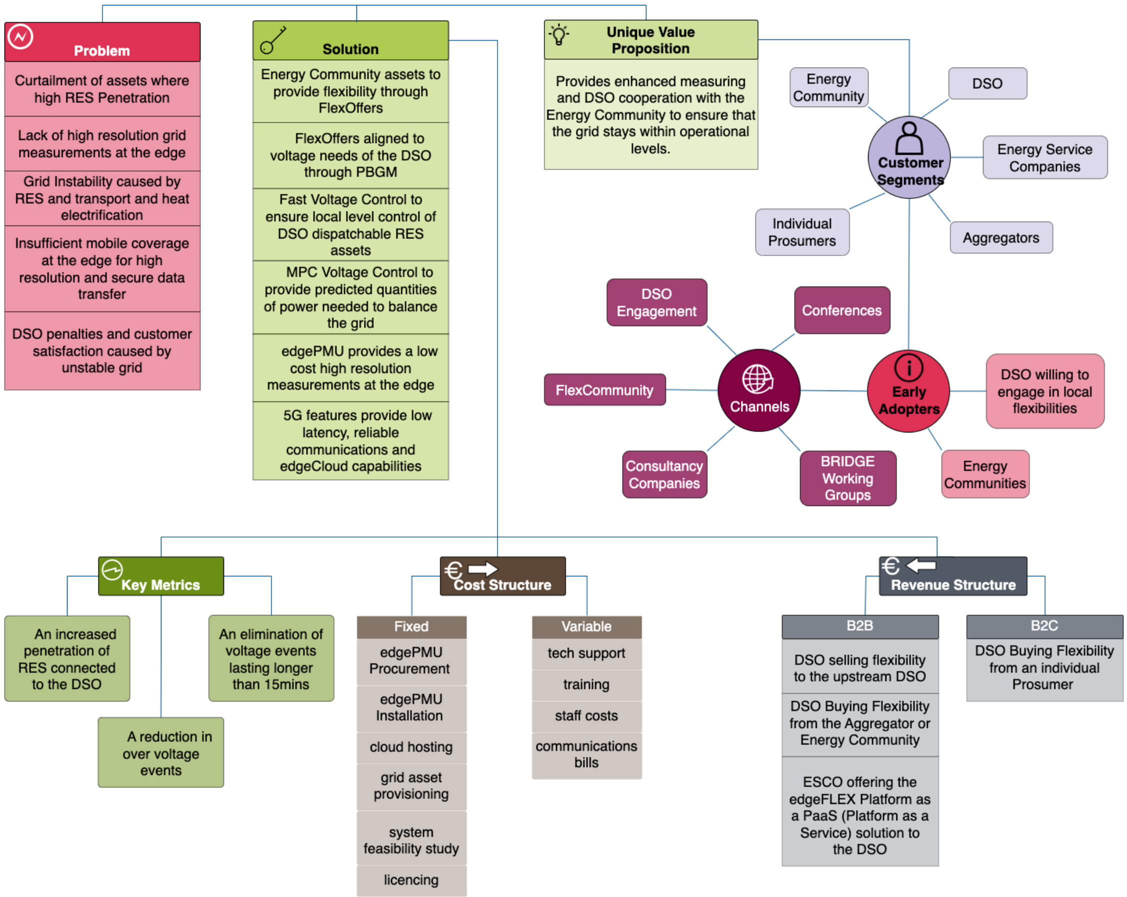

Figure 4-1 - Business Model Canvas for VPP2.0

4.1.1 Social and economic impacts of the model

This model scenario entails positive outcomes for all parties involved. As the DSO is also the aggregator, it can manage their grid in a more efficient manner while using existing and local flexibility and load shifting potentials from within their grid. This more efficient grid operation translates directly to money saved on power loss, maintenance of assets and physical grid infrastructure as well as saved penalties and personal costs for attending to issues of grid operation.

By offering their assets for grid management, for flexibility-providing asset owners from the Energy Community this means an additional revenue compared to self-supply from their RES assets and fixed small remuneration for excess energy feed-in to the grid. In addition, with the VPP2.0 end-customers are enabled to participate in wholesale markets to increase profitability of their RES assets. Furthermore, in future, the aggregated flexibility could be used for other grid supporting services offered to the TSO. Whether those ancillary services will be offered to the frequency control market, or a form of proposed inertia market needs to be further investigated.

With a more efficient grid operation and management — or even reduced need of investment in grid infrastructure — the local community can benefit from a more secure and locally produced energy supply for the same if not more affordable prices. This will empower citizens, which will further promote the active participation of citizens in the electricity supply chain. For those not able to invest in their own RES assets, they could jointly invest in assets as an Energy Community. Also, an efficient energy supply and management of the local grid within the Energy Community can reduce pressure on those citizens in paying their energy bill, especially with geopolitical developments which lead to increased energy costs.
Basing energy sources in renewables and its increased efficiency will result in less local pollution and greenhouse gas emissions. Long term external costs on society can be reduced, such as fewer sick days due to cleaner air causing fewer hospitalisations.

4.1.2 Relationship of edgeFLEX results to this scenario

This scenario was implemented in the edgeFLEX trial in Wunsiedel described in Section 3.2.1.1. In this trial, it was shown that utilising the assets of the energy community using a flexOffer solved an overvoltage in the system. The overvoltage was identified using the edgePMU, and in utilising the edge monitoring of the edgePMU, the DSO was able to identify the location of the overvoltage and solve it locally by engaging with prosumer assets. While voltage events are a part of everyday grid management, this business scenario allowed the DSO to aggregate the flexibility of the prosumer assets to maintain a stable grid while remunerating the prosumer through flexOffers.

4.2 VPP operator as aggregator

This scenario is closely related to pre-existing, larger-scale VPPs and is based on the VPP1.1 introduced in Chapter 2 of this report. In this scenario, the usual VPP operator assumes the role of the aggregator, using the specific instantiation of the edgeFLEX platform enabling an optimised asset management for them. The VPP operator engages in energy trading of the combined generated energy from the VPP assets, and Figure 4-2 gives an overview of the business model canvas created for a VPP1.1.

Problem
The identified problem is an uncertainty in production when assets are located over a wide-spread geographical area due to differing weather conditions and the lack of weather forecasts for such wider areas.

Solution
With the solution of improved management of the portfolio developed in the edgeFLEX project, the VPP can be optimised in operation against the energy only market, including an improved weather forecast.

Customer segments
From edgeFLEX viewpoint, the customer segments firstly included the VPP operator, who faces such a problem in their asset portfolio. Secondly, software providers for VPP management, operation and optimisation are considered a customer for the proposed solution.

Early adopters
VPP operators are early adopters who face challenges such as the assets in their management portfolio being spread over a vast area, and the desire to improve their portfolio management. They also already might have the plan to leverage flexibility from those assets to increase profitability by offering ancillary services.

Channels
The most promising channels to reach customers are considered webinars and conferences, including direct contacts as follow-up.

Key metrics
In terms of key metrics, it is expected that the number and type of assets can be increased, and higher profits can be achieved with the new optimisation solution.

Cost Structure
Fixed costs arise with, for example, purchasing of the optimisation software and personnel for maintenance, investment in infrastructure and cloud hosting, whereas variable costs occur from forecast services and operations personnel.

Revenue structure
The revenue structure is strictly business-to-business, as RES assets of that size are business-owned. Revenue can be generated from optimisation against existing energy markets with improved ability to sell generated energy when the cost of energy is high. In future, further optimisations can also be made in ancillary services markets or from direct provisioning of ancillary services.

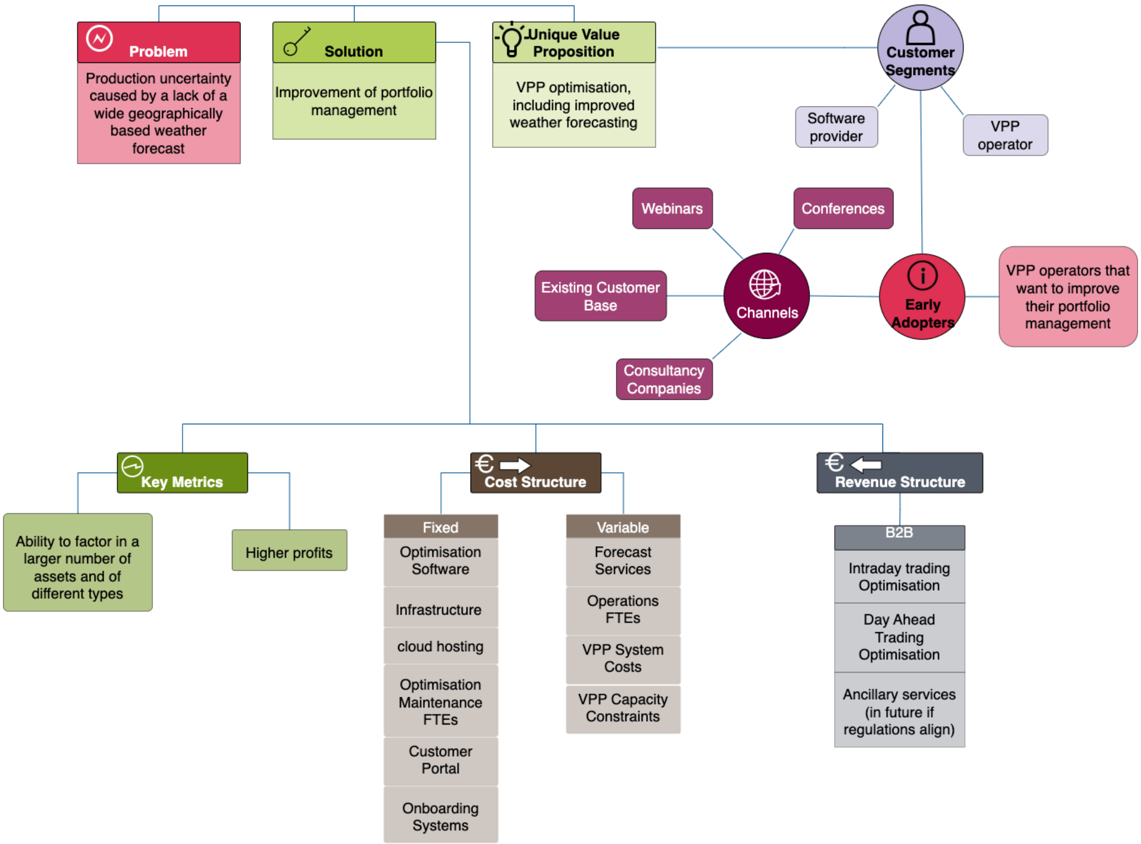

Figure 4-2 - Business Model Canvas for VPP1.1

4.2.1 Social and economic impacts of the model

The aggregation of assets as a VPP1.1 by a VPP operator is a first step that directly benefits the asset owners and the aggregator. It allows asset owners to increase their profit from their assets. This might lead to them considering and eventually even investing in additional RES assets, thereby increasing the share of renewables in the energy system. With an increasing share of renewable energy sources also results in non-monetary benefits for the public. Those benefits range from decreasing costs for electricity purchase due to generation from renewable sources and more efficient use of existing assets with future provisioning of ancillary services. The benefits range from reduced air pollution locally to a reduction of greenhouse gas emissions which benefits the whole society.

4.2.2 Relationship of edgeFLEX results to this scenario

The ALPIQ trials have shown that additional profit can be achieved by using the edgeFLEX optimisation solution for VPPs. This optimisation is only possible with a multi-asset portfolio for which the owners can provide their assets for management by the VPP operator. This profit is distributed to the customer of the VPP aggregator, which are ALPIQ's customers in this case. The trials have thus revealed further opportunities for improving the profitability of the management and optimisation model currently established on the market.

4.3 Use of mobile networks in edgeFLEX business scenarios

In this sub-section, we analyse the potential impact of mobile communications technology on the business scenarios of the edgeFLEX results. We first describe the general communications and business requirements that an aggregator will have on the communications infrastructure it uses. Then the relationship of the options for fulfilling these requirements with mobile network communications are defined.

Communication requirements of aggregators

Aggregators will need communications networks to enable connectivity between many devices. The use of mobile communications comes with several benefits over cabled communications. It would reduce the cost and time required to deploy the many new devices needed to collect the required data and simplifies the maintenance of the communications devices through the possibility remote management of the devices' software.

When using the most advanced versions of the edgeFLEX services and the edgePMU, hosting the virtualised service software is enabled by the 5G Edge Computing infrastructure.

Business requirements of aggregators

The general business requirements which aggregators will place on their communications infrastructure will include the following issues:

- Ensuring that communications networks offering open interfaces and those based on international standards can switch suppliers avoiding vendor lock-in and ensuring communications availability as the aggregator can switch to another network if needed.
- Support for interfaces over periods of up to 30 years or more so that the need to physically visit sites where devices are located can be avoided.
- High requirements on the security of the communications infrastructure to minimise the possibility of cyber-security and physical-security attacks being successful.
- Wide-area coverage of communications infrastructure will be needed to support the addition of existing and new assets to the VPP.

How mobile networks fulfil these requirements in edgeFLEX aggregator business scenarios

All generations of mobile network can support the basic connectivity requirements of aggregators. 4G and 5G networks will support the most advanced features of the edgeFLEX services when the aggregator implements these services.

Edge Computing can be supported by both 4G and 5G networks, with 5G offering many technical features not available in 4G.

All generations of mobile networks support all of the business requirements of aggregators, with 5G offering the most options for ownership models, interoperability and security features. Each generation of mobile networks are supported in the market for periods of many decades, with 2G and 3G network features still being supported thirty and twenty years after market introduction.

The two edgeFLEX aggregator scenarios share a common perspective on the power distribution infrastructure and its management. However, the connectivity that facilitates the data exchange between the assets, devices, the aggregator, and the markets differ between the two scenarios. This means that the data communications services, which collect on energy production and use, needs to provide this data to different organisations and markets depending on the business scenario implemented.

Use of distributed cloud for the edgeFLEX business cases

VPP or power grid operators collect data from their own assets or those owned by energy communities. Assets are deployed in geographical areas with limited access. In some cases, private or dedicated networks could be used, for example, a private network could play the role of VPP SCADA systems. In this case, applications managing local assets could be deployed in the cloud. The cloud can be hosted in the mobile network or can be deployed on the operator hardware.

Furthermore, coordination and interactions between power grid owners or VPP operators with assets or groups of assets distributed in wide geographical areas would be needed. An example where coordination would be critical is the scenario when a SCADA system fails. In that case, another SCADA system could take over the management of the SCADA system that failed, utilising low latency and reliable mobile transmission links. The migration of applications could be also used in this scenario.

Use of (wireless) transmission links for long distance connections

In both edgeFLEX business cases, the transmission link, either wireless or fixed, can be deployed to provide connectivity between VPP/EC assets and the DSO control centre, or between the aggregator/EC operator and the DSO control centre. Transmission links can also be deployed for interconnections among them.

The VPP as aggregator business scenario

The VPP, as aggregator, could operate a local or regional private mobile network, especially in the vicinity of its key energy assets. It could use a public mobile network or combine private and public infrastructures as a hybrid network.

- If using a public network, the VPP might chose to implement a network slice to ensure its desired parameters for QoS and security are provided to all its communications links.
- It could own the network infrastructure while having a service provider maintain and operate the private mobile network.

The DSO as aggregator business scenario

The DSO, as aggregator, has the same possibilities as described above for the VPP.

5 Exploitation Pathway Analysis Process

To perform a comparative analysis of the business cases that were presented in the previous section, it is first necessary to assess each business scenario from the perspective of the business and explore how the scenario impacts that business. To gauge this impact solely from the perspective of the business would be flawed, as the adoption of such business cases would require the involvement of actors at all levels of the business. In the case of the DSO for example, the CEO may not typically have to manage the technical aspects of deploying an edge device needed for monitoring just as the Grid Technician may not need to consider the cost of the management of the edge device.

Given that the business scenarios above are related to cost and revenue, have regulatory and standards aspects that need consideration, and technical aspects that need to be managed both from an ICT and grid perspectives, it is necessary to explore them in a way that is built on the perspectives of all layers of the business. The following section details this process from defining the questions that need to be asked, the context in which they are asked, identifying who in the organisation needs to be engaged and how the outputs are interpreted.

5.1 The Questions Posed

Identifying the questions that the relevant actors in the organisation might ask is key to the adoption of new technologies into a business. As mentioned in the previous section, the business models that are being assessed are underpinned by a set of edgeFLEX tools and services with data and cash flows. These items have varying impacts on the different levels of the organisation with the actors at each level having various concerns and decisions to make around how the item will fit into the systems or business functions that they are responsible for. The questions they may ask are loosely grouped under the following headings:

Financial: This category of question would centre on the financial impact of the application of the business scenario. The nature of these questions would be at the highest level, for example,

- How much will the solution cost?
- How much would the company make from it?

At a deeper level the questions might seek explore how much cost is involved in the maintenance of the solution and its impact over the benefits to gauge if it is worth implementing the business scenarios. These decisions would typically be made by upper management or a specific financial department within the organisation, and it would be actors at this level who would pose these type questions.

Management: This is a broad category of question as the system will require management at different levels in the organisation. For example, the technical aspects of the solution may need to be managed in part by the field technicians, whereas software, the output of the business scenario and the cash and data flows may all be managed by separate divisions. In each case the questions would be centre on,

- Who is going to manage it?
- What is to be managed?
- How is it to be managed?

Answering these questions is key to building trust in the business scenarios throughout the organisation and allows the organisation to identify the barriers to adoption from a management perspective.

Regulatory: These questions would centre on the regulatory implications of the application of the business scenario and would look to explore the Network Codes that the business scenario or its components might be subject to, the GDPR implications of the business scenario and the standards — electrical, ICT or software — that the components that underpin the business scenarios might be subject to. Answering these questions would help remove uncertainty from the adoption of the business scenario and identify areas where standards and regulatory alignment activities might be needed.

Skills: The adoption of the business models detailed above involve the deployment of novel tools and techniques, some of which require skills that may not be present in an organisation or generate outputs that might not be familiar to some of the employees. These factors would lead to questions such as,

- What expertise will be needed to manage it?
- What do I need to know to maintain it?
- Will the components come with support?
- What are the requirements from a power, ICT or software hosting perspective?

The answers to these questions will help identify the skills gaps in the organisation that might be addressed through hiring or upskilling. Furthermore, these answers will enable the decision makers identify whether the impact of change within their organisation outweighs the benefits of the business scenario. While this might be seen as a negative outlook, it is part of the decision-making process, and the answers can feed into refactoring the business scenario or business model to address the concerns from industry.

Perception: This category will centre on how the stakeholders — the employees and shareholders — would view the business scenario. These questions would typically be asked by upper management or a dedicated Corporate Social Responsibility or Customer Satisfaction Unit within the organisation. These questions would seek to gauge the impact of the business scenario on customers and stakeholder assets and aim to build confidence in it.

System Impact: This group of questions would be aligned to the impact that the implementation of the business model would have on the systems currently running within the organisation, for example,

- What impact will it have on the grid?
- Is it controllable or can it be overridden if it is having a negative impact?
- How will it integrate into the systems already running? Will I still be able to use my existing system?
- Can my existing system perform this function?

The answers to these questions will enable the decision makers to assess the impact of change on their current system and allow actors at all levels to identify how their systems are likely to change because of implementing the business scenario.

Work Process: This group of questions will centre on actors trying to identify the impact of the implementation of the business scenario on their day-to-day work process. These questions may be,

- Who is going to manage this?
- How much visibility will I have on this?
- What do I have to do with the outputs?
- Will this have an impact on my workload?

5.2 The Actors

In the assessment of the control services within the edgeFLEX platform and through assessing the trials it became apparent that evaluation of the platform and control services could not be carried out in a comprehensive way by one actor. A comprehensive assessment would provide grid and VPP operators with enough confidence to accept the control services as part of their tool suite and as “business as usual” tools or services, as opposed to merely assessing the service under the criteria outlined in D4.4 Description of Assessment of Platform Control Service Performance. The lack of a comprehensive assessment of such research may inhibit the widespread adoption of the technique.

Although the goal of the assessment was to examine the control services with a view to their continuous improvement within the timeframe and scope of the edgeFLEX project, it would be an oversight to not at least briefly explore assessing such research within a wider context. This section will outline some things that could be considered when assessing a control service from the multiple actors within an organisation. In this assessment we have broken down the actor types into four broad groups.

Business Focused Actor: This actor is mainly concerned with the corporate affairs of the organisation. Their main goal is to ensure that the actions of the company are financially viable and that the company activities are managed in a responsible way. With regards to the edgeFLEX platform and its deployment in the organisation, they would assess it from a cost-benefit perspective to ensure that the cost of maintaining, licencing, or purchasing the platform would not outweigh the benefits of using it. In the context of edgeFLEX, this actor may be a Chief Executive Officer (CEO) or head of Trading.

Compliance and Governance Focused Actor: This actor would have the goal of ensuring that the operations at a grid and corporate level would comply with the company best practices on security, privacy, and quality criteria, and with regulatory and standards directives imposed by sectoral governing bodies. In terms of the deployment of the edgeFLEX components and services within their business, they may need to assess them from the perspective of complying with grid codes and standards, market rules and regulations, or agreements made with other sector actors. Furthermore, they may need to assess the platform components from a cybersecurity perspective to ensure that the software and the systems deployed are compliant to their best practice standards. A Chief Technology Officer would fall under this area and is one that is relevant in assessing the edgeFLEX solutions.

System Focused Actor: This actor would have the goal of ensuring that the grid system would run in a safe and efficient way. An example would be control room operatives who would have screens and control tools that would present them with information which would allow them to make decisions and take actions. These actors would mainly be concerned with ensuring that the grid is stable given multiple scenarios, identifying faults, planning upgrades, planning grid changes, instigating fault isolation and service restoration schemes, and ensuring that the grid would always maintain within operational limits. Regarding the edgeFLEX components and control services, this actor would be concerned with monitoring the outputs of the control service and identifying and analysing their impact on the grid. They may need override mechanisms to disable the control service or change the inputs to account for changes to the grid. A Control Room Operators and Grid Planners would be examples of such an actor.

Technically Focused Actor: This actor would primarily be concerned with the asset and the grid at a local level. This actor could be a field operative or a grid technician that would be charged with the maintenance and upkeep of the grid assets. Their main concern would be physical safety, the stability of the grid at a local level and the work required to maintain devices that may be required to host components from the edgeFLEX platform. They may also be concerned with resetting breakers and switches if there was a trip event or replacing damaged physical assets in the grid.

Based on the actor descriptions, the assessments that would need to be carried out by each of the actor groups are very different as each actor has very different business or process goals. It also could be the case that the assessments required may be company-specific based on their current processes and the systems that they already have in place. To define these assessments, it would be necessary to engage with each actor group to analyse their concerns and build a set of actor group-specific assessments that would specifically address their needs and concerns.

Within the edgeFLEX project, the focus of the work was not only to assess with the aim of improving the control service and platform components but also to raise the Technology Readiness Level (TRL) of the control services to a level where a company would deploy the services at scale within their organisation and assume it as a “business as usual” tool. Future work would be required to develop a multi-actor assessment process where all the actor groups would have a mechanism to assess the service in a way that would provide confidence at all levels of the organisation.

5.3 How the answers are used

Figure 5-1 illustrates the process and shows the targeted questions being posed to the relevant actors and the answers being input to activities that centre on cost-benefit analysis, change management analysis, regulatory impact assessments, skills auditing, stakeholder and employee engagement, impact of change on systems and the impact of change on work practices. These activities can provide the organisation with a comprehensive view of the impact and elements of change needed to facilitate the implementation of the business scenario. The outputs of these activities would be used to expand on and refine the business models and help identify the exploitation pathway of the business models and of the edgeFLEX components that underpin them.

Core to the success of the adoption of a business model and the exploitation of techniques, services or software is the identification of the barriers that may be in place. The answers to the questions asked in the process and the feedback from the actors at all levels can help identify these barriers and allow the business models and the organisations to be agile in their approach in implementing the business scenario.

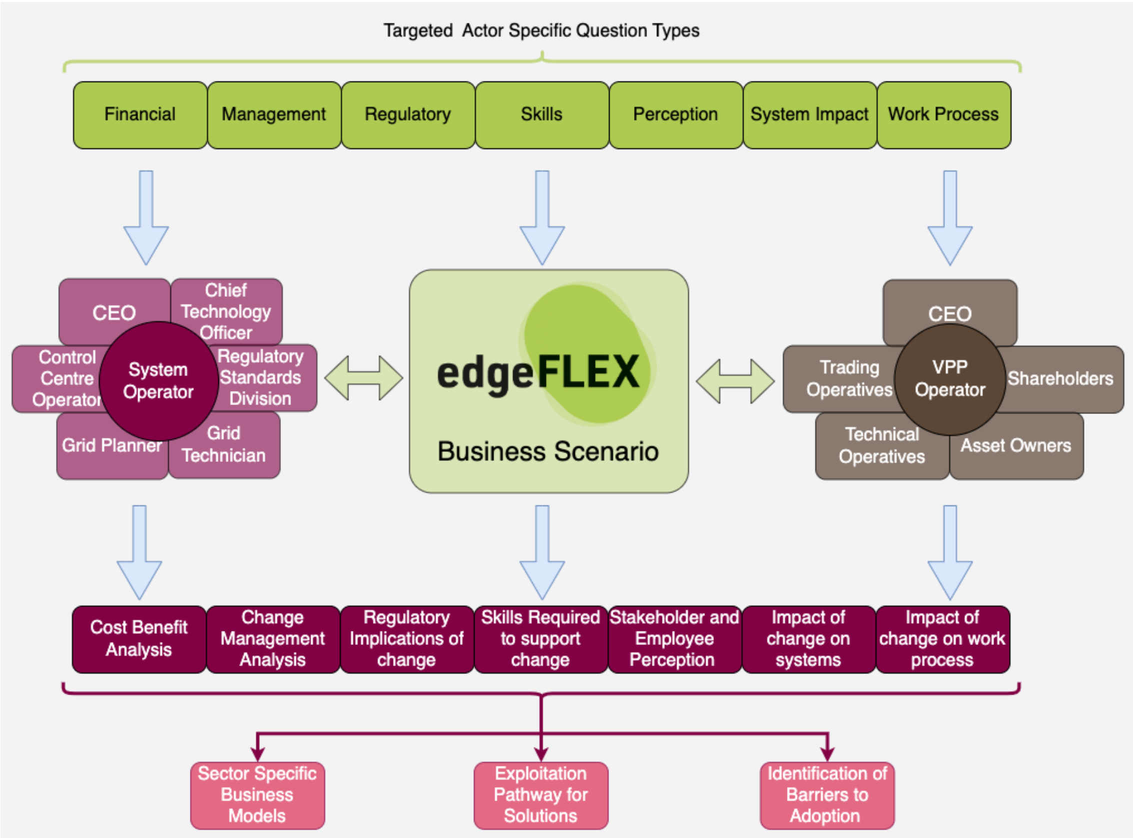

Figure 5-1 - Actor Targeted Assessment

6 Results of Exploitation Pathway Analysis

The following section presents the results of the assessment of the edgeFLEX components from the various sector actor perspectives. As stated in section 5.2, various actors have different concerns and ask different questions when looking to adopt new processes and techniques into their day-to-day operations and business.

6.1 System Operator from a VPP2.0 Scenario

6.1.1 Technically Focused Actor

The technically focused actors manage the grid in the field and would typically need to install, maintain, and manage the "in the field" components of the edgeFLEX Platform. The questions posed from this actor's perspective were mainly centred on:

- Who is responsible for maintaining the application?
- What would they need to do to maintain the application?
- How would it fit into their current system?
- What expertise would they need to manage it?
- What were the communications technologies involved?
- Was there a potential to override the application if was having a negative impact?

The questions from the technical perspective were mainly focused on the components that have the potential to have a direct impact on the grid, particularly on the grid assets and equipment that they manage. Those components were the Voltage Control (online), Voltage Control (MPC) and the edgePMU, and the analysis is as follows.

In terms of maintenance, the actor specifically asked who would need to maintain the component and what would be needed to maintain it. In analysing the Voltage Control (online) it was found that the technical actor would play a part in maintaining this service, but it was identified that at present such an actor may not have the expertise with electronic devices or the IoT technologies required to manage the component; either the component be developed further into a plug and play application that would be easy install, troubleshoot and maintain or a training course could be developed to provide upskilling for the technician.

When analysing the Voltage Control (MPC), it was identified that the technician would have no role in its maintenance as it would be most likely deployed in a cloud environment, although it may be necessary for the technician to manage and monitor the required data streams onsite to ensure that they remain operational. The analysis of the edgePMU found that the technician would need to play some role in the maintenance of the component; they may be required to provide a secure location to house the hardware but may not have the expertise to provide debugging or troubleshooting as with the Voltage Control (Online).

In terms of the communications requirements of the edgeFLEX components, the technician specifically needed to know how the component would communicate to both the cloud, other devices, and the assets. In analysing the Voltage Control (online) it was noted that the component would need to communicate directly to the asset to send a control setpoint and would need access to grid monitoring data so that voltage issues could be identified. At present, the deployment of the databus and its connection to the Voltage Control (online) would provide the monitoring and the setpoint to be actuated by the simulation service generating the overvoltage. In future work, an intermediary piece would need to be built that extends the online voltage control service to allow it to communicate with an asset, but this was outside the scope of the project.

The Voltage Control (MPC) is cloud-based and relies on a stream of monitoring data for which the technician might be responsible for the monitoring component and ensuring that the PMUs or other devices are measuring, working, and transmitting to the databus or somewhere that the edgeFLEX platform could access the data. For the edgePMU to operate effectively, it needs to transmit at a high resolution with a high sampling rate. In this case, the technician would need specialist knowledge such as IT networking to enable this item to operate optimally and would require the DSO would to employ a specialist to manage the communications aspects.

A concern that the technician displayed regarding the edgeFLEX components involved the ability for them to override or elegantly shut off a component if it was having a negative impact on the local grid asset or critical system currently in place. Given that a microservice architecture is in use, some of the components can be shut off and the rest of the architecture can run independently, but during the project there was no formal process defined around what happens if a component is having a negative impact. Having this in place and having a mechanism for all actors to override or shut off a component that is having a negative impact on an entity they manage is paramount. This would need to be carried out on a service-by-service basis and consultation would be needed with the technical actor to define the criteria and process that would form the override or shutdown event.

While a large portion of the edgeFLEX components assessed are in the cloud, the technician queried the impact of the edgeFLEX component on both their work process and the systems that they currently have in place. In looking at the edgeFLEX services, the Voltage Control (online) and the edgePMU would have the largest impact as they would be deployed close to and be connected to assets or equipment. They may need to provide a secure place in the field for them to be deployed and may need to connect them to the assets or equipment. While day to day maintenance might not be necessary once correctly deployed, troubleshooting, and fixing issues would be necessary should they arise. This may require a change to current work processes and additional training, and a deployment and troubleshooting handbook for the edgeFLEX components and the platform in general would be crucial to its adoption.

6.1.2 The Compliance and Governance Focused Actor

In the analysis of this actor and their impression of the edgeFLEX components, it was noted that there were two types of actors here, the Chief Technical Officer (CTO) and the actor responsible for regulatory alignment. While both actors have different remits, their overarching goal is to maintain the Governance and Standards aspects of the company.

6.1.2.1 Chief Technical Officer

The Chief Technical Officer (CTO) within a company would have oversight on the management of technical aspects like ICT, skills alignment, and software standards. Their responsibility would be to ensure that the systems deployed in the organisation would be secure, maintained, built, and deployed to best practice and be architected in the best way to suit the company and its day-to-day business functions. In analysing the business scenarios, the CTO had questions on all components, and these questions were typically broad. They were focused on how they would support the implementation of the component, how it compares to existing components, whether it is secure and up to standard and how much it will cost up front and to maintain.

A sample of the questions the CTO posed were:

- What do I need to do to maintain this?
- Who is going to manage this?
- How much visibility will I have on this?
- How can it fit into my current system?
- Is it secure?
- What are the communications requirements?
- What expertise will I need to be able to manage it?
- Are there any alternatives available in industry?
- How much will it cost to maintain this?
- Is this compliant from a software standards perspective?
- Can I do this already without this component?

Like the Technical Actor, the CTO was concerned with the impact of the components on their system, their work processes and the technical team they manage. These actors share the same concerns but typically at different levels; while the Technical Actor would be focused on the specific grid or system, the CTO would have a focus on a broader context. While the CTO would still have oversight on the grid-connected components like the Voltage Control (online), Voltage Control (MPC) and the edgePMU, they would also look at the data interfaces and storage, the visualisation, the Policy Based Grid Management (PBGM), the interaction with internal and external systems, and the edgeFLEX platform. Therefore, the components assessed were the Voltage Control (online), Voltage Control (MPC), edgePMU, Databus, Monitoring, PBGM, FlexOffer, edgeFLEX Platform.

In terms of maintenance, the CTO was specifically concerned with who would maintain the edgeFLEX components and what would be involved in maintaining it. Their focus was centred on whether their organisation had the skills and capacity to manage it while maintaining their existing levels of productivity and standards. In analysing the Voltage Control (online), Voltage Control (MPC) and the edgePMU, it was identified that these components would need multi-layer management involving the grid, the control room and the cloud management teams. Each component would need either physical management at the edge in terms of connecting it to a grid asset, or cloud management as the component of a cloud application monitoring it or providing data would be deployed in the cloud.

From this analysis, the skills required would involve someone with an Internet of Things background so that the edge-to-cloud data transfer and the edgeFLEX Databus could be managed from a connectivity perspective. To manage the edgePMU and the Voltage Control (online), the organisation would need to upskill or employ a resource with electronic engineering expertise who would also have the expertise to interface with the relevant grid assets. The CTO would also need to ensure that the appropriate ICT team would be in place to deploy, configure and manage the cloud-based platforms like the Voltage Control (MPC), edgePMU, Databus, Monitoring, PBGM, FlexOffer and the edgeFLEX Platform components that enable the data transfer between services.

It was also noted that depending on how the components were offered to the System Operator, whether they were licenced as a managed service meaning that a company would operate and manage the platform or licenced to the System Operator as a self-managed platform, would greatly influence the impact within the organisation and greatly influence the cost of adoption. For this, a deeper analysis would need to be carried out based on the current skill levels within the organisation and around the definition of the pricing model of the platform and its components.

One of the remits of the CTO is to ensure that any component that is deployed within the organisation is aligned with company and industry standards from a cybersecurity, architectural, commercial sensitivity, and software perspective. On each of the components assessed, the CTO questioned its security level, which would need to pass certain security criteria and most likely be assessed by the cybersecurity teams within the organisation prior to adoption. Such an assessment would raise the TRL of the component while also removing a barrier for adoption.

While the services that require over-the-air transmission of data like the edgePMU, edgeFLEX Databus and the PBGM have TLS encrypted and authenticated connection methods, extra levels of security might be needed to adhere with company security protocols and standards. In large organisations, how a system is architectured would normally be defined by a solution architect, who would be an expert in the current system architecture and best practice. The solution architect would typically work under the CTO and would assess the edgeFLEX Platform and the architecture to ensure that it conformed to the standards laid out by the company.

These standards and solution architectures would typically be company-specific, and when analysed it was noted that the edgeFLEX components would provide adequate flexibility so that they could fit into a solution architecture given that they are built using a microservices architecture. From a software standards perspective, the PBGM component and the cloud data interfaces both internal and external in the platform have been built to a high standard, with software testing and continuous integration as a core component to the building of these components. In other cases, the fundamental research was the core focus, and some work would be needed to increase the level of testing on the code and code quality to raise the TRL to a level where they would be ready for adoption.

At present, the edgeFLEX components are deployed to self-hosted Linux servers, and with the migration of such components from the present research context to a business context, they are likely to move away from self-hosting towards a managed service, such as AWS, MS Azure, or Google Cloud. This provides some security to the stakeholders in terms of the reliability of the component infrastructure, the safety of the data and the cost reduction compared to having resources manage the hosting infrastructure on-premise. Given that the edgeFLEX components are designed to be portable and rely heavily on Docker to containerise the application, migration to cloud hosting platforms is easily achievable with minor configuration and code refactoring.

The CTO also queried the availability of proven alternatives in industry. While alternatives to edgePMU exist, none can provide the ability to perform edge computing on the raw data at source which will allow future uses cases to be built around the raw data. In the case of the edgeFLEX Databus, as an MQTT broker, alternatives exist such as the MS Azure IoTHub, IoT from AWS or IoT Core from Google. These alternatives allow IoT devices and applications to connect to them to publish data and subscribe to data streams, similarly to the edgeFLEX Databus.

The edgeFLEX components, such as the Voltage Control, can be configured or extended with middleware that would allow connectivity to such data interfaces. In the case of the PGBM, this is an innovative piece of technology that has been developed in edgeFLEX and there is nothing in industry at the time of writing that performs the same function. The voltage control algorithms developed in edgeFLEX are both the online and the MPC. The online control, consists in the direct control of the controllable assets to solve rapid voltage variations in the grid, only based on measurements data. Conversely, the MPC voltage control, which is interfaced with KIBERNet to provide flexibility offers, uses forecast values, which are also normally provided with a large time interval, to calculate control output within a future horizon. The result of the MPC calculation are flexibility offers (FlexOffers) that are provided to KIBERNet.

Ensuring that any new systems fit into existing systems is a key concern of the CTO and in the case of the edgeFLEX components such as the Persistence and Monitoring, these can be integrated into timeseries databases already in place and dashboards already in use or can be deployed and used in parallel as they do not affect the workings of existing components. Given that the PBGM will need to integrate into existing systems and that the Voltage Control will need data streams to operate and will need to send control signals, the impact of these components on the existing system would need to be assessed prior to implementation in terms of a potential conflict with other existing technologies or processes, or in terms of the lack of technological capabilities of existing assets of components to allow integration.

6.1.2.2 Regulatory and Corporate Governance Officer

The Regulatory and Corporate Governance Officer at the DSO would be responsible for setting and reviewing corporate governance policies in compliance with external regulatory requirements. External regulatory requirements in this case would include legislation that defines the role of the Distribution System Operator in the energy system and establishes their responsibilities and business courses of action. When analysing the business case, questions typically asked by the Regulatory and Corporate Governance Officer were about regulatory and security issues. Essentially, the questions were about regulatory implications of installing a solution, technical security, who manages the solution and data protection aspects.

An example list of questions asked is as follows:

- Are there any regulatory implications to installing this?
- How much visibility will I have on this?
- Is it secure?
- Who is going to manage this?
- Is GDPR an issue with this?
- What are the communications requirements?

Compared to the CTO, the Regulatory and Corporate Governance Officer naturally focused more on the regulatory aspects, including GDPR, but also raised questions about visibility, technical security, management, and communication requirements, albeit from a less technical perspective. For the Voltage Control (online), Voltage Control (MPC), edgePMU and the Policy Based Grid Management (PBGM) components, no regulatory relevance or hurdle could be identified, so that there is nothing to prevent integration into the system from this side. Still, it should be checked in in detail in other settings, as regulation usually differs between countries.

Currently, the Voltage Control (MPC) service becomes relevant from a regulatory point of view as remuneration for the provision of flexibility is to be paid to the owners of the assets. Instead of a remuneration, a payment by means of waived network charges is conceivable here, which is left to the respective DSO. In general, the use of aggregated power services such as the Voltage Control (MPC) is of regulatory relevance if the aggregated power is to be offered on flexibility markets, since the DSO must precisely check whether it is allowed to offer its flexibility at all and, if so, on which markets.

As far as GDPR is concerned, for the edgeFLEX Databus does not process user data, only telemetry data from measuring devices and performance specific data.

The question about visibility only concerned the FlexOffer concept. Here, it should be possible to allow the functionality to be confirmed and evaluated regarding regulatory framework, company standard and fairness aspects. In particular, the edgePMU, the edgeFLEX Databus, FlexOffer and the PBGM were explicitly mentioned in the questions about security. At this stage of development, the Platform is of a TRL that might not make it suitable for deployment as a “business as usual” tool. A security audit and refactoring on the outcomes would need to be carried out in the context of DSO business prior to its adoption. Given that this is a cyber-physical component, physical and cyber security assessments would need to be carried out and these would be specific to the location and the systems that are in place at the respective DSO at present. Regarding security of the edgeFLEX Databus, it is a secure component that has an encrypted and authenticated connection. For the edgeFLEX Platform, the Regulatory and Standards division needs to detail what they need to ensure compliance for according to their rules and policies.

6.1.3 Control Centre Operator

The role of the Control Centre Operator in the DSO centres on analysing the state of the network and putting mitigation measures in place to manage network events. It their responsibility that these events, such as over voltages and power outages, are identified, interpreted correctly, and mitigated against as efficiently as possible. Their main concern is the stability of the system which would be conveyed through displays where power levels would be plotted, events listed, and alarms highlighted. They would have systems and processes in place to address network issues and lessen the impact on the customer. These systems and processes would be formalised and very familiar to the operator and it is widely accepted by the developers of the edgeFLEX Platform that anything developed would need to integrate seamlessly into the existing platform our system.

The edgeFLEX services that were most relevant and of most concern to the control centre operator were the PBGM, edgePMU, Voltage Control (MPC) and Voltage Control (Online), FlexOffer and the edgeFLEX Monitoring.

The questions the Control Centre Operator posed where as follows:

- Can I override this if it is having a negative impact?
- How much visibility will I have on this?
- How can it fit into my current system?
- What problems will it solve for me?

Based on the nature of the questions, the Control Centre Operator was mainly concerned with the impact of the implementation of the edgeFLEX Platform and its components on the grid and the systems they use to manage it. One of the main questions they posed was around how they could override an edgeFLEX component if it was having a negative impact. This question was mainly aimed at the FlexOffer, the PBGM and the Voltage Control components as these have actionable functionality that can change the operation of the grid.

The PBGM component can disable a policy through the user interface, which will render the component calling that service unable to act on the policy and thus disable it. This is particularly relevant for the FlexOffer as the details that create the FlexOffer are stored as policies within the PBGM. The Voltage Control components currently have no user-driven override and must either be shut off or have the data streams that feed them stopped. This would not be seen as a suitable override mechanism and having a user centred override mechanism for each component would be an essential next step in its development if adoption of the Voltage Control elements of the platform is to be achieved.

The Control Centre Operator also queried the impact that the deployment of the edgeFLEX platform and its components would have on their system, their work process and on tasks that they manage from day to day. In general, an instantiation of the platform for the Control Centre Operator's perspective might only consist of some additional monitoring dashboards. How they would be presented within the existing system would need to be reviewed on a case-by-case basis, and in most cases the data to be shown would be integrated in the existing monitoring dashboards.

It was also identified that the Control Centre Operator would have no role in the management of the platform within their day-to-day tasks, but feedback would likely be sent to the CTO to ensure that the platform is fulfilling the needs of the Control Centre Operator. One exception to this is the Voltage Control (MPC), which would require some method to engage with the prosumer. In edgeFLEX, the PBGM and the FlexOffer protocol was used, which are aligned to participating nodes on the network. In the event a system was in place that managed voltage in the overall system there might be a conflict and an alignment may be needed from that perspective. The operator may also need to be aware of the FlexOffer protocol and have a list of the participating nodes.

It was identified that the edgePMU component that provides the most benefit to the Control Centre Operator. It can provide high quality data at the edge of the network at low cost so it can be deployed in at scale. This would provide a granular visibility of the network and provide the operator with an extra set of measurements that may alert them to an impending larger issue on the grid that they manage.

6.1.4 Chief Executive Officer

As the highest-ranking executive of an organisation, the role of the Chief Executive Officer (CEO) covers several responsibilities which have wide-reaching impacts on the organisation. Broadly speaking, these responsibilities include major decision making regarding corporate direction, managing overall company resources and operations, and serving as a point of communication with stakeholders and board members. The primary concern of the CEO is the efficiency and management of company resources, and the profitability such that the organisation is sustainable in the long-term to continue operations and attract and sustain stakeholder involvement and revenue streams. Their responsibility would be to ensure that systems deployed within the organisation benefit and support the company vision and operations and have a positive impact on profitability and revenue. From the analysis of the business scenarios, the questions of the CEO overlap somewhat with those of the CTO, though less focused on the technical aspects of deploying the system within the organisation, and more towards the cost-benefit analysis and business impact such a system would have on the organisation.

The questions the CEO posed were as follows:

- What do I need to do to maintain this?
- How much will it cost to maintain this?
- How can I get remunerated for this?
- How much visibility will I have on this?
- What problems will it solve for me?
- How much will it cost?
- How will my stakeholders view this?
- Will this impact my customers?
- How much can I make from it?
- Can I do this already without this component?

The CEO was concerned with the impact of components such as the edgeFLEX platform, PBGM, edgePMU, FlexOffer and Voltage Control from a cost and business impact perspective. The CEO queried the impact of the edgeFLEX platform in terms of cost, maintenance, the problems the platform aims to solve for the organisation and the need for the system to solve these problems.

Regarding the individual components, questions centred on the impact Voltage Control would have on customers as this service would directly actuate on the grid in an automated and dynamic fashion, therefore these actions need to be considered from the perspective of the end customer.

In addition, the CEO considered the view of stakeholders regarding the implementation of additional assets such as the edgeFLEX platform and the edgePMU, which would have a direct financial impact in terms of cost of purchase and deployment which would scale depending on the level of implementation on the grid. The CEO also had queries regarding renumeration when considering interaction with the flexibility market via the FlexOffer component, and the specific problems which components such as the PBGM system look to solve.

As whole, the CEO is concerned with the view of the organisation as whole and the impact these components have in terms of financial impact, their profitability, the impact they have on the customer, and the view of the stakeholders who have a direct stake in the organisation's sustainability in the short and longer-term.

6.1.5 Grid Planner Assessment

The distribution grid is undergoing constant expansion with the addition of new commercial, industrial, and domestic customers. This, combined with the changes to the energy industry is driving a need to ensure an accessible, affordable, and environmentally conscious energy supply. The role of the Grid Planner is to determine optimal methods of connection for new customers, to define the reinforcement requirements that allow for the demand growth on the system by utilising load-flow, to assess the impact that new loads will have on the grid based on the operation of the network, and to propose mitigation against these impacts in accordance with defined planning standards. With these responsibilities in mind, the Grid Planner would need to ensure that systems deployed within the organisation do not have a negative impact on grid and network planning, to assess the impact they would have, and to consider reinforcement and impact mitigation when planning new loads on the network. From the analysis of the business scenarios, the questions of the Grid Planner centre around the impact the system would have on their role in terms of grid planning.

The questions the Grid Planner posed were as follows:

- Can I override this if it is having a negative impact?
- Who is going to manage this?
- How much visibility will I have on this?
- How can it fit into my current system?
- What problems will it solve for me?
- What is the impact on the grid likely to be?

From the perspective of the Grid Planner, the main components of concern were the edgeFLEX Platform, edgeFLEX Monitoring, edgePMU, FlexOffer and PBGM system. As described above, the Grid Planner is directly concerned with analysis of the grid to support network expansion with consideration for mitigating network impact; therefore, services such as the Voltage Control, FlexOffer and PBGM system, which have a direct impact on the operation of the grid, are of key concern. The Grid Planner posed questions around the impact of these components, how they will fit into the current system and whether the Grid Planner can override their operation if they are having a negative impact on the grid.

However, one of the key findings was how such components can support the Grid Planner when considering the proliferation of RES into the grid. As these sources of energy are not necessarily stable, the ability to balance the grid at a local level by leveraging technologies such as Voltage Control (MPC), coupled with engaging flexibility closer to the grid, for example, will enable a higher penetration of RES and therefore support the move to a more carbon neutral energy grid.

Due to the increased visibility offered by the edgePMU and edgeFLEX Monitoring, the Grid Planner posed questions around the level of visibility and access they would have to these components and the problems that these components would solve in terms of assessing the impact new loads may have on the network. Altogether, the concerns of the Grid Planner focus on the practical impacts that edgeFLEX components in terms of integrating them into their current systems and the impact they will have on the grid as this directly effects their ability to effectively plan new loads and assessing the required reinforcement and mitigations needed.

6.1.6 Prosumer Assessment

Prosumers play a vital role in the assessment of VPP 2.0 scenario. They allow their assets to provide flexibility to the DSO for the management of the grid. Prosumers, both residential and commercial, are commonly known as consumers who can produce electricity as well. Residential prosumers often produce using their PV asset or with the potential for vehicle-to-grid applications for their battery electric vehicle as well. Although the term *prosumers* is used in this section, flexible consumers as well as prosumers with stationary energy storages, i.e. battery storages, are part of the group of flexibility providers. It became clear in the assessment that many of the questions relevant to other stakeholders or stakeholder groups are also relevant to prosumers when faced with the decision to make their assets available to be managed in a flexible way. The questions involve maintenance effort and costs, remuneration, data privacy and security, and their influence on the asset when it is providing flexibility.

An example of questions is as follows:

- How can it fit into my current system?
- What is the impact on my asset likely to be?
- What control do I have over my asset and how it participates?
- How much does it cost?
- Are there any alternatives available in industry?
- Can I do this already without this component?
- What are the communications requirements?
- Is it secure?
- Is GDPR an issue with this?
- Who is going to manage this?
- What do I need to do to maintain this?
- How much will it cost to maintain this?
- How can I get remunerated for this?
- How much can I make from it?

As flexibility provisioning in the VPP 2.0 scenario is realised through the flexibility trading application which uses FlexOffer to formulate a flexibility offer, this assessment will focus only on this application. An assessment of the various applications assessed for the other stakeholders is not needed.

The current prosumers system will be extended and enabled to participate in flexibility trading. This can be delivered through a software update of the asset management system or as an interface which enables the asset to create FlexOffers for the flexibility trading application as well as an improvement of communications if needed. The question about the impact on the existing assets was considered important as it should not have any negative impact on the functionality of or present a danger to the assets. Prosumers asked during an open day event in the trial site in Wunsiedel confirmed that the activation of assets for grid management purposes in a manner that would not have any noticeable impact on its regular usage, e.g. an electric car, would be considered acceptable. Prosumers still wanted to know about the control they would have over the asset and how it participates. This can be decided by the asset owner themselves and adapted in the FlexOffer management system if desired.

Questions related to investment costs, alternative systems available and whether participation was possible without that system were asked. As the provided flexibility should be of use to the DSO for better and more efficient grid management, investment costs would be absorbed by the DSO in this case. As the systems of the DSO and the person managing the asset need to be compatible, it has not been possible to use any available solution on the market, as interoperability with the existing system cannot be guaranteed and needs to be assessed and developed in further detail. Realisation of flexibility provisioning without the use of the FlexOffer application by the DSO is considered not possible.

Questions about security of the system were asked by prosumers, which mainly focus on cybersecurity aspects as this system is based in software and algorithms. The creation of FlexOffers is realised within the energy management system of the asset or the home energy management of the prosumer and therefore only information about actual flexibility, the respective offering of the flexibility and the location of it in the grid will be communicated to the "outside world", and in pseudonymised and encrypted manner. As discussed in Section 6.1.2.1 regarding the hosting of the edgeFLEX platform and its modules, the system is at present developed in a research context. When moving towards a business context, hosting would most probably move to managed services for cloud solutions resulting in guaranteed security from some of the most experienced leading companies. Considering this move to managed services, the direct follow-up question was about data protection and privacy, which the edgeFLEX partners are aware of the particular importance of to residential prosumers and we make every effort to ensure that no user data itself will be processed.

Questions about responsibility of management of tasks and the cost of maintenance were asked on the Flexibility Trading solution. The answer is that the respective DSO would take care of these as it is in their interest to have all assets in use to remain updated. The questions of whether the system can be overridden if it has a negative impact was asked and how much visibility the prosumer will have on the system were asked. This would be dependent on the agreement that the DSO would have with the Prosumer and on the maturity of the engagement and the systems in place between the DSO and the flexible asset or asset management system.

The question about remuneration for offering flexibility was not asked by all prosumers. Some residential prosumers, e.g. those with PV systems installed or BEVs which are charged at home, would even provide their flexibility to the local DSO for free if their assets would not be damaged, would not age faster and if they would not be affected in their daily lives. Others clearly expect some kind of remuneration. Through the Flexibility Trading solution of edgeFLEX, the most cost-efficient flexibility providing assets will be chosen to solve existing grid management problems. This does not inherently include billing or payment for flexibility provisioning but rather enables the DSO to track which asset provided flexibility when and how often. By tracking those activations and times, the DSO has the option to remunerate the prosumer by providing a discount on future grid fees, for example. Several constructs for remuneration are possible and need to be developed by the respective DSO, ideally with input from their customers. The question on how much can be made from it depends very much on various aspects, such as the assets and the resulting flexibility available from prosumers, on the remuneration constructs with the DSO and on the state of the grid and how much flexibility is needed.

6.2 Virtual Power Plant Operator

The role of a VPP operator is to aggregate and manage their own and/or third-party assets. Their main concern is optimising their portfolio to maximise their revenue and that of their customers, thereby making them more competitive on the market and increasing their attractiveness for other potential customers. The VPP operator has duties relating to not only its customers but also towards its shareholders. In addition, the existing processes and different systems' security imply stringent rules for the integration of new systems to their own.

The edgeFLEX services that are most relevant and of most concern to the VPP operator VPP Optimisation, the Intraday Market Modelling, the Stochastic Weather forecasting and the edgeFLEX Platform in general.

The questions the VPP operator posed were as follows:

- How much can I make from it?
- Can I do this already without this component?
- Is it secure?
- How much does it cost?
- What is the impact on my asset likely to be?
- Is there any regulatory implications to installing this?
- What control do I have over my asset and how does this participate?
- Will this impact my customers?
- How much visibility will I have on this?
- Can I override this if it is having a negative impact?
- Have I any alternatives available in industry?
- What is the licensing model on it?

The main concerns of the VPP operator revolve around the additional profitability incurred by the edgeFLEX services as well as the integration of the system into their own, with security being of utmost importance. When considering the actor perspectives within the VPP operator, three were identified, the CEO, CTO and Trading Operative. The primary focus of these actors is centred more towards the trading aspect of the edgeFLEX services, rather than the strictly technical as opposed to the System Operator or DSO.

6.2.1 CEO (Head of Trading)

Similar to the CEO as described in section 6.1.4, the VPP Operator CEO has broad responsibilities that guide the direction of the organisation in terms of decision making, the company vision and is concerned with the long-term sustainability of the company. When considering the perspective of trading, the CEO (Head of Trading) is responsible for overseeing the companies' trading activities, trading positions, and evaluating these activities with a view of risk management and ensuring profitability. In addition, the CEO is concerned with the regulatory compliance, from both a local and national level of the organisations trading operations.

With these factors in mind, the questions the CEO (Head of Trading) posed were as follows:

- How much can I make from it?
- Can I do this already without this component?
- Have I any alternatives available in industry?
- Is it secure?
- Will this impact my customers?
- What is the licensing model on it?
- Is there any regulatory implications to installing this?

From the questions posed by the VPP Operator CEO, they are interested in the capabilities when considering a move towards the VPP2.0 and how solutions such as edgeFLEX can support this evolution within the organisations. When considering the edgeFLEX services, several key concerns arose from the CEO perspective. Firstly, the question of financial impact was forefront, with the profitability of integrating the system considered the most important factor. Related to this, the CEO was concerned both with the cost of deploying the system and whether the issues the edgeFLEX services look to solve would benefit their specific use-cases, whether industry alternatives are available and the advantages of the edgeFLEX solution vs. these potential alternatives. The question of security was also highlighted both from a communications and operation standpoint.

In addition, when considering the impact that edgeFLEX services such as the VPP Optimisation and Intraday Market Modelling will have on trading activities, the question of regulatory effects was raised by the CEO. As described above, a key concern of the CEO is ensuring that trading operations within the organisation are within the bounds of the regulations set out at a local, regional, and national level. Furthermore, the CEO queried the licensing and aspect of the solution, when considering integration of the edgeFLEX services. From the perspective of the VPP operator, the license model in place for such a solution is vital to understanding the motivations of the supplier and in determining their credibility and sustainability of their business model and from this gauge whether it is valuable to engage with them, or alternatively to pursue an in-house solution.

6.2.2 CTO (Head of Trading)

As described in section 6.1.2.1, the CTO is concerned with managing the technical aspects within the organisation, ensuring that any systems or solutions integrated into the organisation are robust, secure, and maintainable. Many of the questions posed by the CTO when considering the edgeFLEX services targeted at the VPP Operator revolved around the security when considering integration of the services and the level of visibility to evaluate the effects of this system.

The questions posed by the CTO were:

- Can I do this already without this component?

- Have I any alternatives available in industry?
- Is it secure?
- How much visibility will I have on this?

Like the CEO, the CTO posed questions relating to the need for the edgeFLEX services and whether the problems they look to solve can already be done with the systems already in place. From the CTO perspective however, this is more from a technical aspect rather than a purely cost and company vision perspective, as they are responsible for provisioning the appropriate ICT resources and personnel to deploy, integrate and maintain any edgeFLEX services the VPP operator would look to leverage. Related to this, a key concern of the CTO is the security of the system, due to the nature of the VPP Operators activities, such as trading, the need to ensure robust and secure communications and cybersecurity to protect commercially sensitive data and information is vital. To enable the continual evaluation of the solution by these criteria, the CTO queried the level of visibility that they would have on the system to directly view the real time impact from an operational context.

6.2.3 Trading Operative

The role of the trading operative is the management of the organisation's portfolio, interacting with the market and making decisions which look to maximise value while minimising risk to the company and its stakeholders. To operate within their role effectively, the trading operative needs access to tools and information to support their decision-making processes, such as understanding various energy markets and timeframes (day-ahead, intraday etc.,), interpreting meteorological data and weather patterns when considering renewable sources, and energy risk management, regulatory and compliance requirements.

The questions posed by the trading operative were as follows:

- What is the impact on my asset likely to be?
- What control do I have over my asset and how does this participate?
- How much visibility will I have on this?
- Can I override this if it is having a negative impact?

As the trading operative is responsible for decision making related to trading, optimising assets and minimising risks, the questions posed related much closer to the assets themselves and the effects of services such as those proposed by edgeFLEX will have on these assets.

Crucially, the trading operative was concerned with the level of visibility of the system, to see in real-time, the effect on operations and value that the outputs of VPP Optimisation, market interaction and stochastic weather forecasting generate, as these outputs would have a direct impact on the decisions the trading operative would make daily. In addition, the trading operative queried the level of control they would have on assets in terms of how they would participate on the market, and the capability to override the system if it was determined to have a negative impact. In this scenario, these would relate to the flexibility schedules generated by the system and whether these are optimal as determined by the trading operative, and if not that they can be overridden.

7 Comparative Analysis of Business Scenarios

To compare both the business scenarios in a like-for-like way is difficult, as they have different sector actors, different societal impacts, different business goals and the participating organisations and individual stakeholders may have different levels of digitalisation and technological capabilities. However, since both underpin the evolutions of the VPP concept, it is possible as they both can be compared in terms of the technological landscape and how they differ technologically, how they impact on society if they were implemented at scale and evolve further, how the regulations support or inhibit each evolution and how they both differ from a business perspective. The following sections analyse both, from the perspective of VPP1.1 and VPP2.0

7.1 Technological

In the previous sections, the technical solutions have been assessed at the level of the business functions within the sector actors in which they will be deployed. From the perspective of VPP1.1, the implementation of the VPP Optimisation, Stochastic Weather Forecasting, and Intraday Market Modelling services within their organisation would be a straightforward process, if it made enough business sense. This means that they are reusing data streams that are already present and extending their portfolio management tool suite for these services. The complexity for the implementation of VPP1.1 comes if the TSO engaged with the VPP Operator to provide Inertia and Frequency Control across their portfolio to enable the TSO to better balance the transmission grid. This would require a technological enhancement within the VPP Operator's hardware at a substation and asset level to embed frequency control, inertia estimation and inertia allocation in the field.

In assessing VPP2.0 under the same criteria, this change would be incremental in technological terms, though, as in the case of VPP1.0, a larger technological shift at the DSO level and at the prosumer level would be needed in the event where the company makes a business decision to implement VPP Optimisation, for example. From a technological perspective, the implementation of VPP2.0 requires large penetration of controllable RES at the consumer level, a high coverage of monitoring at the LV level, a method for the DSO to engage with the prosumer in terms of engaging flexibility from their assets and edge computation capabilities so that the relevant control can be deployed close to the asset. These require a lot of changes from both the DSO and the prosumer, but it does mirror an incremental evolution which SWW are making, and which could be rolled out at scale all be it at different levels of implementation, when proven.

In summary, VPP1.0 enhancement of the VPP Operator's portfolio management with VPP Optimisation, Stochastic Weather Forecasting, and Intraday Market Modelling could be implemented quickly without a large technological extension to their current operation if it made business sense. However, if the VPP Operator decided to offer Frequency Control to the TSO as a service then a large technological shift would be needed. From the perspective of VPP2.0, this change could be more incremental with varying levels of implementation capable of being deployed in clusters, as in SWW, but large technological advancements would be required to both the DSOs' and the Prosumers' systems for this to occur at scale.

7.2 Societal

From a societal perspective, it is difficult to compare both scenarios as one has no direct impact on society from the outset, and the other has the potential to change how society views energy consumption and production. For VPP1.1 there is no direct impact on society unless operators move to provide services to the TSO with Frequency and Inertia support. Indirectly, a larger portion of RES supplying their energy and while lessening the reliance on gas, coal and oil thus providing a natural decoupling of their energy costs from rising fuel prices would be a long-term societal impact.

For VPP2.0 the potential impact on society is far greater mainly because it is centred on providing a stable energy supply to the consumer by utilising the flexibility that is available through RES and controllable load at the household and in the community. This evolution of the VPP has the potential to cause a large societal shift in how they consume power and how they view energy security by providing them with the tools and incentives to deploy RES and engage with the DSO to offer flexibility. It also offers the potential for society to reshape their typical consumer-supplier relationship with the grid actors where the consumer who has RES and controllable load is considered part of the solution rather than the problem, and the energy supplier and the DSO are seen as an enabler to monetising the customer's assets and rather than an inhibitor. At a micro level, VPP2.0 could de-risk the investment in RES for the citizen and enable them to better manage their own energy security. At a macro level, VPP2.0 would provide for a larger proliferation of RES among businesses and householders and thus provide cleaner and cheaper energy for society while unlocking community business initiates like peer to peer or electrification of community heating using RES if adopted at scale throughout the energy sector.

7.3 Regulatory

VPP1.1 does not currently need any regulatory change in the edgeFLEX implementation, as it is an extension of their portfolio management. In future if the VPP was extended to provide frequency and inertia services using all types of sources, conventional and RES. The regulatory authorities belonging to different European states already had initiatives and even secondary legislation to regulate the operation of VPPs. The main challenges and implicit additions to the regulatory framework aim at the integration and attribution of an active role in grid management of the VPPs together with the energy community and small assets owners. Likewise, the implications of using ICT solutions in the provision of ancillary services must also be taken into account from the perspective of updating the regulatory framework. From a regulatory perspective, VPP2.0 would need some regulatory change for it to be viable. Small scale downstream DSOs, like SWW, have the capability to become a Balancing Responsible Party due to their size and the nature of their assets and customer base, and that will allow them to engage with the flexibility available in the community. However, it is not possible to deploy it at scale and with larger DSOs, and changes to the regulations on Voltage Control and Flexibility Trading are needed.

7.4 Business

The business impacts of VPP1.1 have been proven throughout the ALPIQ trials, and it was shown that using VPP Optimisation and assets like battery storage can have benefits for the company and the full potential can be reached if further enhanced and validated in ALPIQ's "business as usual". This would lead to increased profitability of RES asset investment.

The business impacts for VPP2.0 are broader and more complex. The DSO can avoid penalties by ensuring that their grid stays between operational limits. Limiting asset life shortening by solving voltage issues at source and early is another impact to their business. They can optimise their own RES assets by engaging with the system flexibility available at a prosumer level to provide a stable energy supply, which would be less likely to be impacted by heat and transport electrification than a traditional grid would be. Prosumers, individual or organised as an Energy Community, can increase profitability to their RES and battery asset investment by participating in flexibility provisioning to their DSO as they would get additional remuneration. The use of local flexibilities is more efficient and leads to lower grid management costs. This in turn can lead to lower electricity costs for end-customers.

8 Study of the edgeFLEX Solution in a Utility Focused Business Case

In Section 2, we described VPP2.0 and how it can form part of an incremental evolution for the energy sector that views flexibility systemically. Our partner SWW, a small DSO in Wunsiedel, is looking to view flexibility systemically and is doing this by using the outputs of the edgeFLEX project to perform congestion management through engagement with the Energy Community assets, enabling them to move towards VPP2.0. The following sections detail how SWW's situation is leading them to the need to evolve, the business case that frames the evolution, their overall vision for VPP 2.0 in SWW and the barriers that will need to be overcome for it to be fully realised.

8.1 SWW Current Situation

8.1.1 Distribution System Operation

In Wunsiedel, as DSO, SWW draws its electricity from the upstream DSO (Bayernwerk AG) at the transmission station, lowers the high voltage into medium voltage, which is then distributed to all parts of the distribution grid within the jurisdiction of the SWW. The role of SWW is to ensure the load within the entire grid is balanced and operations run smoothly. This includes, among other actions, feed-in management measures affecting all generation systems owners, congestion management and data and information exchange between SWW and system owners and between SWW and the upstream DSO/TSO.

8.1.2 Energy Retailer

SWW takes up the role of a retailer, purchasing energy directly from a balancing service provider Uniper, who manages the balancing area of the Wunsiedel county. SWW, as a retailer, uses a direct marketing model, in which energy is being purchased directly from RES-owners (prosumers), who are remunerated in accordance with the remuneration agreement as stated in the German Renewable Act (EEG). This balancing group purchases the energy generated by the SWW generation systems, wind turbines and WunBio, to sell it in the local electricity product green electricity from the region, communal and transparent initiative in Wunsiedel, the "Fichtelgebirgsstrom".

8.1.3 Local Flexibility Aggregation

During the GOFLEX project, SWW, alongside INEA and other GOFLEX consortium partners, have established a new and innovative flexibility infrastructure. Participating prosumer agreed to certain conditions and in exchange, the new Home Energy Management System (HEMS) developed within the GOFLEX project was installed. Participants could now join the local flexibility market and generate additional income. SWW will provide energy in times of high demand and purchase the energy surplus in times of low demand. Industrial prosumers can be involved as well and have a Factory Energy Management System (FEMS) installed for that purpose. All flexibility-offering consumers could trade their flexibility directly with the SWW as an aggregator or get the opportunity to offer it directly to the local flexibility trading platform, if the flexibility is big enough.

8.1.4 RES asset owner and operator

SWW also owns and operates several DRES plants and trades those via Lumenaza, a BRP specialising in RES, trading the electricity via the local German market bonus scheme (remuneration model in subsidised direct marketing under the Renewable Energy Sources Act) and in accordance with the German renewable energy act remuneration framework. This asset portfolio consists of wood-pellet CHP, wood gasifier, Solar PV and Wind and combined have a capacity of 48MW.

8.2 SWW Business Future Case Description

8.2.1 SWW vision towards VPP2.0

Rather than the traditional VPP, which relied on large assets, VPP2.0 allows smaller assets to be included and as a resulting in increased citizen participation and higher acceptance.

As VPP2.0 offers a much more transparent view of events within the grid alongside the possibility tackling various supply issues, fast and slow, including even the smaller prosumers, this approach is very much sought after. SWW shall move forward towards and promote the implementation and integration of this concept to ensure a more efficient chain of supply, energy safety and reducing redundant environmental impacts from the energy sector. In addition, since SWW became a full BRP for its area, alongside implementing the edgeFLEX solution, a new round of planning took place. SWW will assume additional roles, namely DSO, RES owner, retailer, and aggregator. Balancing the grid involves participating in the energy exchange markets, while also using the local Energy Community and VPPs for physical balancing purposes. This will be monitored and controlled with the help of the newly installed edgePMU, allowing more enhanced transparency on grid events as well as utilisation of ancillary services schemes for voltage control and congestion management, with the so-called “Redispatch 2.0” system. This system allows remote control of certain generation assets for eliminating grid bottlenecks in the area.

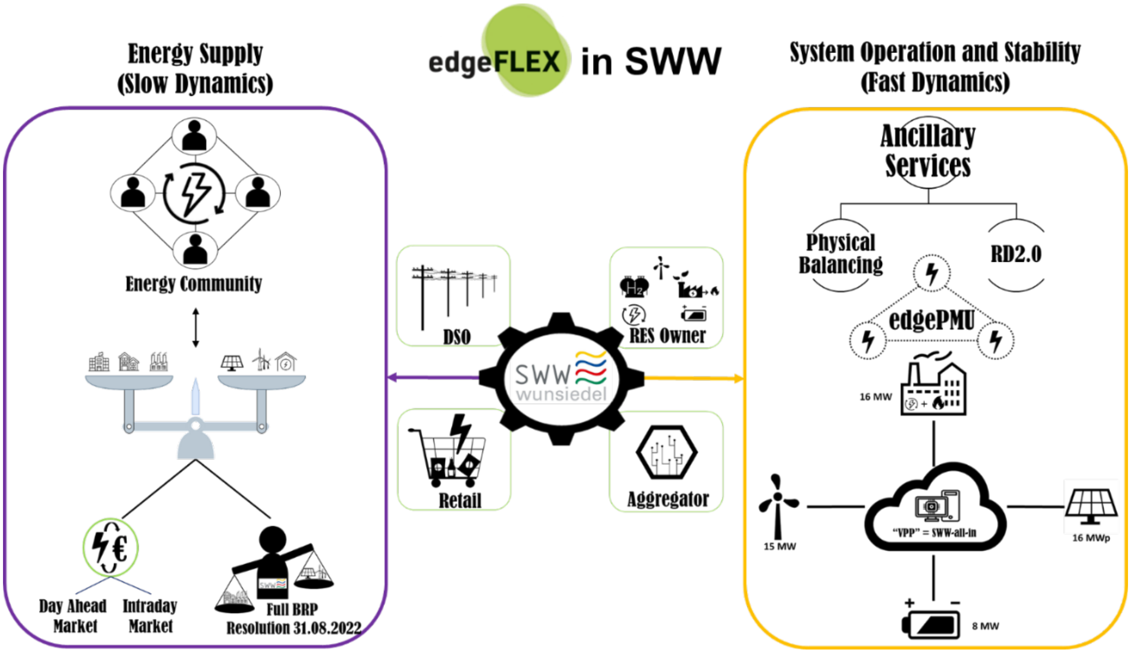

Figure 8-1 - SWW New Business Case Schematic

8.2.2 Changes needed to SWW current situation

SWW has already started integrating a new initiative alongside the edgeFLEX solution, the so-called Future Power Plants (“Zukunftskraftwerk”), which will be combined with the integration of the local Energy Community. This approach aims at singular “energy cells” formed by each of the participating houses acting as individual power plants with storage, which will be aggregated by the DSO or an aggregation entity via IoT platforms. Those cells will be consuming their own generation as much as possible, will be able to trade flexibility between themselves and will offer flexibility services as an aggregated entity (VPP) to other parts of the grid – local, regional, and national levels, tackling fast and slow dynamics issues.

Moreover, SWW are participating in a cross-regional initiative, in which new projects for installing new RES will begin. This initiative consists of 19 cities and energy provision companies and allows citizens as well as entire communities to participate in those projects and become owners of such assets.

To win investors and operators for virtual power plants, full balancing group responsibility must be transferred to the virtual power plants. Balancing groups are the basis for network management ("schedule management") and only plants under the Renewable Energy Sources Act are released from the balancing group tasks as "balancing group for the Renewable Energy Sources Act", since these are performed by the transmission System Operator. The balancing group model reduces the amount of energy required to compensate for errors in the wind energy forecast and thus the costs of virtual power plants.

Putting the idea of virtual power plants into practice requires powerful information technology, which must be available across the board in the power grids. This requires a significantly expanded use of the information and communication technology infrastructure and new service offerings from the operators. Distributed and central generation must coexist in the future. In the long term, the power grid must be expanded in such a way that the supply is secured even if the Renewable Energy Sources Act and combined heat and power generation are not available.

Furthermore, so that no green electricity must be wasted in the event of future overproduction at peak times, more and new types of storage are required. This requires investments in the millions for research into storage technologies.

8.2.3 Changes needed to SWW & Stakeholder Relationships

SWW is conducting workshops and working on citizen engagement and involvement in the power supply process. Initiatives are already taking place, including cross-regional activities and community-ownership models.

This is however limited due to regulations. Once the concept of Energy Community will be accepted and approved, stakeholder-SO relationships can prosper and achieve even more.

8.3 Current Limitations and Changes Needed

8.3.1 Regulatory

Most crucial regulatory limitation involve the implementation and integration of the concepts of Energy Community and Peer-to-Peer trading into the power supply process.

Implementation of VPP on a regional level in Germany cannot be done, as there are currently several obstacles to do so, mainly the lack of mechanisms to remunerate flexibility on the local level. Furthermore, exemption form fees, levies, apportionment, and other surcharges are still applicable, making it hard for establishing a mechanism for marketing and trading of regional flexibility. In any case, VPPs must have the ability to fulfil the grid's requirements, in particular the frequency as defined in the different power grid operations and market regulations.

In 2017, Germany introduced the Market Master Data Register (Marktstammdatenregister - MaStR) which is the official register for master data of the electricity and gas market used by authorities and market players in the energy sector. It is the Internet portal through which the players in the German electricity and gas market enter their master data and the master data of their plants. As an online database, MaStR represents a central directory of energy industry data. The goal of MaStR is to create an all-encompassing regulatory registry that maps the electricity and gas markets, simplifies private-sector and regulatory reporting, and increases data quality and transparency.

Market players, including operators of renewable energy systems, are required by law to register themselves and their plants, meaning all operators of solar plants, CHP plants, and stationary battery storage systems as well as wind energy plants or large power plants. This might be seen as an excess process with many bureaucratic steps. To be allowed to trade energy in Germany, any party in question is required to submit a formal admission request. These requirements can be found on the EEX Exchange Rules frame document from the European Energy Exchange (Exchange) .

For citizens to be allowed to participate on the energy exchange markets, they need to be properly aggregated. Remuneration schemes for renewable assets can be either with accordance to the German Renewable Energy act (EEG) or they can in a different trading scheme such as direct marketing or bilateral agreements of purchase (Power Purchase Agreement - PPA). If remunerated with accordance to the EEG, the type of the generation unit, its size, and the year of putting into operation are the main factors affecting the amount of reimbursement. For direct marketing, renewable based power generation units, remuneration occurs via a market premium in the amount of these factors in accordance with the EEG. From 2016, all new units with minimum nominal power of 100 kW(p) are obligated to sell via direct marketing. For VPP purposes, the so-called Mertit-Order-Curve as well as the Levelized Costs of Electricity (LCOE) illustrated in Figure 8-2 need to be adhered to.

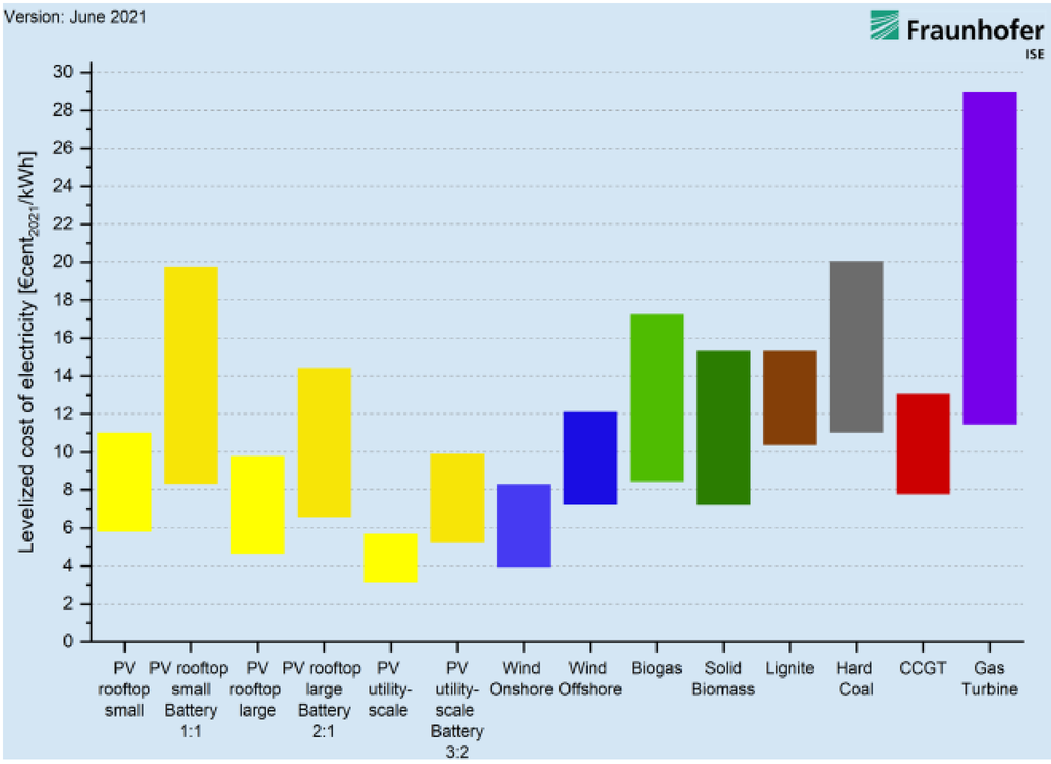

Figure 8-2 – LCOE of renewable energy technologies and conventional power plants at locations in Germany in 2021.

For a VPP to be able to participate on the market with as few disturbances and hurdles as possible, there is a need for standardise the methods of payment. This will also avoid the possibility of discrimination. Bilateral agreements, or PPA, for a certain and exact amount of power are recommended.

8.3.2 Technological

Energy provision and aggregation require advanced management systems, as control and data exchange play an important role. This is typical of the digital transformation that the sector is going through to make the supply chain more efficient. While advancements have been made in recent times, there are areas that require further digitalisation to enable a full implementation of VPP2.0. Several technological changes were identified by the research in utilising flexibility at scale using small assets at the Low Voltage (LV) level, where the goal is to have no green energy wasted. The main technological changes identified are as follows:

Communication

To fully harness the flexibilities in an efficient manner, it is vital to have the ability to communicate to the edge of the grid in a reliable and stable way. Traditionally, fibre would be used to provide stable, reliable, and secure communications, but this would not be feasible to deploy right to the household. In edgeFLEX, we have shown that the existing and new features of 5G can enhance the communications for the sector and greater coverage would need to be achieved. This could be managed with a dedicated 5G network for the DSO where they could manage the coverage and rollout where the need arises.

Ability to Control

To make flexibility a core function of the full system, the ability to control is vital. This control could take various forms, simply turning on or off a device for a period of time to consume or conserve energy, charging or discharging a battery to either provide power to the grid or store power when there is a surplus of green energy, or providing setpoints to a smart inverter to ensure that operational limits are maintained. While these controls all may align to the same goals, they all have different technological requirements. This is further complicated by the range of devices which may have varying levels of technological readiness in terms of the ability to communicate and in terms of their ability to receive the control. While a lot of research has been done on this aspect, namely in the RE-SERVE project where consumption was controlled and setpoints sent to inverters was carried out, to achieve a level where this would be possible at scale a large standardisation piece on all control at LV level would be required.

Storage

To ensure that the goal of having no green energy wasted is realised, storage is seen as an important component. This involves battery storage, which must be balanced at a prosumer level and at a DSO level, where the storage at prosumer level would play a part at the local level and the larger storage would play a role in solving larger system events. Storage is currently expensive, and a significant investment would be needed to ensure that it is available at a sufficient scale to reach this goal.

Monitoring

An important component of VPP2.0 is monitoring at the edge with a view to identifying and solving problems as close to where they are occurring as possible. In recent times, monitoring at the MV level has become widespread and smart meter rollouts have provided data at a household level, but there is a gap in monitoring at the edge. This means that local level issues are seen at a system level, and even if the assets could be controlled at a local level to solve the issue without identifying the issue and its location as close to the source, a delay in inferring the source at a system level could occur. Monitoring devices are typically expensive and rolling them out at scale would involve significant investment which may outweigh the benefits. In edgeFLEX, the low cost edgePMU rolled out at scale offers a solution, as it would provide enhanced monitoring at a local while also providing some edge computing capabilities where potential control techniques could be distributed close to the source.

8.3.3 Societal

Core to the adoption of the solutions that would enable the evolution of the VPP towards the energy community assets is the need to ensure that it is inclusive and societally accepted. It is arguable where the largest and most widespread change is needed for several reasons. These reasons include the current market structure, where the relationship between society is largely a consumer-supplier relationship which may lead to scepticism in adopting techniques or schemes, such as load shifting and peer-to-peer, that require alterations to that relationship, particularly when proposed by industry. Furthermore, a lack of knowledge and awareness around the need to engage with the flexibilities available at all levels of the energy sector can lead to further scepticism. To alleviate this, an enhanced level of user engagement is needed to promote awareness, increase their understanding of the technologies and their need, and reassure them as to the motives of industry, the changes needed to the market and to their consumption patterns.

Constantly rising energy prices require a cost-optimal integration of green electricity in order not to overwhelm consumers and to ensure their acceptance in the long term, and present investment in RES and the electrification of heat and transport is a limitation to adoption of VPP2.0 at a large scale. Such technologies are expensive, and viable funding and incentivisation schemes need to be put in place to de-risk this investment. This coupled with an increased observability provided to the consumer through smart metering and price differentiation which is shifting usage to off peak times requires a market change to include the consumer and the prosumer so that they can get a return on investment.

9 Conclusions

Large VPP Operators like ALPIQ are looking at smarter ways to manage their asset portfolio, and to address this, they are employing techniques like Intraday Market Modelling, Weather Forecasting and VPP Optimisation, which are driving an evolution of the traditional VPP model towards the VPP1.1. Likewise, System Operators, such as SWW and the Energy Communities that they engage with, are looking outside the traditional supply/consume model and are furthering this relationship to allow Energy Community assets to participate in ensuring that grid stability is maintained when consumption is increased as Electrical Vehicle charging, Heat Electrification and variable RES are deployed in the grid. This results in Energy Communities and the grouping of their assets taking on the characteristics of a VPP and is hence driving the evolution of VPP2.0.

This shift in focus within industry is driving evolutions like that of the VPP, resulting in a pull from research towards providing solutions to facilitate this evolution, rather than the research pushing solutions towards industry. This pull comes with the caveat that to achieve full adoption with industry, they need to be rigorously assessed from multiple levels within industry and from multiple perspectives. We describe the VPP1.0, VPP1.1 and VPP2.0 concepts, and assess the edgeFLEX components that are used to drive this evolution while comparing them from a business perspective. While they have different actors as the VPP 2.0 is at the large VPP Operator level whereas VPP2.0 is more Energy Community DSO centric, they both can be framed in the assessment and from the context of how likely the solutions are to be adopted within the specific industries.

In this deliverable, we also looked at the advancements in techniques and technologies that underpin the edgeFLEX business scenarios and how their current state and future advancements can enable solutions like the ones that edgeFLEX offers, which will have a wider impact on the evolution of the VPP from 1.0 to 3.0 and beyond. This future impact comes with the need to have such solutions adopted into the “business as usual” functions of grid actors, and for that they need to be assessed and evaluated within these organisations. Through consultation with grid actors, such as System Operators and VPP Operators, it was identified that a multi-level organisational assessment of the edgeFLEX solutions was needed to identify the questions that they may ask to gauge the openness to adoption and help identify the enhancements needed to bring them to a standard where grid actors would adopt them through answering those questions. This is a step towards exploitation that provides confidence in our solutions from an industry perspective.

One of the main outcomes of the assessments was the practical nature in which the components were viewed by the actors, and this view unearthed some of the most interesting feedback that would make the solutions more palatable to industry, as this practical perspective can often be overlooked in research. One such feedback item was centred on the possibility of over-riding a solution if it was having a negative impact; this is a practical item that is vital to the actor. Aside from the practicalities, the Market and Regulatory landscape has been assessed, which identified the market and regulatory changes needed. These outcomes make the adoption pathways for the solutions clearer and having the Key Exploitable Results from edgeFLEX developed and delivered provides momentum for the exploitation and adoption of the edgeFLEX solutions.

In time, the regulatory landscape will have changed and directives like ReDispatch 2.0 will become more commonplace, coupled with an effort to unbundle the energy system, the changing market and conscious effort to lower CO_2 through the electrification of heating, transport, and the increasing penetration of RES. These changes, supported up by

- The rollout of 5G and the increased use of the features of 5G in the electrical industry.
- The advancements of grid control techniques, like Voltage Control, Inertia Estimation, Frequency Control.
- Advanced measuring devices like the edgePMU.
- Automated cross sector engagement tools like Policy Based Grid Management.
- AI techniques like VPP Optimisation, Intraday Market Modelling and Weather Forecasting.
- Energy Community focused tools like Reactive Energy Trading and FlexOffers.
- and modular, open source-platforms like edgeFLEX.

Furthermore, these facilitate and drive an incremental evolution of the energy sector towards systematic flexibility by providing a dynamic set of solutions and service, and thus better position the electrical industry and society to meet the global challenges being posed with climate change.

10 List of Figures

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12 List of Abbreviations

API	Application Programming Interface
BRP	Balance Responsible Party
CEO	Chief Executive Officer
CHP	Combined Heat and Power
CTO	Chief Technology Officer
DSO	Distribution System Operator
EC	Energy Community
eSIM	embedded-SIM
FEMS	Factory Energy Management System
GDPR	General Data Protection Regulation
HEMS	Home Energy Management System
HV	High Voltage
ICT	Information and Communication Technology
IoT	Internet of Things
IP	Internet Protocol
LCOE	Levelized Costs of Electricity
LDES	Long-Duration Energy Storage
LPWA	Low Power Wide Area
LV	Low Voltage
MaStR	Market Master Data Register
MPC	Model Predictive Control
MQTT	Message Queue Telemetry Transport
MV	Medium Voltage
NB-IoT	Narrow Band IoT
NPN	Non-Public Networks
PBGM	Policy based Grid Management
PMU	Phasor Measurement Unit
PPA	Power Purchase Agreement
PV	Photovoltaic

QoS	Quality of Service
RES	Renewable Energy Source
ROCOP	Rate of Change of Power
SCADA	Supervisory Control and Data Acquisition
SLA	Service Level Agreement
SO	System Operator
TRL	Technology Readiness level
TSO	Transmission System Operator
UE	User Equipment
URLLC	Ultra-Reliable Low Latency Communication
VPN	Virtual Private Network
VPP	Virtual Power Plant
VPS	Virtual Power System
WP	Work Package

ANNEX

A.1 4G in the edgeFLEX context

A.1.1 Introduction

4G networks have been widely deployed throughout Europe and rest of the world and public 4G networks are available for use by utilities as single networks or as part of hybrid network solutions addressing utility use cases. 4G networks are widely used to support communications to raise assets such as wind parks and wind turbines, to support smart meter reading, and as mission critical private networks to support communications in power stations and their surroundings. As hybrid solutions, 4G private and public networks can be used to support wide area national and regional communications while 4G or 5G private networks are used to support campus area networks. Such solutions support the communications needs of the edgeFLEX business models and deployment scenarios.

In this subchapter, we describe how 4G networks can support massive IoT communications and mission critical requirements often characteristic of utility use cases.

A.1.2 4G features supporting edgeFLEX services

4G mobile network solutions for massive IoT- communications

LTE for Machine-Type Communications (LTE-M) and Narrowband Internet of Things (NB-IoT) technologies have been co-existing with LTE since 2017 (Ericsson White Paper: Cellular IoT in the 5G era, February 2020). LTE-M extents LTE to support machine-type communications and include access to the low-complexity device category series called Cat-M. NB-IoT is a standalone radio access technology based on the fundamentals of LTE. At the beginning of 2022, over 170 commercial networks supported NB-IoT and Cat-M access globally (GSMA: Mobile IoT Network Launches, February 2022) with more than 0.5 billion of commercial users (Ericsson Mobility Reports, 2022). Forecasts indicate more than 2.5 billion connections will be in place by 2027.

Two dominating types of Cat-M/NB-IoT modems exist in the market: single mode NB-IoT modems suitable for ultra-low-cost devices, and dual mode Cat-M1/NB-IoT modems suitable for low-cost devices. Dual-mode devices can switch between Cat-M1 and NB-IoT access depending on the coverage. Cat-M1 modems have 1.4MHz bandwidth. Cat-M1 and NB-IoT have future-proof evolution in 5G networks when combined with dynamic spectrum sharing, dual-mode 5G cloud core and continued standardisation in 3GPP.

In certain cases when no critical communication is needed for edgeFLEX services, cost efficient narrowband Cat-M/NB-IoT modems can be used for connecting field devices to edgeFLEX service applications.

Mission Critical Mobile Networks

Mission Critical Networks (MCN) were built for public protection and disaster relief and as such are able to conduct voice and data communications under the extreme circumstances. (Ericsson White Paper: "Ensuring critical communication with a secure national symbiotic network", December 2021) On top of this, mission critical networks provide secure and reliable communication in all geographical areas with guaranteed performance. Coverage of mission critical networks is extendable comparing to commercial mobile networks. Data are protected by securing authentication, authorization and integrity of all communication. Enhanced features such as QoS priority and pre-emption allows prioritize and secure communications for mission critical applications even in congestion situations.

Mission critical networks built on 3GPP 4G and 5G technology and standard spectrum, enable users to benefit from the 3GPP evolution and standardised products as well as to gain a cost advantage. MCN services were standardised by 3GPP where the work already started in 3GPP

Release 12. The first mission critical push-to-talk service was standardised in 3GPP Release 13. MCN services can be deployed both on public and private networks. Additional MCN services were added into 3GPP Release 14, 15 and 16 such as mission critical video and data as well as other enhancements, including the addition of interworking with existing systems like TETRA and P25, migration and interconnection of MCN services between different MCN service providers.

Mission critical networks provide mission-critical push-to-talk, video, and data services based on solutions standardised by 3GPP. Furthermore, proximity communication services enable two users to discover each other and communicate even out of network coverage. Furthermore, mission critical networks resilience mechanisms are significantly higher than those in commercial mobile networks such as having power backup and redundant transmission even after several days without power. Mission critical networks have a dedicated geo-redundant core network when deployed as a static infrastructure what is needed in utility use cases.

Since both commercial mobile and mission critical networks are using the same technology standardised by 3GPP, their interactions can bring a number of benefits to mission critical services in terms of resilience communication, flexibility to handle all types of extraordinary situations sharing of infrastructure investment between mission critical and commercial networks and many others. The evolution of technology has made it possible to develop and deploy such network referred to as **symbiotic network** without creating unmanageable complexity or long lead times.

The following features support symbiotic networks: roaming, network slicing, capacity and coverage. Roaming from a mission critical network to public mobile network provide extended coverage and capacity. Separation and encryption of mission critical traffic and its prioritisation is provided in this case. Network slices can extend over the public mobile and mission critical network infrastructures. In this case, a network slice operated by mission critical network owner could use resources from public mobile networks resulting in additional coverage and capacity of mission critical services.

A.1.3 Conclusion on use of 4G solutions in edgeFLEX context

4G solution	Benefits to edgeFLEX services
4G mobile network solutions for massive IoT (LTE-M and NB-IoT)	• Extended coverage (improved radio signal penetration) • Support to low-complexity devices (long battery life…) • Standardised modems with future-proof evolution to 5G
Mission critical mobile networks	• Able to conduct voice and data communications under extreme circumstances • Provide secure and reliable communications in all geographical areas with guaranteed performance • Extendable coverage comparing to commercial mobile network • Ensure prioritisation and secure communication even in congestions situations • Provide standardised mission critical services such as push-to-talk, video, data communication • Proximity communications even out of network coverage • Resilience mechanisms significantly higher than by commercial networks (power backup, redundant transmission)

	• High reliability enabled with geo-redundant core network • Additional flexibility through interactions with commercial networks supported with roaming, network slicing, extended capacity and coverage

A.2 5G in the edgeFLEX context

A.2.1 Introduction

5G networks have been deployed world-wide. Already in July 2022, 181 new 5G networks have been deployed world-wide. Utilities are purchasing private 5G networks for campus area communications in and around power stations and key assets and are expressing interest in combining their private campus networks with wide area networks as hybrid solutions. Utilities are also looking for new possibilities to make 5G easier for them to use and would like to have the possibility to themselves perform network operations such as onboarding of new devices to the network. 5G network has been standardised by 3GPP in Releases 15, 16 and 17.

In this subchapter, we describe basic elements of 5G networks, the evolving features of 5G and key deployment options related to the needs of edgeFLEX business models and use cases.

5G features support the low latency and high throughput required for virtualisation of the edgeFLEX PMU control software and of the new edgeFLEX voltage and frequency control and inertial estimation services. 5G edge infrastructure can host the virtualised software, increasing power network resilience and cyber security. The high availability and reliability of 5G networks compared to 4G and 3G networks offers utilities industrial grade reliability with service levels for availability and reliability equivalent to those available in power network itself.

The forthcoming URLLC service will further reduce network latency while maintaining network reliability. Time sensitive networks (TSN), currently in development, offer bounded latency as hybrid solutions for utilities covering both the national, regional and local area contexts. As part of edgeFLEX development work, an innovative API was implemented as a proof-of-concept. It provides utilities with the possibility to manage device connected to their 5G networks without the aid of a 5G network operator or technical specialist. This simplifies the management of 5G networks by energy communities, VPPs and DSOs and reduces their costs while speeding up their operations.

5G features and planned enhancements offer solutions to needs of energy communities, VPPs and DSOs when deploying the business models proposed by edgeFLEX.

Key 5G network elements for edgeFLEX services

In principle, the 5G network comprises two functional domains: the next generation radio access network (NG-RAN) and the 5G core, which are built on underlying transport network (Ericsson Technology Review: Critical IoT connectivity: Ideal for time-critical communications, June 2020). The NG-RAN is deployed in distributed way in order to provide a good compromise between radio coverage and availability, reliability and performance. The 5G core network provides the management functions needed to operate the network as a whole and ensures connectivity between devices and external services and applications.

Reliability is defined as the success rate of delivering data within a certain time constraint required by the service (3GPP TS 22.261 V19.0.0: Technical specification group services and system aspects, service requriements for the 5G system, stage 1, Release 19, September 2022). Service availability is defined as the success rate of delivering the service according to an agreed Quality-of-Service (QoS) in a specific area (3GPP TS 22.261 V19.0.0: Technical specification group services and system aspects, service requriements for the 5G system, stage 1, Release 19, September 2022).

A.2.2 5G network features supporting edgeFLEX services

5G network features and their capabilities relevant for edgeFLEX services are described in detail in this subchapter.

In this subchapter, the following features are described:

- Ultra-Reliable Low Latency Communications (URLLC)
- Edge computing
- Network slicing
- Enhanced 5G device management exposure
- Embedded subscriber identification module (eSIM) solutions
- Network energy efficiency
- Security enhancements
- Lightweight security protocols
- 5G Reduced Capability UEs
- Time Sensitive and Deterministic Networking

Using the resources of edgeFLEX project, the latency support which 5G could provide to each edgeFLEX power service was tested using a standard 5G live network in an indoor laboratory setting. The test demonstrated that 5G latency is sufficiently low to support all the edgeFLEX power services. We tested the edgeFLEX frequency service on a prototype URLLC 5G network and described this work below. Additionally, we implemented and tested a novel 5G device management API and tested the functionality of edgePMU using edge computing in a live 5G network. A detailed description of the test results is available in the D5.5 (edgeFLEX D5.5: 5G use case validation results in laboratory tests, September 2022).

Ultra-Reliable Low Latency Communications (URLLC)

The 3GPP standards define support for ultra-reliable low-latency communication which is essential for use cases that require both high reliability and low latency. 3GPP has developed an URLLC toolbox of technical enablers for high reliability and low-latency that are described in this subchapter.

Example of one of the most stringent requirements of utility use cases such as distributed automated switching for isolation and service restoration that 5G is expected to fulfil is as follows (3GPP TS 22.104 V18.3.0: Technical Specification Group Services and System Aspects; Service requirements for cyber-physical control applications in vertical domains; Stage 1 (Release 18), December 2021):

- End-to-end maximum latency between two UEs (two wireless links) <5ms
- Communication service availability up to 99.999 9 %
- End-to-end latency is the time taken to transfer a data packet from a source to a destination, measured at the communication interface (3GPP TS 22.261 V19.0.0: Technical specification group services and system aspects, service requriements for the 5G system, stage 1, Release 19, September 2022).
- Communication service availability is calculated as a percentage value of the amount of time the end-to-end communication service is delivered according to a specified QoS, divided by the amount of time the system is expected to deliver the end-to-end service (3GPP TS 22.261 V19.0.0: Technical specification group services and system aspects, service requriements for the 5G system, stage 1, Release 19, September 2022). The end point in "end-to-end" is the communication service interface.

1) 5G features enabling high reliability requirements of edgeFLEX services

Reliability represents the capability of transmitting a given amount of traffic within a predetermined time duration with high success probability (3GPP TS 22.261 V19.0.0: Technical specification group services and system aspects, service requriements for the 5G system, stage 1, Release 19, September 2022). 5G networks includes number of network features that ensures that 5G networks deliver the required level of reliability as well as required levels of network availability and resilience (Ericsson Technology Review: Robustness evolution: Building robust critical networks with the 5G System, November 2011). Decision on which features will be used in a specific deployment depends on use cases that need to be supported. Additionally, different features can be used for different UEs in the same network.

The following 5G features enabling high reliability requirements are described in sequence in the text below:

a. 5G RAN features ensuring high reliability of communication services

b. 5G core network features ensuring high reliability of communication services

a) 5G radio access network features ensuring reliability of communication services

Examples of mechanisms and features that 5G radio access network supporting a reliability of communication services include:

Radio access network features addressing high reliability comprise a range of robust **signal transmission formats** (Ericsson Technology Review: Critical IoT connectivity: Ideal for time-critical communications, June 2020).

There are features for **duplicate transmissions** both within and between carriers. For transmissions within a carrier, transmission through multiple antenna ports is used. For transmissions between carriers, carrier aggregation or multi-connectivity is used.

Advanced antenna systems have a huge potential to improve the link budget and reduce interference.

As in the 5G core network, various **vendor-specific solutions** such as radio network configuration, algorithms for scheduling, link adaptation, admission and load control ensure high reliability of communication services while optimising utilisation of available resources.

b) 5G core features ensuring reliability of communication services

5G core features ensures reliability on both software-component and network level. Some features are standardised, but some are vendor specific. At network level, 5G core provides standard session reliability support instead of vendor-specific georedundancy solutions. Communication service providers requirement on availability of 5G network functions for mobile broadband services is 99.999 % but the requirement on availability of time-critical services is even higher. Examples of mechanisms and features that 5G core provides:

Network function set concept has been introduced by 3GPP for 5G control plane core network functions to support end-to-end session resilience at network level. Several network functions can be deployed inside one network function set to provide (geo)redundancy and scalability. In case that a network function fails, an alternative network function from the same network function set will replace the failed one.

All 5G control plane core network functions includes **load (re-)balancing, overload control and NAS-level congestion control** to ensure network function operating under nominal capacity. NAS-level congestion control ensures protection against congestions on the protocol stack layer between the core network and user equipment.

To support high reliability, one standardised 5G core solution enables the UE to establish two end-to-end **redundant Packet Data Unit (PDU) sessions** over the 5G network. A PDU Session provides user plane end-to-end connectivity between the UE and a data network such as the 'Internet' or private corporate networks. **Dual UEs and dual network partitions** is another possible solution.

For critical services, a **vendor-specific resilience solutions** are usually required to maintain user plane traffic in case of 5G user plane network function failure. E.g., Ericsson has developed mechanisms for both user plane session resilience and georedundant deployment of 5G user plane core network function.

2) 5G radio access network mechanisms and features supporting low latency requirements of edgeFLEX services

5G systems from Release 15 has introduced various features ensuring low latencies of communication services (NGMN White Paper: 5G E2E Technology to support verticals URLLC requirements, February 2020):

Flexible numerology feature significantly reduces transmission duration comparing to LTE.

Non-slot-based scheduling feature ensures shorter transmissions and allows transmissions to start immediately.

Grant-free uplink transmission feature allows that the device can directly transmit when it has data to send reducing the average radio access delay for uplink data by more than half.

Pre-emption for downlink feature enables time-critical services to pre-empt resources already allocated to other less critical services.

Flexible timing relation feature optimises the timing relation between the reception of data and the transmission of the acknowledgement.

We had the opportunity to test the edgeFLEX frequency control on prototype URLLC enabled live 5G network in the indoor laboratory setting. The test showed that URLLC provides a one-way latency under 2ms. The edgeFLEX frequency service is the service that requires the lowest latency of all the edgeFLEX services. The successful test of the edgeFLEX frequency control service demonstrate that URLLC will provide very low latency to other edgeFLEX services.

Edge computing

Edge computing often called Mobile Edge Computing (MEC) or Multi-Access Edge Computing provides compute, networking and storage execution resources for applications close to the end devices typically withing mobile operator network (Ericsson White Paper: Edge computing and 5G, 2020). Edge computing can also be deployed at enterprises premises, e.g., in factory buildings, in homes and vehicles. The edge infrastructure can be hosted and managed by communication service providers or other types of service providers.

Edge computing provides support for specific application use cases such as augmented and virtual reality, and utility use cases (Ericsson White Paper: Edge computing and deployment strategies for commuinication service providers, February 2020). Different use cases require applications to be deployed at different sites. In such use cases, a distributed cloud is useful providing execution resources for applications through multiple sites, including connectivity managed as one solution. The key advantages that edge solution solutions provide are low latency, high bandwidth, device processing and data offload and securing data by processing it locally in trusted environment.

Ecosystem for edge computing is evolving quickly but is till fragmented. Standards and business models are not set. Typically, several players must be involved to create end-to-end solution.

All three key 5G network elements described above - NG-RAN, 5G core and transport network – add to the end-to-end communication reliability and latency (Ericsson Technology Review: Critical

IoT connectivity: Ideal for time-critical communications, June 2020). On top of this, the device itself contribute to them. The network latency between the application and the RAN is often major contributor to end-to-end latency.

Figure 12-1 shows the relationship between an application deployment location in 5G network and end-to-end service latency. If an application is deployed in a national data centre (DC), the round-trip latency (RTT) can vary between 10ms and 40ms depending on the distance to the data center. In this case, the transport network is major contributor to the end-to-end latency. A quality of the transport network will also influence the end-to-end latency. The end-to-end latency will be reduced by moving the application to the regional center to 5-20ms or to the edge sites to 1-5ms. When the application is deployed on-premises, the transport latency becomes negligible.

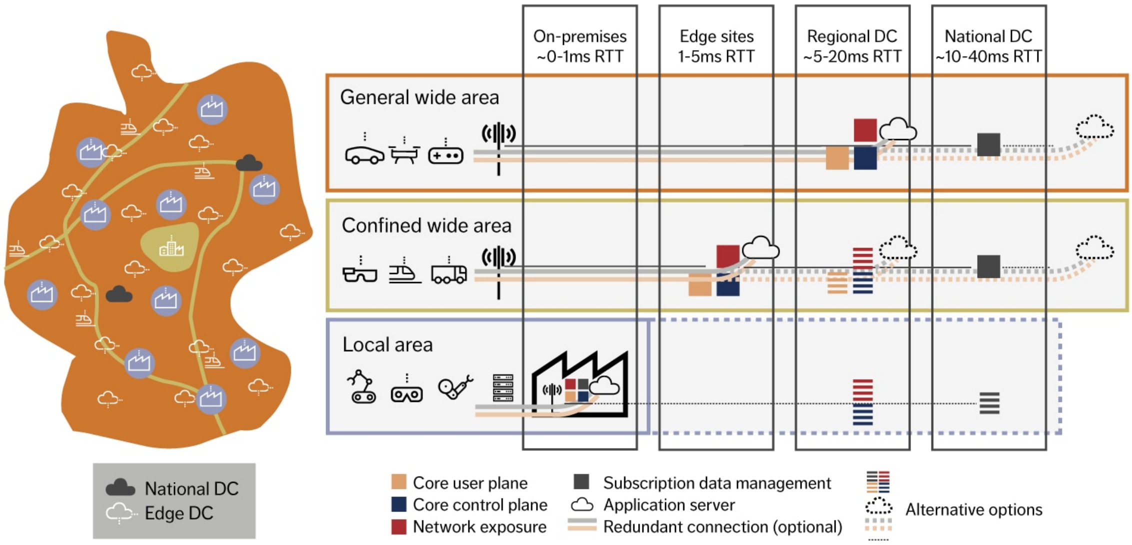

Figure 12-1 Relationship between network architectures and service latencies

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Therefore, control of the end-to-end latency can be achieved by placing virtualised core network functions at any location within the distributed computing platform of the 5G network. In addition to running of the 5G network functions, the distributed computing platform can host applications in the 5G network.

How edge computing supports the edgeFLEX edgePMU use cases

The edgeFLEX edgePMU provides advanced power services to energy providers buy collecting raw data and undertaking the analysis of data using processors located in edge clouds. This architecture enables more complex processing of large volumes of raw data and easier operating of software of functionality than would be possible if processing was collocated with the sensor and deployed in the field as a single unit including PMU sensor devices and processors to analyse the raw data.

The volume of raw data that need to be transmitted from the PMU sensing devices to the data processing algorithms running in the edge cloud is very high requiring the bandwidth of 5G connectivity and very low latency. The requirements and tests run by edgeFLEX are described in detail in D3.1 (edgeFLEX D3.1: 5G ICT requirements, development and testing for edgeFLEX solution, September 2022) and D5.5 (edgeFLEX D5.5: 5G use case validation results in laboratory tests, September 2022) and results show that 5G can fulfil the requirements of the edgeFLEX services in their use of edge computing.

The edgeFLEX edgePMU requires the support of 5G networks to enables its functionality. All previous mobile network generations lack this capability.

Network slicing

The network slice is a logically separated and secured part of the network providing requested network performance requirements such as latency and reliability (Ericsson: Network slicing early use cases, n.d.). The performance that the network slice provides could be low latency and ultra-reliability for a critical use cases or higher latency and lower bandwidth for use cases serving massive number of devices. Network slicing is enabled by fully virtualised 4G/5G infrastructure where a sliced network comprised of a set of logical networks sharing the network infrastructure. Automated operational and business processes supported by programmable 5G networks and advanced artificial intelligence, and service level agreement driven orchestration enable high flexibility and efficient management of network slices allowing new use cases.

Due to diversity of use cases and customer requirements, a wide range of network slice scenarios exist (Ericsson Technology Review article: Applied network slicing scenarios in 5G, Februar 2021) (Ericsson White Paper: The essential network slicing building blocks, June 2021). Engineering of appropriate network slide is built on evolving toolbox of 3GPP standardised enablers in five areas: radio access network, transport, core network, cloud infrastructure and operation and business support systems. For engineering of appropriate network slice, different combination of enablers from these areas is required.

The most important enabler is a single network slice selection assistance information (S-NSSAI). This is a slice identifier associated to each protocol data unit session that is created as soon as a UE context is created. Enablers that can be used in a radio access network can select appropriate function and capabilities for network slices. To illustrate complexity of network slicing mechanism, the following enablers in radio access area are listed: associating of an S-NSSAI to dedicated radio bearers and selected network functions, tailoring of layer 1 and layer 2 configurations for slice policies, use of radio resource management policies framework to allocate resources and assign quality of service levels per slice, and differentiation of dedicated radio bearer traffic within a slice or between slices. Sometimes, for optimal network resource usage trade-off in performance need to be done. E.g., the trade-off between the use of dedicated resources to specific slice services, and the overhead in maintaining numerous resource partitions.

Enhanced 5G device management exposure

5G network capability exposure through APIs has been identified as a development which would be of benefit to many vertical sectors which want to purchase private 5G networks or to use hybrid private and public networks to support their use cases. Many potential APIs which would be useful in sectors such as energy making 5G easier to use and integrate into vertical sector applications such as edgeFLEX use cases. Series of network exposure capability interfaces focusing on device management in particular use cases related to the management of communication services for devices have been proposed by 5G-ACIA organisation for industrial automation sector (5G-ACIA White Paper: 5G Non-Public Networks for Industrial Scenarios, September 2021).

All of these interfaces would be equally useful to energy sector users, enabling energy providers (VPPs, DSOs) who purchases private 5G network to undertake many basic day-to-day network operations without the need to involve 5G experts or mobile operators. These features reduce the time needed to perform basic operations thus reduce the costs of 5G network owners. Exposure of 5G device management capabilities through an easy-to-use 5G device management API would be of great benefit to energy providers. In the edgeFLEX project, we focused efforts on implementing and demonstrating such a 5G device management API and providing results to standardisation experts in Ericsson for submission to 3GPP. Standardisation needs to be completed before any products or services based on 5G device management API could be considered for market introduction.

Through 5G device management API, the management of connectivity between applications and devices through 5G network, the monitoring of connectivity, the management of device group communication, and provisioning and onboarding of devices, the capabilities available exclusively to communication service providers nowadays, can be provided to application users to innovate on (Ericsson Report: Enable innovation with open network exposure, 2020) (Ericsson Technology Review: Creating programmable 5G systems for the Industrial IoT, October 2022). Device management capabilities are exposed to application users through standardised easy-to-use 5G API composed that hide the complexity of the underlying 5G network infrastructure.

5G device management API in support of edgeFLEX energy services proof-of-concept has been successfully integrated and tested by the edgeFLEX project. In edgeFLEX, we have investigated how the network capabilities focusing on device management could support edgeFLEX use cases (edgeFLEX D3.1: 5G ICT requirements, development and testing for edgeFLEX solution, September 2022). Furthermore, we have tested the network capabilities with edgeFLEX use cases and developed demonstration of the network capabilities being used to support an edgeFLEX use case (edgeFLEX D5.5: 5G use case validation results in laboratory tests, September 2022). The results of the work were provided to Ericsson standardisation team for submission to 3GPP. Our edgeFLEX results were further developed by EDD in our role as a partner in IoT-NGIN project, and have recently resulted in two Ericsson standard contributions being accepted and published by 3GPP (Provisinal Change Request S6-223069: New solution for KI#8; Specification TS 23.700-34 v1.0.0, October 2022) (3GPP Pseudo Chenge Request: Pseudo CR on KI#8; Specification 3GPP TS 23.700-34 v0.6.0, August 2022).

Embedded subscriber identification module (eSIM) solutions

Embedded Subscriber Identification Module (eSIM) or Embedded Universal Integrated Circuit Card (eUICC) can be soldered directly into device comparing to removable SIM cards (Ericsson Report: eSIM technology, n.d.). This provides the flexibility in terms that the device can connect immediately when it is deployed. It can survive in intense environments that experience humidity, high temperatures and vibrations. The device user does not need to look for communication service provider or go to the provider shop to buy SIM cards. eSIM can choose a new local communications provider and activate a new subscription. This guarantees a global connectivity across the entire device life cycle. Enterprise eSIM management platforms can provide visibility and remote provisioning across millions of devices.

Network energy efficiency

ICT business must adopt a value-chain approach to setting climate targets according to a Net Zero timeline to halve total emissions by 2030 and reach a Net Zero state by 2050 (Ericsson Report: On the road to breaking the energy curve, 2022). Mobile network represents about 0.2 % of the global carbon emissions, and about 0.6 % of global electricity use according to Ericsson’s research. The demand on mobile networks will continue to grow and without taking actions, the energy consumption and emissions will grow as well. E.g., digital processing in 5G base stations can increase more than 300 times compared with early 4G network products due to increasing number of antenna branches, broader bandwidths and shorter transmission time intervals (Ericsson Technology Review: Improving energy performance in 5G networks and beyond, August 2022). However, increased energy consumption is not caused so much by traffic growth and increased subscriptions as by deployments of new frequency bands and network equipment leading to increased population coverage with multiple mobile generations. Ericsson research shows that the carbon footprint of ICT industry could be reduced by 80 %, if all of its electricity requirements were satisfied from renewable energy sources.

In order to reduce total network energy consumption, Ericsson is taking the following approaches:

Holistic view of company targets and network realities supporting network planning, operations and sustainability

To run a sustainable network and to achieve operational target, the network planning and operations need to evolve. Holistic view of all perspectives including organisational objectives and network realities need to be taken into consideration in the network evolution plan. Correlating user experience towards energy consumption opens new opportunities to optimise radio access network efficiency. Network planning should encompass all aspects of core, transport and radio access including site equipment. Utilisation of renewable energy sources as well as high-capacity batteries must be considered. RAN energy efficiency must be prioritised since radio access network represents more than 75 % of the network energy consumption.

Networks modernisation when scaling 5G to reduce network energy consumption

To reduce energy consumption when scaling up 5G, modernisation of the existing equipment plays a vital role. Multi-band technology allows combining of several radio units into a single physical unit for existing frequency bands. Furthermore, energy efficiency of radio equipment units was significantly improved in recent years. The test pilots show that the 5G technology is up to 90 % more efficient that 4G in terms of energy consumption per unit of traffic (Ericsson Blog: Achieving sustainability with energy efficiency in 5G networks, March 2021).

Maximised traffic performance with minimised energy use through network operation automation

As traffic varies daily, energy saving functions such as one that act on millisecond range and features deactivating larger shares of equipment enable large savings in networks by delivering the best user experience. Since different regions and sites need unique energy-saving protocols, automated solutions streamlined by AI and ML will be needed to manage mobile networks through predictiveness, automation and orchestration.

The increase in digital processing in 6G base stations is expected to become even larger than in 5G. It is essential that the future 6G standard is to extend the lean properties of 5G new-radio, such as lean as possible enabling up to 160ms of transmission-free periods, better support to network densification, Keeping the amount of mandatory and always-on signalling at a minimum that will enable high level of dependency between load and energy consumption of network components, etc.

Security enhancements

Mobile telecommunication networks comprise four main logical network parts: radio access network, core network, transport network and management system. Core network and management system are critical parts of the network in terms of security because affecting one of them can compromise security of all mobile network services (Ericsson Report: A guide to 5G network security 2.0, September 2021). Radio access network is also sensitive part in terms of security as it can be placed in critical location and because of handling of user data. By deploying of edge cloud, some network functions are brought closer to radio access sites which makes the radio access also critical.

Data is a critical asset in terms of security in mobile networks. Subscriber data is the most critical in this category comprising communication data such as voice, text and data sessions, and subscriber related information such as identities, location, subscription profile and connection metadata (call data records and signalling traces). Furthermore, mobile network management data is another critical asset comprising infrastructure and service configuration data, as well as monitoring data such as performance metrics, logs and traces. All data need to be protected over its entire lifecycle, during transport, at storage including secure deletion.

Security aspects of mobile networks such as interface definitions, security protocols, key lengths and the strength of cryptographic algorithms, have being standardised through open and globally agreed standards. Security standards have been defined trough different standardisation organisations. The main standardisation organisation for mobile networks is 3GPP defining security for 3G through 5G including security architecture (3GPP TS 33.501 V17.7.0: Technical Specification Group Services and System Aspects; Security architecture and procedures for 5G system (Release 17) , September 2022). The Internet Engineering Task Force (IETF) defines security protocols such as IPsec, Extensible Authentication Protocol (EAP) and Transport Layer Security (TLS) that are incorporated in 5G security architecture. The European Telecommunications Standards Institute (ETSI) defines security for network functions virtualisation. The National Institute of Standards and Technology (NIST) defines crypto solutions such as Advanced Encryption Standard (AES). To ensure secure implementations, 3GPP and Global System for Mobile Communications Association (GSMA) created the Network Equipment Security Assurance Scheme (NESAS) framework for security assurance.

Certain parts of security standards are mandatory to implement such as the mutual authentication between the device and the mobile network, and integrity protection of signalling. Other parts of security standards are optional to use such as IPsec between the nodes of mobile network. Standardisation is only one step in securing of mobile networks. After standardisation, it is the responsibility of the mobile network vendor to implement standards for functional network elements and systems. This includes incorporation of third-party components, proprietary and open-source solutions. At network deployments, it is the responsibility of the mobile network operator to configure the network for targeted level of security and turn on security features, and finally to operate the network in a secure way.

In addition to security standards and security assurance schemes (NESAS), there are different initiatives that define regulatory requirements towards 5G networks with aim to achieve specific security demands. E.g., EU toolbox across Europe, Indian Telecom Security Assurance Requirements (ITSAR), and the UK Telecom Security Requirements (TSR) by National Cyber Security Centre (NCSC).

In the further text, we explain the security features and enhancements of the radio access network and the core network introduced in 3GPP Releases 15, 16 and 17.

The radio access network security enhancements introduced in 3GPP Release 15 (Ericsson Blog: An overview of the 3GPP 5G security standard, July 2019):

New flexible **authentication framework** in 5G that allows use of different types of credentials besides SIM cards

Enhanced **subscriber privacy features** against false base stations also known as IMSI catchers or Stingrays

Integrity protection of user data over the air interface

The core network security enhancements introduced in 3GPP Release 15 (Ericsson Blog: An overview of the 3GPP 5G security standard, July 2019):

Additional higher protocol layer security mechanisms to protect the new service-based interfaces, i.e., TLS to protect communication at transport layer, and the Open Authorisation 2.0 (OAuth2) framework at the application layer

Improvement of the security between different mobile operator networks

The radio access network security features introduced in 3GPP Release 16 (Ericsson Blog: A summary of 3GPP Release 16, 5G phase 2: Security and RAN, April 2021):

Full rate user plane integrity protection requesting cellular devices to handle user data integrity protection between the device and the mobile network at any possible data rate

Existing mechanisms for **cellular IoT data security** that existed in 4G have been adopted for 5G. Cellular data security mechanisms have been introduced over the 4G radio access but over 5G radio access.

Wireless backhaul security has been standardised

Security of redundant industrial IoT data paths has been standardised

The radio access network security features introduced in 3GPP Release 17 (Ericsson Blog: 5G Release 17: Overview of new RAN security features, October 2022):

User plane integrity protection has been introduced to the deployment options with 4G core network over 4G and 5G radio access networks

Security of 5G Proximity based services has been standardised for 5G radio access network

Security mechanisms including secure interfaces, authentication and authorization have been standardised for time synchronisation and time sensitive communications **for Industrial IoT** applications

5G Reduced Capability UEs

Reduced capability UEs provide affordable connectivity for massive number of devices. The first reduced capability UEs should be available in 2024 (Ericsson Mobility Reports, 2022). Reduced capability UEs uses advantages of 5G NR and advanced deployment flexibility through the support of enhanced frequency range that 5G technology is providing. Significant reduction in device modem cost compared to standard NR UEs is achieved because of reduced modem complexity. Reduced capability UEs in frequency range 1 - FR1 (4.1 GHz to 7.125 GHz) support half-duplex operations with maximal bandwidth of 20 MHz equipping single receiver and transmitter branches (Ericsson Blog: What is reduced capability (RedCap) NR and what will it achieve?, February 2021). For the comparison, an ordinary FR1 NR UEs support full-duplex operations with bandwidth of 100 MHz, and up to four receiver branches. Furthermore, 3GPP Release 17 specifies support for extended discontinuous reception (eDRX) that allows a device to power down for long periods and save power.

In certain configuration where the communication is not critical for edgeFLEX services, reduced capability UEs can be used for connecting of field devices that provide measurement data to edgeFLEX services via 5G network.

Time Sensitive Networking

The main goal of a Time Sensitive Networking (TSN) is to provide communication services in terms of guaranteed packet transport with low and bounded latency and low packet loss (Ericsson Blog: 5G meets Time Sernsitive Networking, December 2018). Such services are needed in power grids. 3GPP has standardised a number of features to support the requirements of TSN starting from the Release 15.

TSN applies to the following utility use cases (IEEE: Utility Applications of Time Sensitive Networking White Paper, 2018) (IETF RFC 8578: Deterministic Networking Use Cases, May 2019):

Teleprotection where communication latency must be highly consistent and predictable, <10 ms to carry the measurements between the relays at the ends of the transmission line.

Intra-substation LAN where TSN could be a help on the process bus.

Shared IT/OT networks over a common medium through providing converged multi-service architecture that provides guaranteed performance and bounded latency for critical services such as teleprotection and SCADA but also to voice services from field and substation locations.

Field Area Network applications to enable Fault Location Identification and Service Restoration (FLISR) to operate on shared medium networks, to provide low-latency communications for supporting MicroGrids, coordination of Dynamic protection and managing of the potential for reverse power flows.

E.g., local traffic forwarding from a SCADA server that failed to a remote SCADA server in another wind farm site that is under the management of the same VPP operator. Existing QoS and timing requirements need to be met in such case.

Wind Farm applications to provide low-latency communications as requested in MicroGrids because integrating wind resources into a distribution grid is often part of a microgrid.

AR/VR application to support stringent communications requirements when using VR technology for training and AR technology used in the field to increase worker productivity and safety.

A.2.3 5G advanced network forthcoming features supporting the edgeFLEX services

Introduction

5G Advanced networks has been starting building of the new technology components with the direction towards future 6G networks. 3GPP standardisation work on 5G Advanced network started with the Release 18.

5G Advanced will support new applications and improve network performance. (Ericsson White Paper: 5G Advanced: Evolution towards 6G, June 2022). The following five feature areas business cases will be enhanced in 5G Advanced network: intelligent network automation, extended reality, reduced capability NR devices, network energy savings and deterministic networking.

Intelligent network automation

Intelligent network automation will enable simpler and more efficient network deployments and usage. Network performance will be also improved by utilising AI/ML-based solutions. Number of use cases both in radio access network including protocol physical layers and core network that are foreseen to enhance network performance are identified and will be taken into normative phase in the next releases. Mentioning a use case example in each area such as network energy saving in the radio access network, beam management in protocol physical layer, then enhancements of the architecture for network data analytics in the core network.

5G Reduced Capability UEs

Further reductions in modem complexity and optimisation in the device power consumption are expected, e.g., by reducing the supported peak data rates and transport block size scaling. Furthermore, optimisation of the time a device can spend in its most energy-efficient state is expected. Reduced capability UEs will support new use cases such as positioning.

Network energy efficiency

5G was designed to meet increasing traffic demands whereas limiting the power consumption of mobile networks. Dedicated study on network energy saving will be conducted in Release 18. E.g., traffic load balancing and sleep mode for 5G next generation base station (gNB) in urban micro and macro scenarios are one of very important factors contributing to energy saving on network level.

Deterministic networking

The support of Deterministic Networking (DetNet) for applications requiring not only bounded low latency but also low delay variation and extremely low loss is needed. 5G Advanced will add support to deterministic networking in 3GPP Release 18. The use cases supported by deterministic networking are the same that are supported by TSN.

A.2.4 5G Network Deployment Options supporting edgeFLEX services

5G spectrum flexibility supporting network deployment strategies

5G New Radio is able to use all available spectrum assets used for LTE networks either through refarming or spectrum sharing (Ericsson Technology Review: Critical IoT connectivity: Ideal for time-critical communications, June 2020). Accordingly, 5G network continues to use LTE spectrum assets that are in the low and mid bands for wide-area coverage. Additionally, 5G network uses spectrum assets in the mid bands around 3.5GHz and in the high bands such as the millimeter wave frequencies. Therefore, 5G network ensures better coverage and increased capacity that are achieved by adding more spectrum assets, densifying the network and upgrading capabilities on existing sites. Added radio access nodes can use advanced hardware features such as advanced antenna systems to fully capitalise on the benefits of 5G New Radio.

In some regions, dedicated spectrum has been allocated to some industries for local use. E.g., significant TDD spectrum has been allocated for local use in the order of 100MHz in mid-band and millimeter-wave frequency ranges. In the wide-area scenarios, the allocated bandwidth is typically small (10MHz or below) and unable to meet requirements of time-critical use cases. For such scenarios, the reuse of existing public mobile network infrastructures and their spectrum assets brings opportunities and values. This approach enables interaction between public and non-public networks and exploit full potential of various band combinations.

The availability of free or low-cost spectrum to industry means that various industrial sectors and specific enterprises can afford to deploy private LTE and 5G networks for their sole use. The specific frequency bands made available varies from country to country. Private local area networks are also enabled in the spectrum bands at higher frequencies and the market for private local area LTE and LTE Mission Critical Networks to critical infrastructure owners have increased rapidly in the past few years since the new low-cost spectrum.

This brings the big advantage that the owners of these private networks have total control of the security features they enable in their infrastructure and that they can configure QoS parameters to suit the needs of their specific enterprise or industrial sector.

Business models used to support the purchase and operation of private local, regional and national cellular networks vary from single organisation private ownership of networks to models based on the establishment of joint ownership organisations within particular industry sectors, such as the utility sector.

Communication service life cycle management

The communication infrastructure components are deployed in the power grid with the intention that they will serve often for decades, i.e., the same time scale as expected lifetime of the power grid components (3GPP TR 22.867 V18.2.0: Technical Specification Group Services and System Aspects; Study on 5G Smart Energy and Infrastructure (Release 18), Septemeber 2021). 3GPP supports backward compatibility. Any change of the released 3GPP standard occurs only after comprehensive review and acceptance by the community of stakeholders. This results in providing of comprehensive support for diverse telecommunications services by each generation. However, we need to keep in mind that it is suboptimal for mobile network operators to efficiently operate different legacy access networks.

Especially very strong commitment is present to support of legacy terminals. E.g., mobile phones from the mid of 90s can still operate today. Features such as Dynamic Spectrum Sharing (DSS) have been developed by 3GPP that ensure backward compatibility. DSS enables parallel use of 4G and 5G in the same frequency band.

3GPP standardised LTE-M and NB-IoT technologies will continue evolving as part of 5G specifications. This means that mobile network owners can leverage their investments in these technologies already today and continue as a part of the 5G evolution (GSMA White Paper: Mobile IoT in the 5G future, NB-IoT and LTE-M in the context of 5G, April 2018). One of the 5G deployment scenarios allows NB-IoT and LTE-M transmissions to be placed in a 5G new-radio frequency band (3GPP TS 38.211 V17.3.0: technical specification group radio access network, NR, physical channels and modulation (Release 17)). Furthermore, 3GPP investigated the 5G core network options supporting NB-IoT and LTE-M radio access networks (3GPP TR 23.724 V16.1.0: Technical specification group services and system aspects, Study on Cellular Internet of Things (IoT) support and evolution for the 5G System (5GS) (Release 16), June 2019).

Companies using cellular based IoT devices connected via 2G and 3G mobile networks that reaches the point of obsolescence are facing the challenge of transition to the newer cellular network generations (Sierra Wireless White Paper: How to manage the 2G-3G-4G IoT sunset, September 2021). In majority of cases, transition to 4G technology is recommended because transitions to 3G networks would enable accessibility to devices for a short period such as several years when 3G generation reaches the point of obsolescence. However, the transition from 4G to 5G should be simple and straightforward, and not on the scale of moving from 2G, to 3G to 4G. Furthermore, 5G new-radio technology offering massive improvements in capacity and performance will only be needed to deliver huge amount of data over short distances which is not the case for majority of use cases using IoT devices.

5G (non-)standalone mode technology

5G is bringing a set of disruptive functionalities such as ultra-low latency communication, high bandwidth/throughput, higher security, network slicing, and network exposure (Ericsson Blog:

Transforming 4G into 5G: Ericsson's dual-mode 5G Cloud Core, 2019). However, new 5G networks will co-exist side-by-side with 4G ones for many years in practical and efficiency reasons (5G Core (5GC), n.d.). To enable smooth transition towards 5G, 3GPP standardised options for interworking between 4G and 5G (Ericsson White Paper: 5G deployment considerations, 2018). The majority of commercially launched 5G networks are based on 5G new-radio non-standalone technology that uses existing 4G radio access for signaling, and an 4G core network. However, critical use cases will only be feasible with 5G new-radio standalone technology that uses 5G core network (Ericsson Mobility Reports, 2022). 5G standalone compatible devices are increasingly becoming available accounting for over half of all announced devices (Ericsson Mobility Report: 5G SA deployment: Moving beyond eMBB, June 2022).

Public mobile networks

Utilities can often use public mobile networks to complement private mobile networks which they operate. As public networks offer global coverage and cover rural as well as urban areas, they can save utilities the need to deploy their own private networks for supporting some of their use cases requiring communications to devices. Public network operators offer a range of services to industrial users, such as utilities, to support increased security and privacy levels which may be required for specific use cases. In particular, the deployment of devices for distribution grid monitoring and automation often requires the establishment of communications to locations for which utilities do not already have privately owned communications links. In such cases, the use of public mobile networks provides communications to new devices without the high costs associated with deploying private cabled or wireless connections to the new locations.

Many utilities are considering or already using hybrid public-private networks, combining the coverage of public networks, including 2G/3G/4G/5G, with the advantages of privately owned mobile infrastructure.

5G non-public (private) networks

In contrast to public networks that offer mobile network services to the general public, 5G Non-Public Networks (NPN, also sometimes called private networks) offer mobile network services to a specific organisation or a group of organisations (5G-ACIA White Paper: 5G Non-Public Networks for Industrial Scenarios, September 2021).

The non-public network is based on 3GPP defined technologies, and provide high quality of service capabilities, high security, isolation from other networks and accountability. The following 5G NPN deployment scenarios are typical:

- Isolated deployment

  In this scenario, NPN is deployed as independent network, i.e., separated from the public network. Alternatively, NPN devices can be connected to the public network, e.g., to access its services in the remote-control center. This is enabled by dual subscription. Furthermore, the NPN operator can make roaming agreements with several public network providers.

- Shared radio access network

  In this scenario, the NPN and the public network share radio access network while other mobile network functions are provided by the public network. All NPN data traffic stays on-premises.

- Shared radio access network and control plane

  In this scenario, the NPN and the public network share radio access network, and network control functions are performed in the public network. All NPN data traffic stays on-premises. This scenario can be implemented by network slicing or by the feature called access point name (APN). The APN allows differentiation between traffic portions.

- NPN hosted by the public network

In this scenario, both the NPN and the public network traffic are transmitted via the public network infrastructure but treated as they are parts of different networks. This scenario can be implemented by network slicing or APN functions.

In the latter two deployment scenarios, a term **dedicated networks** can be used sometimes. Dedicated networks are virtualised private mobile networks that can be provided to the industrial enterprise typically using 5G network slicing over a public network (GSMA: 5G IoT Private & Dedicated Networks for Industry 4.0). In this case, most of advantages of a private network can be obtained but without the complexity and costs needed for installing and operating a wireless infrastructure on-premises and using one or more services to operate through the public network.

Hybrid 5G networks

Combining a public and private campus network into a Hybrid Network can also offer a flexible solution supporting the communication requirements of edgeFLEX services. Hybrid networks can facilitate the control of critical infrastructure assets using a geographically restricted, private networks complemented using public mobile network operator networks for controlling less important, dispersed, critical infrastructure assets.

Mobile network deployment considerations in relation to edgeFLEX service coverage

The following two complementary network deployment approaches considering edgeFLEX requirements with regards to latency, reliability and coverage area can be considered: general public network infrastructure and dedicated network infrastructure (see Figure 12-2). For edgeFLEX services with moderate latency (~50ms-20ms) and reliability requirements, existing **public network infrastructures** can be reused by adding support for critical communications via software upgrade on the installed 5G base. For edgeFLEX services with very high requirements in terms of service reliability or low latency (~20ms-1ms), **dedicated 5G infrastructure** can be deployed for power system or VPP operators, either as an isolated network or as an extension to the existing public network (hybrid network). The dedicated infrastructure can be deployed either in a local area (e.g., substation) or in a confined wide area (e.g., between substations, or a city center), depending on the users' radio coverage needs.

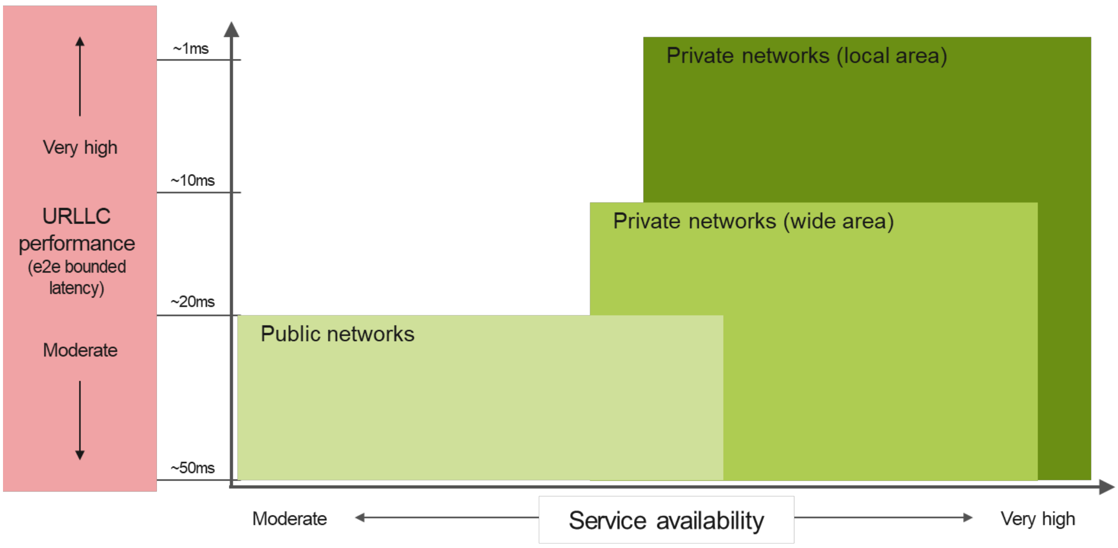

Figure 12-2 Mobile network deployment considerations. Source Ericsson

A.2.5 Conclusion on use of 5G solutions in edgeFLEX context

5G solution	Benefits to edgeFLEX services

URLLC	• Provides communication services with end-to-end maximum latency down to 5ms • Provides communication service availability up to 99.999 9 % • Examples of RAN mechanisms and features ensuring high reliability of communication services: a range of signal transmission formats, duplicate transmissions, advanced antenna systems, as well as vendor-specific solutions • Examples of mobile core network mechanisms and features ensuring reliability of communication services: network function set, load (re-)balancing, overload control and NAS-level congestion control, redundant PDU sessions, dual UEs and dual network partitions, as well as vendor-specific resilience solutions • Examples of RAN mechanisms and features ensuring very low latency of communication services: flexible numerology, non-slot-based scheduling, grant-free uplink transmission, pre-emption for downlink, flexible timing relation
Edge computing	• Enabler for new use cases • Provides compute, network and storage execution resources close to devices that can be customised by application developers • Provides a low latency, high bandwidth, device processing and data offload, and securing data by processing it locally in trusted environment • Hosts user applications in an optimal location (edge, regional or national sites) • Provides development environment for the rapid creation of new industry services and applications
Network slicing	• Enables new business model innovation and new use cases • Provides flexibility and ability to deliver services faster • Ensure requested communication service performance such as reliability and latency in private and public networks • Network slice can be dedicated to one enterprise user or shared by multiple tenants
Enhanced 5G device management exposure	• Enables an application/user management of the connectivity and the device itself without interactions with the communication service provider • Exposes 5G device management capabilities through standardised easy-to-use API hiding complexity of underlying 5G infrastructure
Embedded subscriber identification module (eSIM) solutions	• Products using eSIM can be smaller and of higher quality than those using a physical SIM card • Can survive in intense environments (extreme temperatures, humidity, or vibrations)

	• The selection, contracting and onboarding of a communication service provider is easier; a user does not need to look for providers • Guarantees seamless global connectivity services provided by communication service providers across the entire device life cycle
Network energy efficiency	• 5G technology is up to 90 % more efficient than 4G in terms of energy consumption per unit of traffic • Modernising the existing equipment reduces energy consumption of the mobile network
Security enhancements	• Security aspects of mobile networks have been standardised through open standards by the standardisation organisations: 3GPP, IETF, ETSI and NIST • To ensure secure implementations in addition to the standardisation of security aspects NESAS framework has been created by 3GPP and GSMA • There are different initiatives that define regulatory requirements towards 5G networks with aim to achieve specific security demands
5G Reduced Capability UEs (RedCap)	• Provide affordable connectivity for massive number of devices • Will be significantly cheaper compared to standard NR UEs • Can power down for long periods and save power
Time Sensitive Networking (TSN)	• Provides guaranteed packet transport with low and bounded latency and low packet loss that edgeFLEX fast dynamic services can benefit of

5G-advanced solution	**Benefits to edgeFLEX services**
Intelligent network automation	• Enables simpler and more efficient mobile network deployments and usage • Improves mobile network performance by utilising AI/ML-based solutions in areas such as radio access network energy saving, and beam management in protocol physical layers
5G Reduced Capability UEs	• The complexity and the device energy consumption will be further reduced
Network energy efficiency	• Network energy efficiency will be further improved in areas such as load balancing and sleep mode in 5G next generation base stations
Deterministic Networking	• Besides bounded low latency, Deterministic Networking will ensure low delay variation and extremely low packet loss for evolved fast dynamics services

5G deployment option	**Benefits to edgeFLEX services**

5G spectrum flexibility	• 5G provides better coverage and increased capacity than 4G that is achieved by adding more spectrum assets and reusing 4G spectrum assets • Dedicated spectrums have been allocated to some industries for local use in some regions
Communication service life cycle management	• 3GPP standards bears long lifecycle of energy infrastructure by supporting backward compatibility and providing comprehensive support for diverse telecommunications services by each generation • Dynamic spectrum sharing 5G feature enables parallel use of 4G and 5G in the same frequency band • NB-IoT and LTE-M transmissions can be placed in a 5G new-radio frequency band providing devices improved communication service
5G (non-)standalone mode	• 5G non-standalone deployments enable usage of both 5G and 4G infrastructures that will coexist for many years in practical and efficiency reasons
Public mobile networks	• Can be reused for edgeFLEX services with moderate latency (~50ms-20ms) and reliability requirements by adding support for critical communications via software upgrade on the installed 5G base
Non-public (private) networks	• Can be deployed for power system or VPP operators to support edgeFLEX services with very high requirements in terms of service security, reliability and low latency (~20ms-1ms)
Hybrid networks	• Can be deployed for power system or VPP operators to support edgeFLEX services with very high requirements in terms of service security, reliability and low latency (~20ms-1ms)

A.3 6G in the edgeFLEX context

A.3.1 Introduction

This subchapter describes trends and vision for the future network platform also referred to as 6G network that could be relevant to edgeFLEX. 3GPP standardisation of 6G networks is expected to officially start from Release 21 (Figure 12-3 below). The following three new emerging use cases relevant to the edgeFLEX business models and use cases are described below: connected intelligent machines, digitalised and programmable physical world and connected sustainable world (Ericsson Magazine: Five network trends towards the 6G era, September 2021). In addition, the following four new emerging network blocks supporting the edgeFLEX business models and use cases that will evolve in the future are described: adaptable limitless connectivity, integrity of trustworthy systems, federated cognitive networks and a unified network compute fabric.

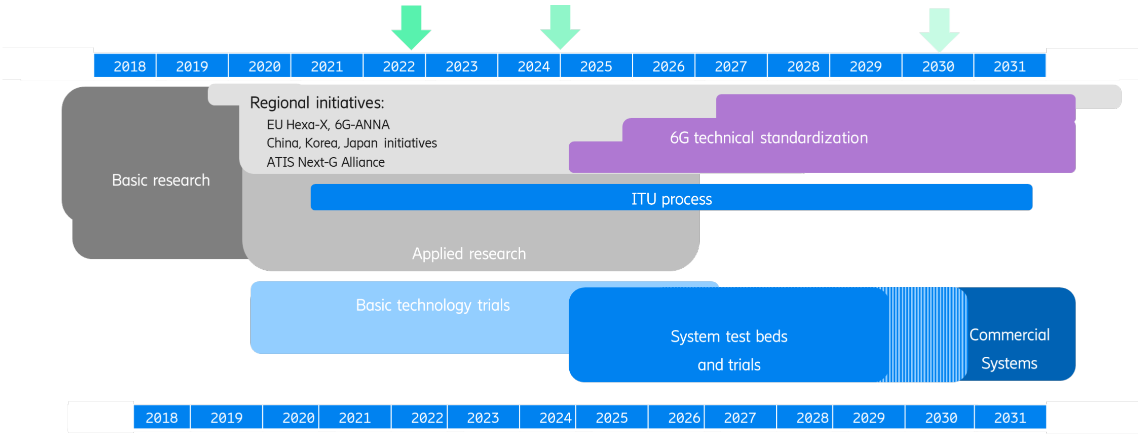

Figure 12-3 6G industry timeline. Source: Ericsson

A.3.2 6G use cases supporting evolved edgeFLEX business models and use cases

The following use cases supported by 6G will drive the edgeFLEX business models and use cases:

Connected intelligent machines

Connected intelligent power grid assets and their corresponding digital agents will operate and perform tasks in both physical and digital domains. They will be connected to applications, users and with each other in collaborative and aggregated structures.

Digitalised and programmable physical world

All physical objects will have a digital representation in the future. Huge amount of data will be processed by digital representation for prediction and planning of actions related to the physical world through orchestration and actuation, i.e., interactions will be fully automated. Accordingly, digital twins will process measurements received from huge number of power grid assets, will do predictions and planning and trigger needed actions automatically.

Connected sustainable world

Building a sustainable world requires huge efforts, with solutions like the ones developed in edgeFLEX enabling use of renewable energy sources on a global scale. This requires global coverage using standardised network solutions connected to huge number of devices world-wide and a network platform with high availability and security.

A.3.3 6G network building blocks supporting evolved edgeFLEX business models and use cases

The following proposed key 6G network building blocks are being researched in many projects and programs, could support evolved edgeFLEX services if the features of these building blocks are discussed in 3GPP and then become standardised features of 6G and commercialised by system providers:

Adaptable limitless connectivity

The following capabilities will be essential to deliver adaptable limitless connectivity: network adaptability, device and network programmability and end-to-end availability and resilience. These capabilities will be beneficial to edgeFLEX services.

Integrity of trustworthy systems

Solutions that will provide trustworthy connections with end-to-end assurance to evolved edgeFLEX services will arrive as part of the following technologies: confidential computing, secure identities and protocols, zero-trust architecture and service availability assurance.

Federated cognitive networks

The future networks will become cognitive by observing the network performance and optimizing it automatically. In this way, full automation of network management and configuration tasks will be provided to operations and maintenance personnel. edgeFLEX services will benefit using highly efficient infrastructure.

A unified network compute fabric

6G will unify across storage, compute, communication and exposure their capabilities to create a distributed unified network compute fabric. This fabric will give access to tools and capabilities beyond connectivity that can be used as a unified platform for evolved edgeFLEX services.

A.3.4 Conclusion on use of 6G suggested capabilities in the edgeFLEX context

6G building block	Benefits to edgeFLEX services
Adaptable limitless connectivity	• Adaptable limitless connectivity will ensure the development of and agile, robust and resilient mobile network where application developers should focus on the task while the network should be able to adapt and support their needs • Open multi-vendor interfaces both in network and in the ecosystem will be offered while system complexity will be minimised • Solutions that ensure dynamic and flexible mobile network site deployments will be available • Ad-hoc and non-terrestrial mobile network nodes and other type of nodes will be seamlessly integrated • Multi-hop routing capabilities will enable cost-effective mobile network densification instead of dedicated transport network links for smaller sites • Integration of distributed and centralised radio access as well as public and non-public mobile networks will be simplified that will be enabled by flexible transport networks • Device programmability will include downloadable software stacks and configurable AI models, while the programmable mobile network will support updated and new device features resulting in optimisation of individual devices for specific use cases • Mobile networks will collaborate with applications to provide the best end-to-end communication performance and suitable communication services to applications
Integrity of trustworthy systems	• Mobile networks will provide trustworthy, always-available connections with end-to-end assurance to mitigate broadened threats • Mobile networks will provide secure services that will verify compliance of the connectivity to security, safety, resiliency and privacy demands

	• Cloud and edge systems will provide isolated execution environments for the execution of sensitive code and data using encryption and cryptographic integrity protection • Evolving technologies like homomorphic encryption, and multiparty confidential computation will become available • A zero-trust architecture will facilitate secure access to mobile network resources using identity centric approach and supervised by humans • Consistency of behavior of communication services in the operating environment will be ensured, e.g., trade-off between radio access network performance and system capacity to mitigate effects of traffic variability for critical applications • Communication service availability will be improved by using predictive analysis and critical user services will be informed about functional safety risks
Federated cognitive networks	• Mobile networks will observe and act autonomously to optimise its performance • Mobile networks will enable full automation of network management and configuration tasks allowing operations personnel to supervise the network • A set of distributed intent managers embedded in the mobile network and controlled by intents specifying requirements and constraints, will observe the environment under control using cognitive functions, draw conclusions from the acquired data, and take actions to fulfil the expectations of the intents • Trustworthy AI will improve transparency of mobile networks so that humans can understand why actions are taken or conditions cannot be met
A unified network compute fabric	• Mobile networks will offer industry service providers and developers access to tools and services beyond connectivity to model new industry services • Mobile networks will offer connectivity together with an embedded execution environment to fulfil future industry use cases that will be highly distributed demanding guaranteed latency, high throughput and high reliability • A network compute fabric will evolve around federated ecosystem involving actors and users of the air interface, the internet, cloud services and devices requiring wide range of bilateral agreements between ecosystem actors