edgeFLEX

D8.6

Publishable Project Progress Report, V3

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Abstract
This document summarises the key achievements of edgeFLEX and describes how these results were developed during the three-year duration of the project.

Keyword 5G, Mobile communications, Renewable Energy Source (RES), Voltage Control, Frequency control, simulation, co-simulation, hardware in the loop, field trial, Virtual Power Plant (VPP)

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

Executive Summary

The edgeFLEX project has made excellent progress during the third period of its three years planned duration towards achieving all the planned goals of the project. All the project activities have been completed according to the schedule planned in the Grant Agreement.

The focus of efforts in the third and final year of the project was on the execution and evaluation of the field trials, the provision of feed-back to the work packages who developed the concepts and implementations and the further preparation of the results for market introduction and exploitation.

Novel edgeFLEX voltage control algorithms were deployed in field trials in Italy and Germany. Virtual Power Plant (VPP) price and power production forecasting methods were deployed in an offline VPP management system in Germany and tested with historical data. The planned fast and slow dynamics field trials in Germany and Italy have been successfully concluded and deliverables describing their results published. The edgeFLEX edgePMU was deployed in live power networks in both Germany and Italy. Strategic results derived from the operational results of the project have been defined and exploitation plans for results have been elaborated.

The concepts for new energy services and 5G support of these services researched by edgeFLEX have been elaborated and investigated in the simulations and field trials. The newly developed concepts of Complex Frequency (CF) and Rate of Change of Power (RoCoP) are fundamental tools which enable the implementation of novel and efficient frequency controllers of distributed energy resources. Tests of the edgeFLEX platform functionality over live 5G networks in a laboratory setting were undertaken and their description in deliverables completed.

Dissemination and communication activities and stakeholder engagement activities made excellent progress during the final project year providing the project with valuable feed-back and supporting our exploitation preparations. Stakeholder engagement with consumers and with people playing key roles in DSO and VPP organisations were fruitful and assisted in exploitation planning and the promotion and uptake of our results. Stakeholder engagement with regulatory and power standardisation organisations provided feed-back on our recommendations for change and demonstrated the interest of sector actors to consider the edgeFLEX recommendations.

Four contributions to 3GPP by Ericsson AB, which included input from EDD on the project results related to the 5G-API for Device Management and the use case for the edgePMU, were accepted for standardisation creating a global market for systems implementing the standardised mobile communications specifications. 39 scientific publications have been published and one book has been edited and includes project contributions.

The project achieved all its planned goals and KPIs. Exploitation of results has been planned and these efforts have made good progress in the final year but a lot of commercial interest in the project results being expressed.

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1. Introduction

1.1 Objectives of the report

The aim of this deliverable is to summarise the key achievements of edgeFLEX at the end of the project and describe the development of the project work and results over the three years of the project execution.

1.2 Outline of the report

An extensive summary of the key achievements of edgeFLEX in Chapter 2 is followed by a detailed presentation of how these key achievements were developed over the three years of project work.

1.3 How to read the document

This report can be read as a standalone document. However, the interested reader can refer to the earlier versions 1 and 2 of the progress report to find more detailed information about the achievements of the first and second years of the project.

2. Key achievements of edgeFLEX

The edgeFLEX project started in April 2020 and was concluded, as originally planned, in March 2023 having achieved all its envisaged goals. It has produced results which go beyond the original expectations of the partners in many respects creating an excellent basis for their further development and commercialisation in the coming years.

The key results of edgeFLEX on providing a wide range of tools to sector actors to increase the flexibility available in the grid make a valuable contribution to the implementation of European policies such RePowerEU, the European Green Deal and the Digitalisation Action Plan as well as National policies such as the German ReDISPATCH 2.0 and 3.0 regulations, all of which aim to enable a decentralised, decarbonised, and flexible energy Figure 1.

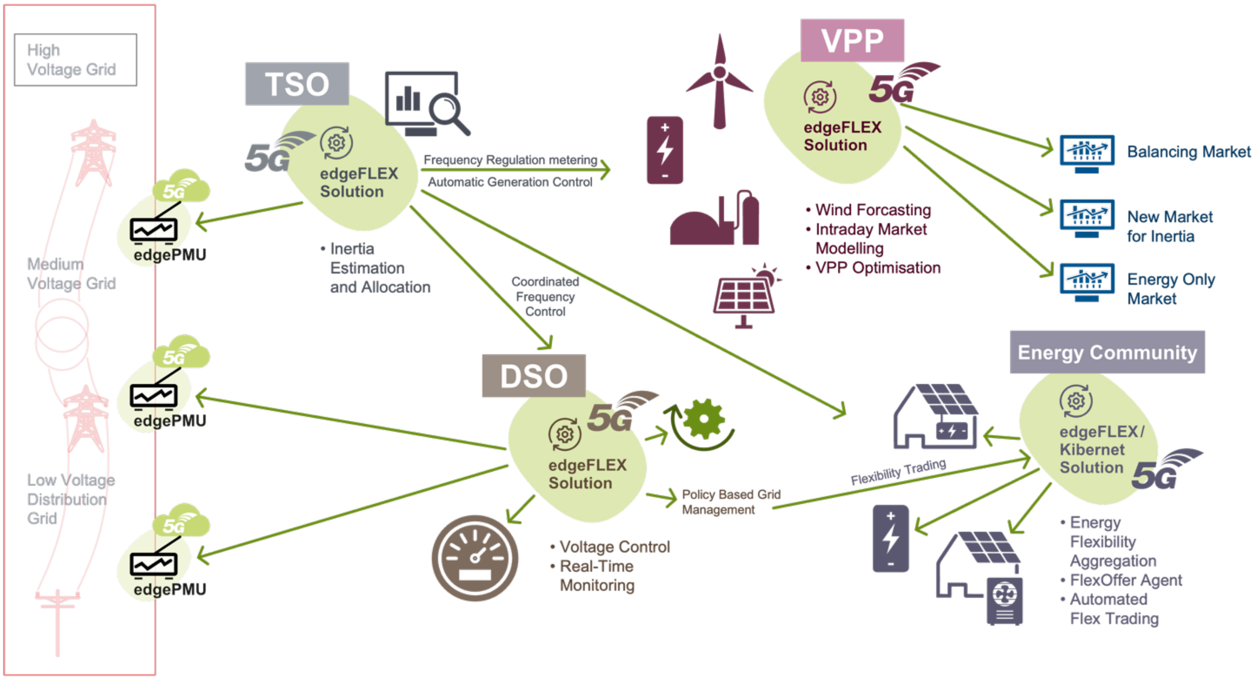

Figure 1 edgeFLEX solution and services

A summary of the key achievements of the edgeFLEX project is provided in this chapter.

2.1 The edgeFLEX Strategic Results

The edgeFLEX project had the strategic goal of placing the VPP at the centre of the evolution of the energy sector enhancing and extending the role it can play in balancing the grid. Achieving this goal will provide a more stable grid through enabling the grid to handle a more diverse mix of renewable energy generation sources and by reducing the risk of investment in renewable energy sources at all levels in the grid system. The strategic placement of the VPP is implemented by edgeFLEX through the edgeFLEX strategic results which describe the potential evolution of the VPP and other energy system sector actors, a systematic view of flexibility which can be enabled by VPPs and novel techniques and enhancements of existing techniques providing the ability to solve problems locally using prosumer assets.

Systematic Flexibility

edgeFLEX interprets grid flexibility as something that should be harnessed and utilised across the entire system rather than viewing it as a by-product of controllable load or micro generation. edgeFLEX therefore offers a systematic view of flexibility by offering a Virtual Power System (VPS) that goes beyond the concept of today's VPP, in which flexibility is integrated into the grid even at the low voltage level. This is in line with the increasing role VPS can play in the future power system, in which the number of thermal power plants will be greatly decreased compared to today and therefore ancillary services need to be provided through the flexibility of a new Virtual Power System. The trial performed by the DSO SWW in Wunsiedel, Germany mirrors this view of flexibility in which the assets of an energy community are engaged to solve local voltage issues for the DSO. Also in the edgeFLEX work on VPP Optimisation studies and trials in which the addition of battery storage to the mix of assets managed by the VPP is shown to provide greater flexibility in the management of the asset portfolio as well as increased profitability. edgeFLEX concepts enable voltage control in low voltage networks to provide fast dynamics services to the grid Figure 2.

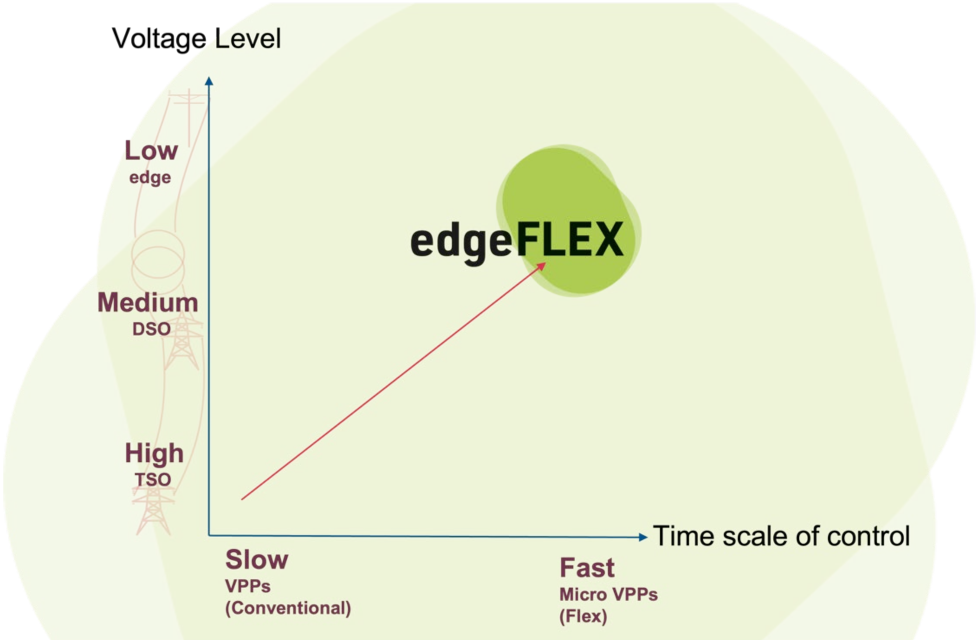

Figure 2 edgeFLEX contribution to frequency control

Incremental Evolution

The energy sector is complex involving many technical components, work and business processes, relationships and regulations developed and optimised over many years by the sector actors. For this reason, it may not be possible for all actors in the sector to evolve at the same pace or indeed the pace at which the energy sector is currently evolving, and this may become an inhibitor for progress. edgeFLEX views the evolution of the electricity sector incrementally and is conscious that all actors cannot evolve at the same pace and our research results reflect our efforts to address the challenges of such an incremental evolution in which sector actors individually evolve at their own pace. Figure 1 illustrates this incremental evolution and the detailed path which the edgeFLEX research results enable towards a fully digitalised and flexible grid. Furthermore, the edgeFLEX platform is designed in a modular and portable way in which a sector actor can choose and integrate the components most suited to the stages of their evolution.

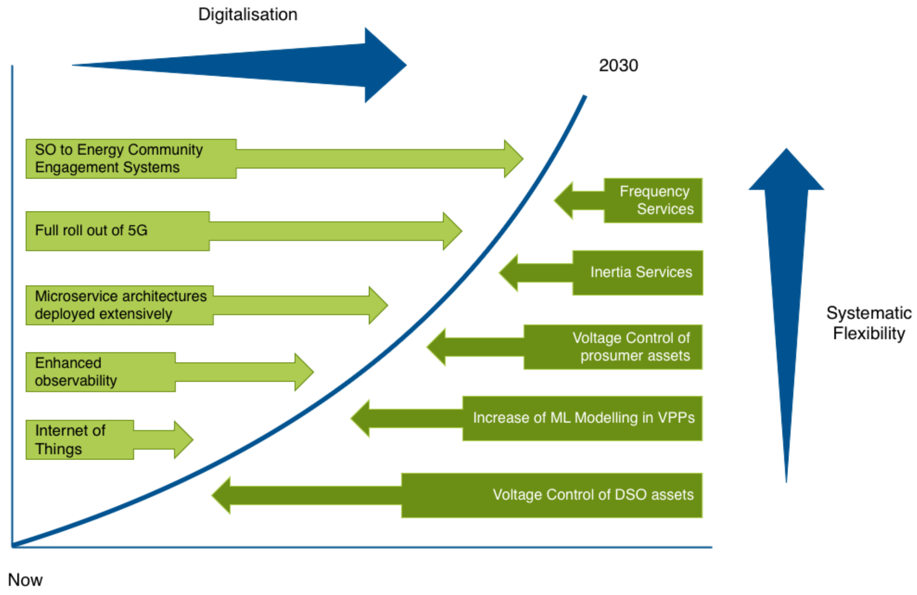

Figure 3 Incremental evolution

5G and Edge Readiness

Distributed Energy Resources (DER) are becoming common place in the evolving energy system. Supporting DERs at scale in the energy system from the perspectives of monitoring, control and management is becoming a challenge and an obstacle to the larger scale adoption of Renewable Energy Source (RES). The grid system is facing a challenge to evolve to accommodate DERs and therefore technologies are required to meet this challenge and lower the barriers to raising the proportion of energy generated from volatile renewable energy sources. The emergence of 5G mobile communications networks and the internet of things provide an opportunity for grid operators to solve these issues by adding autonomy to the management of DER and using the grid and communications network's edges to solve issues locally. The edgeFLEX approach offers such an evolution through offering a set of 5G and edge ready solutions providing the energy sector with a set of tools which can solve multiple issues at their sources. For example, the edgePMU combined with the voltage control can manage the voltage at a single node that was connected to a DER asset to maintain operational limits. Likewise, the edge cloud can be harnessed to install edgeFLEX services that would manage the grid locally. This can feed into incremental development and reduce investment in large-scale digitalisation and investment in asset balancing at the edge.

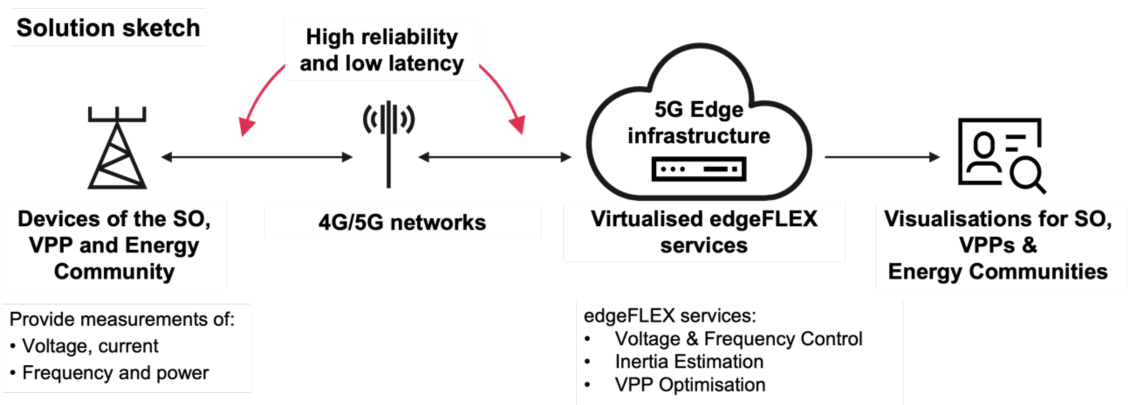

Figure 4 edgeFLEX solutions are 5G and edge ready

2.2 Research on edgeFLEX concepts and services

2.2.1 Frequency control - the new fundamental concept of "complex frequency"

The complex frequency (CF) concept provides novel definitions of frequency of electrical voltages and currents. This definition extends the domain of the frequency to the complex domain allowing for a complete and consistent formulation of the rate of change of power (RoCoP) at the buses in electric grids. The newly developed concepts of CF and RoCoP are fundamental tools that allow for the implementation of novel and efficient frequency controllers of distributed energy resources. They also constitute the theoretical tools building blocks enabling the implementation of the VPP 2.0 concept and of the most advanced services envisaged by edgeFLEX.

The edgeFLEX frequency control algorithms were tested in a realistic lab environment using state-of-art simulation tools developed at UCD. In the final stage of the project, UCD has initiated a collaboration with EirGrid (Irish TSO) to validate the concept of complex frequency. This collaboration is ongoing and will be carried out through on a detailed model of the Irish transmission system. The objective is to test the applications of the CF concepts in real-world scenarios and showcase the ability of such an approach to improve the transient response of low-inertia systems with high shares of non-synchronous resources following severe contingencies.

2.2.2 Voltage control

The voltage control algorithms developed in the project consisted of several solutions to maintain the voltage within the limits in distribution grid. Throughout the project, online and Model Predictive Centralized (MPC) voltage control algorithm has been developed and tested in both centralised and distributed implementation. The online control represents a voltage control algorithm that solves sudden voltage violations using the last received measurements from the field. This approach has been initially presented in a centralized formulation and then re-proposed in a distributed fashion for the implementation in the field trial. The distributed implementation of the online voltage control has been achieved using software containers, which also integrated the peer-to-peer communication among the control nodes. With this approach a fully distributed online voltage control implementation with actual communication has been tested.

The MPC voltage control represents a control algorithm that solves voltage problems also considering a future time horizon, using forecast profiles. With this approach the voltage control algorithm can predict the control set-points to solve future possible voltage violations and can formulate the flexibility requests. This algorithm has been used in its centralized form in the SWW field trial to calculate flexibility requests for the interface to the flexibility trading platform. Additional research has been carried out to develop a distributed implementation of the MPC for voltage control. The results of this research, presented in a journal article, have shown the need for further investigations before considering an implementation in the field. For this reason, the distributed formulation of the MPC has not been further implemented in the field.

The implementation and development of the voltage control algorithms will be carried out during the project BeFlexible, which started on September 2022. In particular, the algorithms will be further developed in a field trial in the city of Rome as part of the RWTH planned exploitation and further development of the edgeFLEX results.

2.2.3 Inertia estimation

The work on the inertia estimation developed in the project consists of the development of the inertia estimation algorithm and the development of a scheduling tool for the optimal allocation of virtual inertia. These tools can be provided to the grid operators to perform an initial estimation of the value of inertia for a portion of the grid and then to calculate the optimal allocation of virtual inertia to increase the overall inertia of the system. The proposed tools have been tested in a simulation environment and developed as services for the edgeFLEX architecture, integrating the interface with the MQTT broker. The two algorithms could not be tested further in the field given the small size of the grid used for the field trials, which, together with the small power generation values involved, could not create any relevant conditions for the inertia estimation and allocation tools to be tested.

2.2.4 VPP optimisations based on improved forecasting of power generation

Building on the ALPIQ experience in developing optimisation methods for VPPs, improved optimisation methods for power forecasting algorithms were developed increasing the level of automation of the VPP algorithms with respect to how they interact with the market.

Building on the existing ALPIQ knowledge of energy markets, edgeFLEX developed enhanced services improving the attractiveness of investment in VPP assets using Green Swops, in the context of the decreasing level of subsidies in many European countries for investment in RES assets, and developed optimisations based on enhanced power generation forecasting.

2.2.5 edgePMU

The edgePMU developed in the project represents the implementation of a novel and more flexible concept for a Phasor Measurement Unit (PMU), which is normally used in the distribution grid. The main concept consists of the separation of the acquisition and signal conditioning which is performed at the device level, and the calculation of the phasor, which is performed in the cloud, possibly placed in the 5G edge cloud infrastructure. This approach offers the possibility to perform additional calculations on the raw data obtained from the devices installed in the field, by simply updating the algorithm used in the cloud. The edgePMU devices have been installed in both the Italian and SWW field trials to provide information on the status of the grid and to provide voltage phasor data to the voltage control algorithms.

Additionally, the edgePMU was assessed by the JRC's Market Creation Potential indicator framework as having a "Noteworthy" level of Market Creation Potential.

The edgePMU will be further developed and implemented in collaboration with the Taiwan grid operator as planned RWTH exploitation and further development of the project results.

2.2.6 Investigations of how 5G communications infrastructure can support VPP evolution and development and standardisation of a relevant 5G enhancement.

How 5G can support VPPs and their evolution

Both 4G (LTE) and 5G Mobile Networks can provide excellent support for the cost-effective operation of optimized VPP systems with AI-enhanced services, evolving within the regulations for VPPs as they currently stand. The main communication requirement of VPP systems is for communications to the assets under management, to monitor and control their operation. Large scale systems may implement both cabled and mobile communications to their key assets to ensure redundancy in the communications links so that should one network not be available, the second network can be used as an alternative means of communications. This redundancy in network availability reduces the risk to a VPP operator of losing transparency on the operations of the assets and of losing control of the assets, potentially resulting in penalties for the VPP operator.

How 5G can support the needs of evolved VPPs as the regulatory environment adapts to the changing needs for flexibility in the power grid

As large synchronous power plants leave the energy system the need for balancing the grid increases. In the future, large VPPs could provide balancing services at the TSO level. To facilitate this, there will be a need to push services such as Frequency Control closer to the edge of the MV/HV network. To enable this, computational resources at the edge of both the grid and the communications networks will be needed to support virtualised services, such as those of the edgeFLEX edgePMU. 5G edge cloud infrastructure could provide support for these services meeting the communications and computational requirements of the services.

The availability of 5G networks to support the near real-time communications with low latency and support for providing computational resources and ICT storage at the edges of the power grid will enhance the financial viability of such a VPP and reducing or eliminating the need for laying cabled communications to all the many small assets under management by the VPP.

edgeFLEX tested the latency which 5G can achieve when supporting the communications of the edgeFLEX services and of the edgePMU on live 5G networks demonstrating that 5G can fulfill the latency requirements of the services. The results are documented in D5.5.

The availability of 5G Advanced Networks with their Ultra Reliable Low Latency Communications (URLLC) features support the most advanced implementations of the edgePMU services, enabling more frequent analysis of the data collected by the edgePMU and hence enabling enhanced accuracy in power system control.

The novel **5G-API for Device Management**, developed in edgeFLEX, makes 5G easier to use for VPP operators who operate their own 5G networks and solution architectures for edge Infrastructure support for the edgePMU which can be deployed in current and evolved VPP infrastructures.

3GPP accepted three submissions by Ericsson AB based on the further development of the edgeFLEX results and has published the submissions as global standards opening the way for 5G system houses to implement products and services based on the open standards.

2.3 The edgeFLEX vision of the evolution of Virtual Power Plants contributing increased flexibility to the grid

edgeFLEX has developed a brief description of VPP operations with three evolutionary steps. The evolutionary steps provide a context for understanding how the research results developed in edgeFLEX can be applied to VPP operations to enable VPPs to make an increasing contribution to stabilising the grid by adding functionality to today's

VPP concept. The edgeFLEX envisaged evolution of the VPP is described in Figure 5 below.

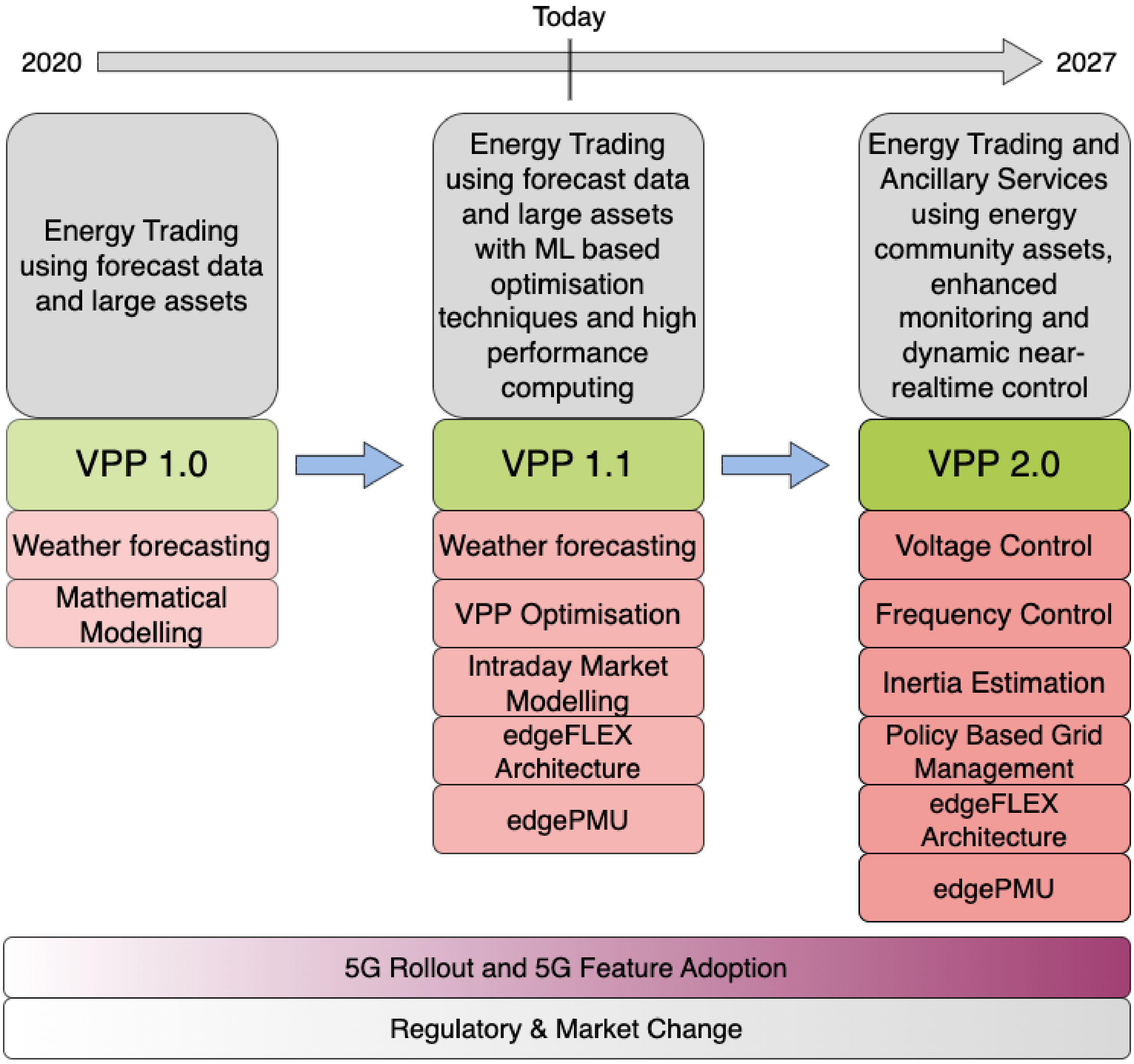

Figure 5 The edgeFLEX proposed evolution of VPP's contributing increased flexibility to the grid

The edgeFLEX VPP 1.0 and 1.1 concepts

The VPP 1.0 concept describes the basic operations of a VPP while the VPP 1.1 concept describes the efforts of many of the leading VPP operators to enhance the effectiveness of their operations using a range of techniques which can be applied commercially today, without the need for regulatory change.

Compared with the original VPP 1.0 concept covering the basic and historically used functionality and operations of a VPP, the VPP 1.1 concept includes AI-based optimisation techniques enabling improved trading revenues to be made by VPPs in both the energy and capacity markets. These optimisation techniques, along with stochastic weather forecasting, intraday market modelling as well as edgeFLEX architecture and edgePMU, are designed to improve the trading activities of VPPs in an environment with increasing RES penetration.

edgeFLEX has developed VPP optimisation techniques contributing to the VPP 1.1 evolutionary step based on improved methods for forecasting energy production and optimized revenue generation from VPP assets through the optimised used of storage assets in the VPP and intraday market modelling.

edgeFLEX has developed the modular edgeFLEX architecture and Platform, which can be deployed incrementally, together with the edgePMU in VPP 1.0 and 1.1 infrastructures, to enable optimisations of VPP services.

The relationship of VPP 1.1 to energy markets

The optimisation of VPPs as envisage in the VPP 1.1 allows the aggregator to improve its participation in the different energy markets. Since the edgeFLEX optimisation of VPPs makes it possible to manage many different classes of assets, the aggregator can participate not only in the energy markets (such as the intraday/day-ahead markets) but also in the capacity markets (such as those for ancillary services).

The relationship of VPP 1.1 to its impact on the Grid

The impact of an optimised VPP 1.1 is advantageous for both the aggregator and the grid operator. Indeed, it has been shown that an optimized VPP leads to a more balanced portfolio and to optimised revenues not only from energy market arbitrage but also through lower balancing charges. This improved balancing of the system also benefits the grid operator since its balancing efforts will be reduced. If this impact were to be generalised – through an increased number of VPPs in the system, one could expect substantial cost savings in grid infrastructure works and improvements, which the grid operator would otherwise need to complete.

The edgeFLEX VPP 2.0 concept

The most advanced operations of VPPs envisaged by edgeFLEX, enabling them to contribution to voltage and frequency control, to inertial estimation and to manage the small assets of Energy Community members require the implementation of new techniques for advanced monitoring of assets and services providing dynamic, near real-time control. Such advanced VPP operations are termed VPP 2.0 by edgeFLEX and their full implementation requires significant changes in the currently applied regulatory frameworks before commercial operation of such a VPP could be undertaken. The results of edgeFLEX research on voltage and frequency control and on inertial estimation as well as the edgeFLEX edgePMU are key enablers for the VPP 2.0 concept.

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 but these assets may not be typically large and may be prosumer owned and part of an Energy Community. This sees the VPP playing a role at a local level and having a presence that has an impact and connection to the DSO grid. The VPP2.0 assets could contain a combination of microgeneration, such as solar PV, storage, and controllable loads, such as electric heat pumps and electrical vehicle charging. This combination of assets, due to its variability could cause balancing and congestion issues for the DSO, with over and under voltage events as a risk for system security due to frequency variations.

edgeFLEX is taking the VPP to a local level, involving the citizen and enabling them to directly interact with the DSO to help the DSO to autonomously solve problems on the grid. 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 any imbalances by availing of the flexibilities available within the local VPP. This engagement is outside the curtailment model which can be enforced in areas of high-RES penetration, and it relies on using the surplus energy rather that curtailing the asset, utilising the energy stored within the local VPP at times of increased load rather than having an energy deficient system.

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, enabling them to respond to system frequency variations in the first few seconds (typically in the range of 1 to 20 seconds) of any disturbance due to generation or load power variations or other events, e.g., short circuit or opening of a line. VPPs can respond to frequency variations by modifying their power output and provide fast (primary) frequency regulation to help stabilise the power system.

These tools help minimise the cost of frequency response provision for the VPP. This approach also ensures an optimised post-fault frequency dynamic response. It also allows for the charging of electric vehicles in large numbers without affecting the system stability, by dynamically allocating the available power in an optimised way.

2.4 The edgeFLEX Platform

As the 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 as described in D4.1. 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 as described in D4.3. 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.

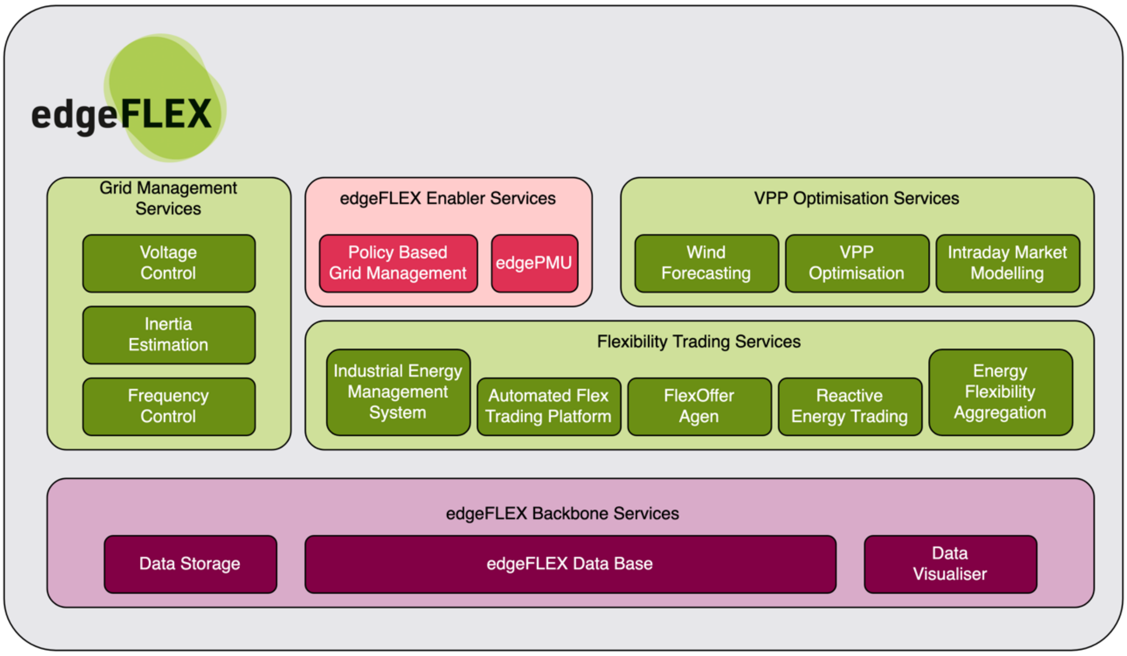

Figure 6 Schematic representation of the edgeFLEX Platform

The edgeFLEX platform has been tested and deployed in the trial site located in Germany, interfacing with external systems to capture and visualise data from the field, enabling flexibility trading and control service functionality, and therefore realising the slow and fast dynamics use cases as detailed in D5.4.

2.5 Validation of the edgeFLEX services and architectures in field and laboratory tests

edgeFLEX organised innovative field trials and laboratory tests in two countries, as illustrated in Figure 7, validating our research and innovation results and creating confidence in our solutions.

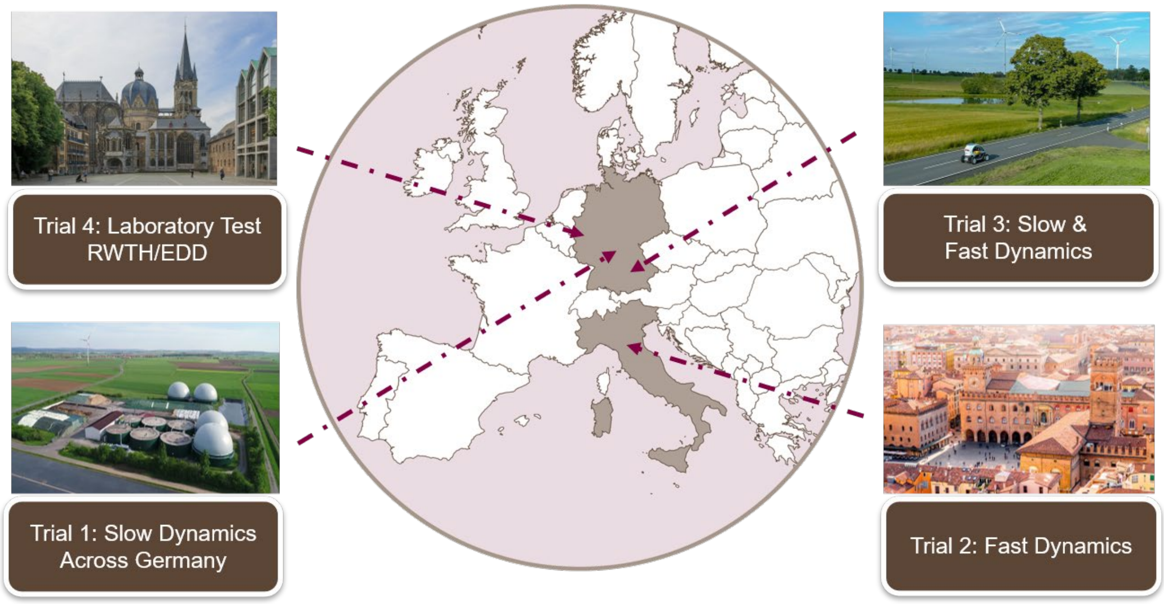

Figure 7 The edgeFLEX field trial locations

2.5.1 SWW field trial of fast and slow dynamics in Wunsiedel with Energy Community implementation in all but legal form

The SWW trial builds on the results acquired and infrastructure developed within a former project conducted in Wunsiedel, called GOFLEX, in which consumers were recruited to allow flexibility trading to fulfil the project's goals of accelerating integration of distribution solutions and establishing a market for flexibility trading. Customers were equipped with Energy Management Systems (EMS) and intelligent measuring equipment to enable automated energy and flexibility trading. These systems were successfully integrated into the edgeFLEX plan as communication between this system and the technologies developed in edgeFLEX was established.

An Energy Community was created and implemented in all forms but legal with stakeholders from Wunsiedel signing contracts in order to participate and to be engaged. The tests conducted in this trial involved power grid supporting services for normal condition operation and stability support services using flexibility potentials. These tests aim to focus on voltage control and grid balancing measures. The communication between the EMS and the edgeFLEX technologies has made it possible to create flexibility offers both for a singular asset as well as from multiple assets simulation an Energy Community acting as a VPP. The results show that voltage control issues can be tackled by utilising flexibility offer schemes and the Energy Community acting as a VPP can support balancing services for power gird operations.

2.5.2 Italian A2A trial of slow dynamics in Milan

The Italian field trial originates from the interest of an external DSO to test the edgeFLEX solutions. Therefore, the existence of this field trial is already a demonstration of the edgeFLEX appeal. The main goal of the Italian trial is to implement the voltage control service by installing a significant number of edge devices (a prototypal and a commercial one) inside the secondary substations of the DSO. The trial confirmed the ease of integration of the HW and SW within the already existing DSO's instrumentation architecture. Of course, some adaptation was needed to match the existing equipment with the new one. According to the metrological theory, to obtain accurate results it is needed to run some preliminary tests on the devices to be used. Therefore, before installing the edge devices, several accuracy tests were performed on them.

The preliminary testing confirmed the accuracy of the prototypal edge device, which is comparable or in some cases higher than the commercial one (10 to 15 times more expensive than the prototypal one). Once measurement setup was installed, the collected measured allowed for the voltage control service validation. The results demonstrated that the complete edgeFLEX solution can produce interesting results starting from the measures collected from the field. The last result from the field trial was unexpected but interesting. The collaboration between the DSO and the partners allowed for making a further step. The digitalization of the portion of grid considered allowed for the development of a simplified version of the digital twin. Its implementation triggers a variety of application like predictive maintenance, fault prediction, accuracy evaluation, etc.

2.5.3 German ALPIQ trial of VPP optimisations based on improved energy generation forecasting and the deployment of battery storage

The ALPQ field trial involved the preparation, execution, and interpretation of a mathematical model of a VPP which includes battery and bio-mass storage as a simulation trial on the off-line version of the ALPIQ VPP Management System using historical data to feed the simulation. The mathematical modeling focused on managing the assets of the VPP so that the revenue they generate is maximised. The effects of optimising the operations of the VPP by applying the optimisations of weather forecasting to predictions of wind generated energy by a VPP, developed in WP 3, is examined.

The sensitivity of the level of revenue generated to changes in a range of input parameters to the model, including the parameter of varying the number, size, and type of assets to be managed by the VPP, has been performed. The inclusion of battery storage and bio-mass assets is specifically examined. The results of the modelling are expressed in terms of the level of revenue generated and the level of investment and the return on this investment generated by the different versions of the model defined by varying the input parameters of the model regarding forecasting methods.

2.6 Regulatory stakeholder engagement and recommendations

Within the framework of organisation of edgeFLEX dialogue activities with policy makers, experts in regulation and standardisation and practitioners, an important action taken was to understand the position of stakeholders and the market needs for a precise correlation with the activities scheduled and performed within the project.

In the first part of the project implementation, a series of initial recommendations regarding the regulatory framework was formulated, to address the broader context of potentially adopting and implementing the edgeFLEX solutions. Going through the stakeholder engagement activities and based on the edgeFLEX research and analysis within the project, the set of recommendations was dynamically updated and completed.

Engaging with policy makers, with organisations and experts in regulation and standardisation was an ongoing and complex activity, carried out throughout the project implementation period, and involves interactions and consultations with all stakeholder categories.

An initial set with new recommendations was developed, and its refinement led to the definition of the following 5 regulatory issues for consideration by regulatory stakeholders:

- The ICT Network Code Continuum is proposed by edgeFLEX addressing missing ICT network code provisions.
- A new ancillary service is needed to address the growing need to provide inertia in the grid.
- A new approach to local Voltage regulation based on integrating ICT solutions is proposed by edgeFLEX.
- A Network Code (NC) for Demand-Side Flexibility (DSF) taking in small assets is required.
- A Network Code on Cybersecurity is needed to address the growing array of threats with the grid is facing.

2.7 edgeFLEX Business modelling and stakeholder assessment

For the envisioned steps of the VPP evolution, the VPP1.1 and the VPP2.0, business models were developed.

The VPP1.0, respectively VPP1.1 business model is based on the use of large-scale RE plants. The VPP operator assumes the role of an aggregator. The edgeFLEX VPP optimisation and existing plant portfolio management differ in their method as well as in the scale regarding numbers of plants that can be managed and thus the achievable results. The number of power plants under management and which can be optimised is about 200 - this high figure can be reached when batteries are included in the asset configuration. In addition, the optimisation is focused on high-speed computing, which is the key element leading to increased profits.

The VPP 2.0 Business Model enables end users to provide their smaller assets to the DSOs for voltage control and congestion management. In future, if regulatory change is enabled, the services end users can offer could be extended to include frequency and inertia services if the small assets were enabled to provide such services. The Energy Community can take on the role of the aggregator, or the DSO can provide these services to the Energy Community or respectively to a group of end-customers. This is a business model which offers a technical solution enabling the DSO to engage with a VPP which is managing small community-based assets to solve local balancing and congestion management issues in addition to its normal portfolio of larger assets.

The business model investigates the technical solution and frames it in the business context in which early adopters, channels, key metrics and cost and revenue structures are identified. The business model developed can identify how a business would adopt the edgeFLEX solution. It helps exploiting parties to prioritise activities for early engagements with adopters of the platform. This Business Model, while DSO focused, can form the blueprint for other technical solutions, such as Frequency Control or Inertia Estimation, both of which are services identified and researched in the edgeFLEX project. Partners who wish to exploit the outputs of the project can take the business model and rework it to meet the goals of a specific technical solution.

The business scenarios associated with the business models were evaluated from the perspective of the company's key stakeholders to explore and assess how each scenario impacts the company and its staff. For these assessments, edgeFLEX developed a questionnaire with specific questions that the various relevant stakeholders in the company would ask about the edgeFLEX solutions if they were considering their implementation. The questions they would ask were broadly categorised as financial, management, regulatory, capabilities, perception, system impact, and work processes. The survey was administered to the five broad groups of stakeholders focused on business, compliance and governance, system, and technology. The structure and breadth of this assessment lead to results that clarify the pathways to adoption of the solutions and facilitate the use and adoption of key actionable results developed and delivered by edgeFLEX. The approach to the analysis forms the basis for a blueprint for the deployment of the edgeFLEX results on a commercial scale.

2.8 Dissemination and impact efforts of edgeFLEX

By the end of the project, edgeFLEX had created impact with its research results through numerous publications, 4 accepted global standards contributions, a book, summer schools and professional courses and through videos, conferences, and other events. Interest in the research results was high and feed-back from energy and communications sector organisations was positive. Our proposals for regulatory change have aroused the interest of the regulatory sector actors in many European countries and we engaged with them in close to 50 meetings in which we discussed our on-going work on regulatory issues with them.

edgeFLEX together with the projects Platone and FEVER developed the idea of the *FlexCommunity,* which was set up and officially kicked off with a big online event in February 2022. The FlexCommunity is a network where all stakeholders in the field of flexibilities can join, discuss, and work together on all aspects relevant for leveraging distributed flexibility in the energy system – from technical, business, and organisational questions on a conceptual level to solutions for Energy Communities and DSOs to discussions on specific topics such as FlexOffer and its role in leveraging of flexibility. After one year with regular working group meetings, in February 2023, a 2-day online conference was organised. The community will continue its work beyond the end of the funding period of edgeFLEX.

The edgeFLEX field trials and Energy Community implemented in Germany and Italy demonstrate the ease of deployment of the edgeFLEX services and show how they can be incrementally deployed with a plug and play approach to suit the needs of specific energy organisations. They have had the impact of creating confidence in the edgeFLEX solutions. SWW, which ran field trials of edgeFLEX slow and fast dynamics services and supports a local Energy Community, has developed a blueprint for the deployment of edgeFLEX services and enablers throughout their network. It is their ambition to deploy edgeFLEX services as exploitation of project results, throughout their network.

The well-developed exploitation plans of consortium partners will further strengthen the impact of project results as further field trials, commercial deployments, products, services and teaching materials are developed after the end of the project.

3. The edgeFLEX approach to addressing the challenge

In this chapter the project management activities followed by a detailed description on the progress made each year on the main topics of research, development, innovation, and field trial deployment is provided. It is complemented by descriptions of the edgeFLEX regulatory issues and business model investigations, awareness, and impact creation activities.

3.1 Project Management progress

The project management has progressed smoothly during the project lifetime with only minor problems which were resolved with frequent and effective communication between partners. All project meetings were held virtually for the first two years of the project. The collaboration between partners in the lifetime of the project was excellent and a key factor in the success of the project in reaching and exceeding its goals.

The good progress made by the project in the first reporting period continued during the second reporting period despite challenges due to staff changes in partner organisations. We were able to implement changes to take on board all of the valuable feedback we received from our Advisory Board and first Periodic Review.

All reports and deliverables have been finalised as planned. We present our final set of strategic and detailed results, on our web site and in our reports. All public reports of the project, and links to project scientific publications, are available on the project web site.

The achievements can be summarised as follows:

Project Year 1

- The Covid-19 pandemic brought restrictions on meetings and travel right from the from start of the project in April 2020. All project meetings were held virtually in the first project year and partners had to adapt to a lot of restrictions and find ways to work effectively without the level of interaction possible in presence meetings. The project management experimented with different techniques to create a relaxed atmosphere and good breaks in the meeting in which the focus was not on discussing project progress or plans. In the monthly PMT meetings, the status of Covid-19 restriction in each partner country and the effect of these restrictions on the work of each partner were reviewed as the first agenda item of the meeting giving us all a good overview and enabling us to make alternative plans as needed to maintain project progress.
- All project deliverables and milestones were achieved on time as planned and technical work progressed well. Quarterly reports on progress were compiled and resource usage monitored. Events were organised as virtual rather than as presence events.
- The first meeting of the edgeFLEX Advisory Board was organised and the feedback from the members was translated into a set of action points followed up in the monthly PMT meetings.

Project Year 2

- The project management contracted a professional trainer to run workshops on presentation skills, with a focus on creating impact in virtual meetings, for project members, with a noticeable improvement in their presentation skills of project participants becoming visible in the workshops.

- The first Periodic Review was prepared and run and the feedback received from the reviewer was reviewed as actions points in the monthly PMT meetings until all points had been integrated into the project plans and implemented. Feedback received recommended that edgeFLEX should place emphasis on the following issues in the second reporting period:
    - The verification of the technical capabilities and further analysis of the customer requirements for the edgeFLEX developments to promote the development and verification of management functionality,
    - Ensuring the deployment and operation of the PMUs in the field trials to provide the basis for utilising the new capabilities,
    - Identifying IPR ownership issues to maximise their exploitation potential,
    - The further improvement of the gender balance at all levels of personnel assigned to the action, including at the supervisory and managerial levels.
- The focus of much of the technical work was on bringing those research results planned to be deployed in field trials to a maturity sufficient to allow their implementation and integration into the edgeFLEX platform.
- New research concepts and algorithm improvements, not planned for deployment in field trial sites, were tested in simulations and with historical data to provide feedback on their effectiveness and to provide a basis for the improvement of the algorithms in a process of continuous improvement and feedback. Tests of 5G support for services and enablers were undertaken with a range of 5G test infrastructures offering capabilities of interest to the project to study.
- The planning of the field trials in Italy and Germany was completed and the roll-out of the trial infrastructure progressed with some delays due to Covid-19 restrictions. The trial of the VPP performance improvements in the ALPIQ VPP management system was organised, run and documented in an initial report.
- edgeFLEX organised a presence stand at ENLIT'21 which was held in December 2021 in Milan, Italy shortly after Covid-19 restrictions applying in Italy and Germany had been partly relaxed. Presence attendance at the event was low restricting the impact the project could achieve.

Project Year 3

- As almost all the research activities in edgeFLEX had been completed in the second project year, the focus of work moved strongly to the execution of the field trials in the live SWW and A2A distribution networks and the interpretation and documentation of test results from the trial sites.
- The business models and regulatory issues inherent to the evolution of VPPs to enable them to take on an expanded role in the provision of flexibility to the grid were intensively studied with many workshops and meetings held to engage with stakeholders and obtain feedback which was used to focus the finalisation of the business models and regulatory issue descriptions.
- The 2nd Advisory Board meeting was organised on 29th September 2022 as a virtual event and regular follow up was organised in the PMT meetings to ensure that project results were improved based on deep consideration of the feedback received from the Advisory Board members. The board proposed that edgeFLEX should consider:
    - The further investigation and documentation of the advantages of 5G systems in comparison to the good performance of 4G (LTE) mobile

systems in supporting many of the requirements of power services,

  - The further investigation and documentation of the benefits of the edgeFLEX results and solutions,
  - The clearer presentation of which research results had been taken to simulation stage and which to implementation and deployment in the edgeFLEX platform and at the field trial sites.
  - Revising the exploitation plans for edgeFLEX results in relation to changing market needs resulting in a growing pull from industry for the flexibility results of edgeFLEX and away from the need to promote the need for flexibility and the pushing of technical results to the market.

  All points were taken up in project meetings and addressed.

- In the final months of the project, an exercise to define the key operational and technical results of our work was organised as our results had in many cases gone beyond those planned in the Grant Agreement. The overview resulting from this exercise was used to synthesise the individual results into a set of strategic results from the project. The strategic results enable target audiences for our results to more easily grasp the meaning of the advances made by edgeFLEX and how different sector actors can benefit from the project results.
- A number of project stands in mobile communications and in energy sector trade fairs and other presence events were organised and as attendance numbers recovered following the lifting of Covid-19 restrictions, the value to the project of presence attendance at events increased. Two project meetings were held as presence events in the final six months of the edgeFLEX project.
- All deliverables were prepared, reviewed by the project to ensure their quality, and submitted on time.
- The preparation of the final project review was completed, and recordings of demonstrations were prepared.

3.2 Dynamic-phasor driven voltage control concepts

The work of WP1 has been dedicated to the development of the voltage algorithms and to testing them in the field. The control algorithms have both centralised and distributed control scheme forms and both control schemes have been implemented and tested in the context of edgeFLEX.

In the third and final project year, the voltage control algorithm has been further improved for use in the filed implementations. The voltage control has been implemented in both the SWW and the A2A field trials with two different types of algorithms.

In the SWW field trial, the objective was to integrate the voltage control algorithm developed in D1.3 with the SLA Monitoring Tool and the KIBERNet platform. The close cooperation with WIT and INEA has allowed the full integration of the voltage control in the field, creating flexibility request for the customers. In the third year of the project, the implementation of the voltage control algorithm has been reviewed and modified, to be able to be interfaced with the customers. Moreover, the data received from the edgePMUs installed in Wunsiedel and the power generation data received by KIBERNet have been integrated in the simulation environment and provided to the voltage control.

In the Italian field trial, a distributed formulation of the voltage control algorithm has been implemented using software containers and integrating peer-to-peer communication. The measurement data obtained from the field have been integrated in the simulator, where the original grid has been extended with a simulated once, to generate a sufficiently large variation of the voltage that would require the action of the voltage control algorithm. This additional algorithm, which has been carried out during the last year of project, represents a novel implementation of the distributed online voltage control using software containers and communication interfaces.

The achievements can be summarised as follows:

Project Year 1

- Analysis of the state of the art related to VPP.
- Definition of a voltage control service scenario.
- Definition of use cases in which the voltage control will be implemented.
- Definition of the project technical terminology.
- Development of voltage control algorithm.
- Preliminary testing of the algorithm.
- Development and testing of the edgePMU concept

Project Year 2

- Development of the voltage control algorithm for engaging customers.
- Adaptation of the algorithm for WP4 further implementation and integration with the platform.
- Test of the algorithm in a simulated environment

Project Year 3

- Integration of the measurement from the fields.
- Implementation of the voltage control algorithm in the SWW trials.
- Implementation of the distributed voltage control in the Italian field trial.
- Improve the voltage control algorithm for accepting both actual and simulated measurements.
- Test of the voltage control algorithms and collection of the results.

3.3 Frequency control and inertial response concepts

One of the objectives of edgeFLEX was to develop frequency control and inertia monitoring services enabling VPPs to participate in providing frequency control and to be able to offer it to grid operators as an ancillary service.

The tasks in work package WP2 have continued through the full project duration. The results were provided to other work packages, e.g. WP 4. In the first year, the optimisation techniques and centralised control approaches to be implemented in real time for frequency control and inertial response from VPPs were developed. They enable VPPs to participate actively in the frequency and voltage control of the grid by providing ancillary services. These services compensate the VPPs normal revenue streams based on selling energy by providing them with an extra stream of revenue. This enables the realization of future generations of VPPs, i.e., the VPP2.0 as defined by edgeFLEX.

Moreover, novel concepts of Geometric Frequency (GF), Complex Frequency (CF) and Rate of Change of Power (RoCoP) were also developed. These concepts contributed towards the development of the novel control strategies and frequency regulation metering, which enables the system operators to reward VPPs based on their contributions in the ancillary services.

Over the subsequent years of the project, WP2 focused on the further improvements in the control strategies and algorithms so that they could be implemented in future generations of VPPs and Energy Communities (ECs). Further advances were made in the concept and applications of GF, CF and RoCoP.

The list of achievements categorised by each year are as follows:

The achievements can be summarised as follows:

Project Year 1

- Analysis of the state of the art of frequency control.
- Definition of frequency control and inertia estimation scenarios.
- Definition of use cases in which the frequency control and inertia estimation will be implemented.
- Definition of the relevant functional and communication requirements for full commercial roll out.
- Development of frequency control and inertia estimation algorithms.
- Preliminary testing of the algorithm.
- First drop of the developed algorithms as software packages for platform integration.
- A detailed analysis of current trends, technical issues, and challenges in frequency control and inertia estimation of VPPs, and the provision of virtual-inertia through non-synchronous devices.
- In depth analysis of the novel concept of VPPs and the variety of devices, topologies, and voltage levels where VPPs can be implemented.
- Definition of relevant scenarios for the frequency and inertial response control services.
- Definition of scenarios for inertia estimation with high penetration of converter-interfaced devices.

- Development of coordinated control strategies for both Primary Frequency Control (PFC) and Secondary Frequency Control (SFC) services provided by the VPPs.
- An AGC approach to coordinated Distributed Energy Resources (DERs) forming the VPPs for the provision of the SFC.
- A new theoretical advancement, namely the concept of the Complex Frequency (CF). This definition extends the domain of the frequency to the complex domain.
- A practical criterion to distinguish between devices that modify the frequency from those who do not based on their Rate of Change of Power (RoCoP). CF allows for a complete and consistent formulation of the RoCoP at the buses in electric grids.
- Applications of RoCoP:
    - estimate the amount of frequency regulation provided by the grid-connected devices;
    - reward ancillary services of grid-connected devices that provide PFC;
    - quantify the inertial response provided by non-synchronous devices;
    - the estimation of voltage dependent loads; and
    - the identification of the source of forced oscillations.
- Proposal of a novel grid-forming control for DERs with inclusion of energy storage and the capability of providing frequency support.
- Analysis of the impact of smart transformer in the coordinated frequency and voltage control of distribution systems.
- An online method to estimate in real-time the equivalent inertia of synchronous machines, converter-interfaced generators forming VPPs and energy storage systems. This is used to improve the fast frequency response provided by the future generations of VPPS.
- Extension of the inertia estimation technique to:
    - clusters of generators and virtual power plants;
    - include also the estimation of the frequency droop control capability of DERs; and
    - allow system operators to assess and quantify the total system inertia and inertia in parts of the grid.
- Comparison of various setups of the coordinated frequency control.
- All of the algorithms developed were tested and validated using computer based simulations.
- The techniques and algorithms developed were dropped as containerised software modules to work package WP4 for integration in the edgeFLEX platform.
- Publishing research in high impact journals and books.

Project Year 2

- Update of the frequency control scenarios defined in the first year of the project.
- Definition of inertia allocation scenarios and use cases.

- New theoretical advancement: the development of the concept of the **complex frequency**.
- Development of the frequency control concepts for LECs, through reactive power/voltage feedback.
- Development of a scheduling tool for optimal allocation of virtual inertia.
- Proof-of-concept testing and validation of the frequency control and inertia allocation algorithms.
- Generalization of the Park transform which is the most important transform utilised in power system modelling and control.
- The concept of CF was extended to multi-vectors (geometric frequency, GF). This provides a novel interpretation of frequency as a geometrical invariant (curvature).
- The GF can better capture the power and frequency variations in a power network.
- A new theoretical concept for modelling, estimation, and control of frequency variations via VPPs.
- Set of novel grid-forming control strategies for VPPs that can provide coordinated frequency and voltage controls in the distribution systems by varying their active and reactive powers. This is step towards the new generations of VPPs, i.e., VPP3.0.
- Methodology to engage ECs towards the voltage control of low-voltage level grid.
- An aggregated VPP model for system-wide transient stability analysis studies.
- A novel approach for coordinated control strategy for charging large fleets of electrical vehicles to avoid voltage and frequency instability in distribution systems by dynamically allocating the available power in an optimised way.
- Novel approach to study the stability of grid-forming converters. The study focuses on current transients and the impact of current limiters. This work offers new modelling tools needed to implement the VPP 3.0 vision.
- A mathematical framework for the study of the control of micro-distributed DERs and ECs at low-voltage level.
- Study of the effect of topology on the frequency support capability of virtual power plants.
- A novel long-term dynamic model that can predict the effect of policies on the development of PV power plants is developed.
- Modelling of stochastic processes for the dynamic analysis of virtual power plants. This work offers new modelling tools needed to implement the VPP 3.0 vision.
- Application of the concept of RoCoP to show how the frequency variations during a transient of a power system distribute as a continuum that can be formulated as a set of partial differential equations.
- The concepts developed in edgeFLEX WP2 were also included in a book.
- Development of a scheduling tool for optimal allocation of virtual inertia.
- Proof-of-concept testing and validation of the frequency control and inertia allocation algorithms.

- Delivery of the developed algorithms as software packages for platform integration.
- Publishing research in high impact journals and books.

Project Year 3

- Refinement of the frequency control services developed in the first two years of the project.
- Dissemination of the control strategies and novel frequency concepts developed in WP2. Among the several publications and seminars, we cite an edited book with title “Advances in Power System Modelling, Control and Stability Analysis”, The IET, 2022, and a survey paper on micro-flexibility presented at the Power System Computation Conference (PSCC), in June 2022, and later published on an Elsevier Journal (Electric Power system Research).
- Application of the RoCoP concept to the study of the effect of the frequency control to improve voltage stability margin of a grid.
- Application of the CF to the taxonomy and control of converters.
- Application of the CF concept to the design of the virtual impedance control of DERs.
- Discussion on the effect of stochastic noise with non-Gaussian distribution on the dynamics and control of the grid edge.
- Publishing research in high impact journals and books.

3.4 Concepts of 5G Dynamically Controlled VPP optimisation

VPP Optimisation Algorithm improvements achieved

Further development of the VPP optimisation service was undertaken and completed to increase the performance of the optimisation algorithm. A journal publication based on the results was prepared and published: “Optimal balancing of wind parks with virtual power plans” in “Frontiers in Energy Research”. The paper was peer-reviewed and published. The methodology was presented as part of a Stonybrook University Webinar which was live in March 2022.

In the third and final project year the work focussed on the finalisation of D3.3 describing the VPP optimisations.

Requirements and potential 5G-powered 5G-solutions finalised

The activity of defining requirements and potential 5G-powered 5G-solutions continued in the third year of the project until project M30. In line with the recommendations of the first periodic review, the focus was placed on the elaboration and documentation of user requirements the requirements of the edgeFLEX services and of the edgPMU. Deliverable 3.1 was prepared and submitted documenting the results of this task. EDD provided the defined requirements to its product and development units to enable improvements to address the requirements of the edgeFLEX use cases. Early requirements had already been provided during the first project year to the Ericsson 3GPP SA1 team leading to an accepted proposal which was published as a standard.

Successful submission of proposals for 3GPP standards based on the results of work on the 5G-API for Device Management

The results of the work of EDD on the 5G API for Device Management were handed over to the EDD team in the IoT-NGIN for further development. The results of that effort led to the successful submission of 3 proposals to the global standards 3GPP SA6 working group and EDD supported the efforts of Ericsson AB to prepare the proposals during the third project year. All three submissions were accepted and published as standards.

The achievements can be summarised as follows:

Project Year 1

- VPP optimisation Results of Task 3.4 VPP optimisation algorithm have resulted in an academic publication.
- Research results showing that the intraday market does not behave in a stochastic manner; it has also been demonstrated that if suitable meteorological data can be provided to a neural network, then the intermittent energy forecast can outperform the commercial models currently available.
- Revision of the research will be proposed to leverage and document the experience feed-back that we will obtain through the field trial in Work Package 5.
- The definition of the ICT requirements of the edgeFLEX use cases was completed,
- The preparation of the edgeFLEX use case for consideration at the 3GPP SA1 meeting in March 2021 was completed and it was successfully adopted into the 5G standard,
- The preparation of the laboratory environment to undertake the development of new features for the 5G API was undertaken, and

- The definition of a solution sketch for 5G support of edgeFLEX services was completed.
- During year 1 the design of data acquisition, on a low-cost computational device, and the required data processing functionalities for the implementation of the edgePMU were completed. The first prototype of the edgePMU unit was completed and characterised in laboratory environment.

Project Year 2

- A new method to increase the performance and scalability of optimisation assets in a VPP was developed and verified. Up to 200 VPP assets were modelled, demonstrating the capability for robust scaling of this optimisation service using the new method.
- The results and methods were published in a paper “Optimal balancing of wind parks with virtual power plants” in the journal Frontiers in Energy Research.
- The results and method were presented in Stony Brook University Webinar in March 2022.
- Investigation of the physical conditions of deployments of devices in the project field trials was finished.
- The integration of the 5G Device Management API proof-of-concept with the edgePMU software was completed and tested in the laboratory environment.
- The demonstration frontend for the 5G Device Management API proof-of-concept was fully developed.
- During the second year of the project the edgePMU prototype was further developed and refined. The first units needed for the deployment in the field trials were assembled and delivered to both the Italian and German trial sites. The integration with the edgeFLEX architecture was carried out, specifically with the data bus and the voltage control algorithm for demonstration and validation purposes.
- The edgePMU was submitted to the European Innovation Radar initiative and was accepted as innovation with a Tech Ready market maturity and a noteworthy market creation potential.

Project Year 3

- The finalisation of deliverable D3.3 describing the outcome of the VPP optimisations was undertaken in the third project year.
- The identified ICT requirements and 5G powered solutions were disseminated to experts in the Mission Critical Business Unit in Ericsson, which has taken them into account in the preparation of plans for 5G product and service enhancements.
- The results of the work undertaken earlier on the 5G-API for Device Management led to the successful preparation by Ericsson AB of three proposals for standards submitted to 3GPP. All three proposals were accepted.

3.5 The edgeFLEX Platform and Services

One of the main aims of the edgeFLEX project from a technical perspective is to build the software components to containerise the research and innovation concepts from WP1, WP2 and WP3 so that they can be deployed in the field and laboratory trials. In the first year of the project work, the aim was to gather requirements, develop the architecture and to prepare the initial prototypes of the services, the SLA Monitoring Tool and the data interfaces. Furthermore, we aimed to develop the technological use cases that would shape the work going into the second year of the project.

The final year of the project focused on leveraging the platform and services to enable the use cases described for realising slow and fast dynamics services, flexibility trading and interacting with the energy community and VPP optimisation and to demonstrate how the platform could enable the evolution of the VPP.

The platform and services were refactored and improved based on feedback gathered from the trial sites via the trial site assessment surveys. In addition, the market platform defined in the previous year was extended to ingest data from edgePMUs in the field and to interface with the edgeFLEX platform in order to capture this data for storage and visualisation. Moreover, the platform was extended to interface with the trading platform in order to realise the Voltage Control, SLA and Flex Offer use case as defined in the first year of the project. This work was deployed to the trial site for WP5.

Finally, the platform interfaces were refactored to facilitate the requirements for the VPP Optimisation to remain within the VPP Operators (ALPIQ) company boundaries, these requirements arose due to security concerns centred around commercially sensitive data. This work was completed and deployed to capture VPP Optimisation algorithm outputs in the edgeFLEX Platform.

The achievements can be summarised as follows:

Project Year 1

- Requirements Gathering
- The functional and non-functional requirements for the services were gathered, correlated and a generic basic container for hosting the services was defined.
- An identity matrix was created, and the project wide services and components were aligned to their specific actor and function in the energy sector. The output of the matrix was the identification of a natural synergy between three components of the edgeFLEX Platform, namely the Voltage Control, the Dynamic SLA Monitoring Tool and the FlexOffer components.
- Solution architecture workshops were conducted to get a multi-layer view of the Grid Management Services so that the interfaces, goals and supplementary components and data streams could be identified.

Software Service Integration

- From the outputs of the requirements gathering phase a set of backbone services, ones that are needed for all the Grid Management Services, were identified and built so that the Grid Management Services could interface with them when delivered.
- Taking input from WP1 & WP2 in the form of software modules and using the outputs of the requirements gathering a set of containerised services were created for Voltage Control, Frequency Control and Inertia Estimation and they were integrated into the platform.

- One of the key activities of the integration work was to build a deployment method where the services could be configured when deployed to connect to trial site components as well as edgeFLEX specific components. This is carried out using configuration files that are injected to the service when it is being deployed and such configurations can include connection strings or data streams that the service can automatically pick up.

Architecture

- From the use cases that are linked to the trials a set of architecture diagrams were created to ensure that the goals of the first phase of the project were achieved.
- These provide the starting point around which the full edgeFLEX platform architecture can be developed.

Dynamic Service Level Agreement Monitoring Tool and Brokerage

- The requirements for this item were determined.
- The nature of the component was identified in terms of what technological. solutions it could provide for the platform.
- A proof of concept of the tool was built and deployed.

Voltage Control – SLA Monitoring Tool – FlexOffer Use Case

- From the identity Matrix this use case was identified that combined grid control with the creation of flex offers via the SLA Monitoring tool.
- This use case has now been finalised in terms of the components needed for it to work in the trials in SWW Germany.
- There has also a development plan created so that we can begin building the software and the data streams needed to perform the trial.

Project Year 2

Architecture

- The edgeFLEX architecture was developed using the SOGNO architecture and extending it from the System Operator towards the VPP and Energy Community by gathering requirements from the trials, the grid management services and other connected platforms like the GOFLEX platform.
- The edgeFLEX architecture was validated in consultation with the relevant partners to ensure that the platform and minimal viable products built within the blueprint of the edgeFLEX platform would be fit for purpose and that the architecture would offer enough flexibility to cater for the wide range of scenarios within the project (and potential new ones beyond the project).

Grid Management Service Interfaces

- The Grid Management Services of edgeFLEX (Inertia Estimation, Voltage Control and Frequency Control) rely on to receive data as inputs and send set points or estimations. This involved the development of the edgeFLEX backbone services which contains a databus (based on the DockerMQTT open-source component developed as part of the RE-SERVE project), a data store and a set of monitoring dashboards.
- The data stream from the KIBERNet platform to the edgeFLEX Platform has been established and the data is available as an interface for the control services.

- The deployment of the cloud element of the edgePMU (the Phasor Calculation service) was deployed within the platform so that field deployed edgePMUs could send data to the platform for use as inputs to the control services.

Grid Management Service Integration and Deployment

- The integration and deployment of the grid management services is an iterative process and during year two of the project focus mainly centred on getting the services trial site ready. This was carried out by using the platform assessment template developed in WP4 to identify areas where the services (and the platform in general) could be improved, making the improvements, and redeploying the services.

SLA Monitoring Tool and Policy Based Grid Management

- In year two of the project the SLA Monitoring Tool was deployed, and policies developed and used to share data and request data, to request flexibility and to provide asset constraints to the grid management services so that they can remain within operating limits.
- A set of APIs have been defined and implemented to both provide observability to external actors via the SLA Monitoring Tool and Policy Based Grid Management and as a method to retrieve data from external sources, which is core to the integration of the platform in the SWW Trial where data from their existing platform, KIBERNet, is required.
- As a concept and as a system that can enable cross sector actor collaboration use cases Policy Based Grid Management was proposed to the Commission as an item that was suitable for the Innovation Radar.

Voltage Control – SLA Monitoring Tool – FlexOffer Use Case

- This use case was further advanced in the 2nd year of the project with developments to the Voltage Control, the SLA Monitoring Tool and the KIBERNet platform (that will facilitate the use case) in an advanced state prior to deployment to the trial in the early part of the 3rd year of the project.
- The components in the SWW trial have been identified.
- The data streams from the relevant components have been identified and established.

Platform and Control Service Assessment and Feedback Loop

- A comprehensive platform assessment has been developed will be completed and reviewed on a bi-monthly basis at each trial.

  This platform assessment has been used within WP4 and in the 5G Laboratory trials and the feedback loop is in place to the relevant researchers and partners within the project to address any issues identified. The feedback loop will receive assessments of the platform deployment in the lab and trials and identify the improvements that need to be made to the platform via WP1, WP2 or WP3 and in within WP4 also.

Project Year 3

Grid Management Service Interfaces

- The edgeFLEX platform interfaces were extended from those defined in year two to support the capturing of outputs from the VPP Optimisation algorithm to meet the security needs highlighted by the VPP operator when considering commercially sensitive data.

- The edgeFLEX market platform interfaces were implemented to enable the interaction with external systems to request both flexibility schedules and observability to enable engagement with the energy community on behalf of relevant grid services.

Grid Management Service Integration and Deployment

- Following on from the work in year two of the project, once deployed to the trials, the platform and services were continually assessed via the platform assessment template which was defined and developed in WP4. This feedback came directly from the trial sites from both a technical and usability perspective, and this feedback was utilised to make improvements to the platform and services.

SLA Monitoring Tool and Policy Based Grid Management

- The work achieved in year two of the project, to prepare the APIs for interaction with KIBERnet was finalised and deployed to the trial. This enabled the SLA to make requests for flexibility on behalf of grid services utilising the flexOffer templates defined in WP4.
- The Policy Based Grid Management concept was accepted into the EU Innovation Radar.

Voltage Control – SLA Monitoring Tool – FlexOffer Use Case

- In year two of the project the necessary components and data streams to realise this use case were identified. Year three focused on making the necessary adjustments to enable the interaction between the required systems.
- The Voltage Control, SLA Monitoring Tool and KIBERnet platform interaction was tested utilising a sandbox environment to prove that in the event of a simulated over voltage, the Voltage Control service can request flexibility from KIBERnet via the PBGM system (SLA) leveraging the flexOffer templates defined in WP4.
- Once the interactions were proven, the PBGM policies referencing the sandbox were adjusted to engage with a set of prosumers on the trial.

Platform and Control Service Assessment and Feedback Loop

- The platform assessment was further utilised to identify issues on the trials. An example was the need to provide and interface on the edgeFLEX platform to capture VPP Optimisation outputs.

3.6 Field Trials

Each of the technologies developed will be validated in one or more sets of tests, in the field or in a lab or in both contexts, as illustrated in Figure 7.

3.6.1 German Slow Dynamics Trials

In the third and final project year the work focussed on the finalisation of D5.2 describing the field trial of the VPP optimisations developed in WP 3 in the ALPIQ off-line VPP management system using historical data.

The achievements can be summarised as follows:

Project Year 1

- The wind parks, the biogas powerplants in Germany were identified. Their locations cannot be disclosed by Alpiq for commercial confidentiality reasons.
- We elaborated the algorithms for the management of the systems with two biogas power plants and batteries operating on the day ahead and intraday markets and managing the imbalances.
- The algorithms have been optimised to work very efficiently to provide decisions in seconds.
- The platform in which the algorithms will be deployed was chosen. It runs on Python and can be deployed either on a cloud or on a personal computer, easily. Everything can be run on open-source software.

Project Year 2

Trial Deployment

- Calculations for utilising biogas power plants for the balancing of wind parks also considering known imbalances as well as simulated.
- Forecasting algorithms was further elaborated and optimised.
- Data acquisition via back-testing of historical data and calculations of imbalances was carried out.

Initial Results

- Two thirds of the imbalance of the wind parks was balanced by the virtual power plant. The remaining imbalance had to be purchased from the market.
- With additional biogas power plants in the virtual power plant, then full balancing (deficits) could be achieved. In 2022, Alpiq started to manage two more biogas power plants. These power plants will be included into the model of a VPP.
- With the VPP optimisation algorithm, profits for the biogas power plants were increased by >2%.

Project Year 3

- In the final project year, the work focussed on the finalisation of D5.2 describing the trial results.

3.6.2 Italian Fast Dynamics Trial

In the third and final project year the aim was to test the voltage control service in the trial. The first step involved the integration of the edgePMU and the commercial one inside the existing equipment in the A2A facilities. The first step was fundamental to initialise the measurement process and data collection from the devices. The second step consisted of simulating different scenarios exploiting the actual measures and a digitalised version of the portion of grid considered.

The achievements can be summarised as follows:

Project Year 1

- The integration of the hardware and software is being carried out as well as the preliminary testing of the project's edgePMUs.
- A nondisclosure agreement was signed with A2A to regulate the legal issues of their provision of their distribution network infrastructure to edgeFLEX for use in our field trials of fast dynamics, although they are not a project partner and not receiving funding from edgeFLEX.

Project Year 2

Trial Deployment

- Talks and agreements with A2A for asset identification, edgePMU and platform installation and integration for running field trials.
- Voltage control measures integration for the purpose of the trials.
- Assessment of 5G communication availability in the field trial area.

Initial Results

- Trail site requirements defined.
- Development of voltage splitter to enable edgePMU installation.

Business & Dissemination

- Support and carry-out of dissemination activities as part of WP6.
- Creation and development of business modelling for ancillary services in line with national grid codes were defined.

Project Year 3

- Validation of the edgePMU and the commercial PMU communication.
- Integration of the edgePMU and the commercial PMU into the existing A2A measurement equipment.
- Acquisition of the voltage and current measurement from the two types of PMU.
- Digitalisation of the portion of physical grid hosting the trial.
- Simulation of different scenario including actual measures and the distributed voltage control service.

3.6.3 Wunsiedel Slow and Fast Dynamics Trial

In the third and final project year the slow and fast dynamic services were deployed for testing to provide proof of feasibility of those services in a real-life operational power distribution grid. To that aim, communication between the already-in-place Energy Management System (EMS) integrated within the scope of the GOFLEX project, the edgePMU developed in WP3 and the edgeFLEX platform was established. Furthermore, SWW was able to secure the acquisition of stakeholders willing to participate in the energy supply system to from a virtual Energy Community, which was implemented in all forms but legal. These actions contributed to the deployment of the services and to a possible flexibility offer generation scheme for running the tests.

The achievements can be summarised as follows:

Project Year 1

- Mapping the grid's topology in PowerFactory.
- Possible locations were found for edgePMUs.
- Cloud was decided upon.
- Communication infrastructure was assessed.

Project Year 2

Trial Deployment

- edgePMU and platform instantiation.
- The KIBERNet system was integrated and FlexOffer requesting schemes were defined.
- Voltage control measures integration started.

Initial Results

- Harnessing data-flows from the GOFLEX project.
- Cash-flow sources identified.
- Flexibility price per kWh was identified.
- SWW–RES owners cooperation agreement was formed.

Business & Dissemination

- Support and carry-out of dissemination activities as part of WP6.
- Creation and development of business modelling for ancillary services in line with national grid codes were defined, including flexibility aggregation, ancillary services and for Energy Communities.

Project Year 3

Trial Deployment

- edgePMUs and platform instantiation.
- The KIBERNet system was integrated capable of communicating with the edgePMUs and the edgeFLEX platform to create FlexOffer and requesting schemes.
- Voltage control measures integration deployed.

Initial Results

- Harnessing data-flows from the GOFLEX project, while flexibility aggregation can be achieved using this system.
- Flexibility aggregation and storage show its cruciality for flexibility trading and business processes.
- edgeFLEX services and edgePMU allow improve transparency when monitoring grid events.

- Grid reinforcement strategy to allow more flexibility and penetration of RES was validated as successful.
- Stakeholder engagement potential to increase flexibility was demonstrated, whereas interest and willingness to participate by additional stakeholders was observed.

Business & Dissemination

- Support and carry-out of dissemination activities as part of WP6 and WP7.
- Creation and development of business modelling for DSOs to have more control over their grid by utilising ancillary services, flexibility aggregation, ancillary services and Energy Communities.

3.6.4 edgeFLEX Energy and 5G Laboratory Tests in Germany

In the third and final project year the focus of efforts was on the documentation and final interpretation of the 5G related test and requirement capture work of the first two project years. Efforts to support the trial sites to get 5G coverage from mobile operators at the locations needed to support our field trials continued during the third project year. Support was given to the successful efforts of Ericsson AB to standardise the results of the 5G-API for Device management results developed in the first reporting period.

The achievements can be summarised as follows:

Project Year 1

- Test cases for each edgeFLEX service were defined and synthetic data streams typical of each service were specified.
- 5G laboratory equipment was configured and integrated in the Ericsson laboratory in Aachen.
- The ICT requirements of each edgeFLEX service were defined. Tests of each edgeFLEX service were performed in the 5G network using synthetic data streams.
- The preparation of the laboratory environment for 5G tests of latency performance,
- A test series measuring latency performance under different conditions of attenuation of the radio communications link the required laboratory configuration was investigated,
- The testing of the ability of 5G networks to fulfil the edgeFLEX use case latency requirements on live 5G networks with synthetic data,

Project Year 2

- 5G performance test with synthetic data of edgeFLEX services on the 5G standard standalone network in the laboratory were completed.
- 5G performance test of the frequency control services with integrated edgeFLEX platform on 5G standard standalone and URLLC prototype networks in the laboratory were completed.

Project Year 3

- The preparation of deliverables documenting the 5G requirements identified and the 5G tests conducted in the earlier years of the project was undertaken and completed during the first half of the final project year.

- Efforts to support partners to get 5G live coverage at trial sites from mobile operators continued up to the end of the project.
- Support was given to the successful efforts of Ericsson AB to standardise the results of the 5G-API for Device management results developed in the first reporting period.
- Results continued to be disseminated within Ericsson global and European operations, particularly in relation to the marketing and development teams working on Mission Critical products and services.

3.7 Regulatory and business model work

In the third and final year of the project implementation, both our regulatory and business modelling work focused on a sharp analysis, interaction with key stakeholder categories, defining the final set of regulatory proposals and recommendations, as well as defining the optimal edgeFLEX business model.

The stakeholder engagement activities were intensified, edgeFLEX looked for synergies for a better substantiation of our initial recommendations regarding the regulatory framework.

After going through several scenarios for defining business models, in the last part of the project implementation, we substantiated and defined the most suitable approach for potential edgeFLEX business models.

The achievements can be summarised as follows:

Project Year 1

- The comprehensive plan of the business modelling and regulatory assessment activities.
- The definition of a new financing model for RES, to simplify investments in RES beyond subsidy schemes.
- Preliminary comparative analysis of potential business impact.
- Defining initial proposals in regulation, mainly addressing in a first stage the technical challenges of edgeFLEX solutions.
- Laying the foundations for preparing the exploitation of the project results.
- Carrying out an intense activity in the process of engaging with policy makers, with organizations and experts in regulation and standardisation:
    - participation in specific events and workshops where we had interactions and exchange ideas with the main stakeholder categories.
    - organisation of sessions dedicated to the regulatory aspects of the edgeFLEX project within consultation events with wide international participation.
    - bilateral meetings.
    - organising the first virtual meeting of the edgeFLEX Advisory Board.

Project Year 2

- Organising workshops within the project to analyse all relevant aspects on exploiting the project results, referring to the specific context of each partner in the project, but also from the perspective of the main stakeholders, and submitting the deliverable D6.6. – Preparing exploitation.
- Part of the second phase of consultations with stakeholders was carried out, from the perspective of validation and completion of regulatory proposals.
- Further assessment and advancing with the reformulation of the two initial business modelling scenarios, which will be the basis for further analysis towards the definition of the optimal business model for edgeFLEX Dynamically controlled VPP solutions: system operator or the energy community operator playing the aggregator role.

- Publication of a scientific article in Frontiers, to generate debates at the academic and practitioners' level regarding the promotion of regulatory measures applicable to the edgeFLEX context.
- The activity of involvement and participation in seminars, workshops and international events continued in the second year of implementation, having the same perspective of validation and completion of concepts and solutions outlined in the first year of implementation.
- Organisation of sessions dedicated to the regulatory aspects of the edgeFLEX project within consultation events with wide international participation.
- Bilateral meetings with key stakeholder organisations, including Agency for Cooperation of Energy Regulators (ACER).
- Planning on further consultation with stakeholders focusing on the regulatory authorities and practitioners.

Project Year 3

- We intensified our stakeholder engagement activities, refining and completing the set of regulatory recommendations:
  - 6 new participations in events where we presented the edgeFLEX project and our recommendations for the regulatory framework.
  - participation in another 10 new workshops and specific information events regarding the context of edgeFLEX and the relevant regulatory aspects
- We had collaborations and consultations with key stakeholder categories for the field of regulation, DSOs and TSOs: CEER, ENTSO-E, E.DSO, and Irish regulatory authority.
- We communicated our recommendations for updating and completing the regulatory framework to national regulatory authorities and DSOs, with the support of the two key organisations, CEER and E.DSO.
- We completed the initial set with new recommendations, finally defining the following 5 regulatory topics:
  - The ICT Network Code Continuum addressing missing ICT network code provisions.
  - A new ancillary service to address the growing need to provide inertia in the grid.
  - A new approach to local Voltage regulation based on integrating ICT solutions.
  - A Network Code (NC) for Demand-Side Flexibility (DSF) taking in small assets.
  - A Network Code on Cybersecurity
- Iterative analysis of several business scenarios evolving towards the optimal scenario for defining the edgeFLEX business model, with the perspective of exploiting the project results.
- A brief description of VPP operations with three evolutionary steps (VPP1.0, VPP1.1 and VPP2.0) was developed to provide a context for understanding how the research results developed in edgeFLEX can be applied to enable the evolution of VPP operations to provide an increasing contribution to stabilising the grid by adding functionality to the VPP.
- For the envisioned steps of the VPP evolution, the VPP1.1 and the VPP2.0, business models and scenarios were developed. An extensive stakeholder

analysis for these two scenarios was developed and performed and laid the basis for a comparison of the two scenarios from fours views – technological, societal, regulatory, and business.

- The partner SWW, uses the results of the edgeFLEX project for congestion management in cooperation with energy communities. The idea is to look at flexibility systemically, paving the way to VPP 2.0 and energy communities. SWW's situation was described in detail and the factors that lead to the need for the municipal utility to evolve. Also presented was the business case that frames SWW's evolution, what the overall vision is for implementing the VPP 2.0 concept in SWW, and what obstacles need to be overcome for it to be fully implemented.

3.8 Dissemination and Communication

The overall edgeFLEX dissemination and communication strategy followed a 3-step process, aiming to stimulate investment in renewable energy sources, to provide new options in flexibility trading exploitable within the current regulatory framework by a new definition of a VPP and to enable the creation of new local energy markets with new fast dynamics services requiring extensions of the current regulatory framework to be adopted at national level.

In the third and final project year the focus of the activities was on engaging actively with the relevant stakeholders to get feed-back to the project and for preparing the ground for large scale uptake of the results. Stakeholder engagement activities through the FlexCommunity have been intensified with 10 FlexGroups meetings in 2022 and a 2-day online conference in 2023 with panel discussion, interactive workshops, and a meeting of all FlexGroups.

A total of 39 workshops, special sessions, summer schools, stakeholder consultations, participations in conferences and project presentation at third-party events have been organised, online and hybrid and face-to-face.

An online blog was set up and maintained throughout the year giving personal insights into the work of the consortium partners to increase the online presence of the project. It was advertised via the project's LinkedIn channel.

2 videos have been produced to show how the trial sites improves the outcome of the technical work packages.

The scientific partners made another 13 peer-reviewed publications and organised a professional (online) course to introduce edgeFLEX concepts to academic and professional audiences.

The achievements can be summarised as follows:

Project Year 1

- Design of visual identity: an overall design was developed to make sure all project activities will be recognized as part of edgeFLEX.
- Set-up of website as the communication hub for the project containing all central information on edgeFLEX.
- Set-up of edgeFLEX LinkedIn group.
- Creation of template for slides, deliverables, and milestones; set of basic slides.
- Publication scientific papers, nine in 2020, eight more already submitted and to be published in 2021.
- Production of a video describing the Wunsiedel trial site.
- Participation at the projects zone of the online IEEE Smart Grid for Smart Cities conference.
- Organisation of Wunsiedel trial site workshop (virtual).
- Project presentation at ten invited talks talks in workshops and at international events, all of them at digital events.
- Co-organisation of online event for closer collaboration with H2020 sister projects FEVER, Platone and DECIDE.

Project Year 2

- Slide set with an overview of the project for presentation at events prepared.
- 2 project roll-ups.
- 18 peer-reviewed publications, in total 27, already exceeding the KPI of 15 scientific publications for the whole runtime of the project.
- Organisation of 26 workshops, special sessions, summer schools, stakeholder consultations, participations in conferences and project presentation at third-party events, most of them online, as of October 2021 also hybrid and some face-to-face.

Of the 26 workshops, the following are particularly noteworthy:

- Project presentation at EUSEW policy session and virtual booth at EUSEW energy fair.
- Booth at EU project zone at Enlit in Milan (face-to-face event!).
- Official kick-off event with other projects of the *FlexCommunity* in February 2022.

Project Year 3

- Online blog *Inside edgeFLEX* on the project website, advertised via the project's LinkedIn channel.
- Production of 2 videos of the trial sites Wunsiedel and Milano emphasise their importance for the project results.
- 13 peer-reviewed publications, making a total of 39 scientific publications for the whole runtime of the project (one to be published by the end of 2023).
- Consolidation and further expansion of the FlexCommunity through 10 FlexGroups meetings, representation at Smarter E and Enlit 2022.
- A professional course to introduce edgeFLEX concepts to academic and professional audiences.
- Organisation of 39 workshops, special sessions, summer schools, stakeholder consultations, participations in conferences and project presentation at third-party events, online, hybrid and face-to-face.

Of the 39 events, the following are particularly noteworthy:

- Project presentation at Smarter-E in Munich & EUSEW'22.
- Virtual booth at EUSEW'21 energy fair.
- Open Day at the German Trial Site with visit of a member of the federal parliament.
- Booth at EU project zone at Enlit'22 in Frankfurt.
- 2-day online conference for the one-year anniversary of the FlexCommunity in February 2023 with panel discussion, interactive workshops and a FlexGroups meeting on the second day.

4. Conclusions

Progress in the last year of the edgeFLEX project has been excellent. All deliverables and milestones were prepared as planned and submitted on time. All planned project goals and KPIs were reached, and many were exceeded due to the outstanding team efforts of project partners.

Research activities in the final year focused on the documentation and publication of results as well as on the synthesis of the detailed results into a description of the strategic outcomes of edgeFLEX.

The three planned field trials in Germany and Italy took place with successful outcomes. Extra results were produced in relation to the promotion of an Energy Community and the engagement of consumers in Wunsiedel in the Energy Community. A further extra results was the promotion of new services to consumers in the region around Wunsiedel undertaken by edgeFLEX partner SWW. Additionally, assessments of the issues arising in the deployment of our results were analysed from the perspective of people playing a range of key roles in DSO and VPP stakeholder organisations. In depth investigations of how mobile network technology could support the deployment of the edgeFLEX results were undertaken and documented.

A wide range of stakeholder engagement activities were successfully undertaken supporting our exploitation planning and creating support and visibility of our results and recommendations for regulatory change. 39 scientific publications have been published based on edgeFLEX results. Our results contributed to four accepted contributions to 3GPP global standards for mobile communications during the project lifetime creating a global market for products and services implementing the standardised specifications.

Exploitation plans for all results of the project have been prepared and interest by sector actors in the use of project results is high with several further field trials already planned.

5. List of Figures

6. List of Abbreviations

3GPP	3rd Generation Partnership Project
API	Application Programming Interface
CF	Complex Frequency
DER	Distributed Energy Resources
DSF	Demand-Side Flexibility
DSO	Distribution System Operator
EC(s)	Energy Community(ies)
edgePMU	edgeFLEX Phasor Measurement Unit
EMS	Energy Management Systems
GF	Geometric Frequency
ICT	Information and Communication Technology
MPC	Model Predictive Centralized
NC	Network Code
PMU	Phasor Measurement Unit
RES	Renewable Energy Source
RoCoP	Rate of change of power
SLA	Service Level Agreement
TSO	Transmission System Operator
VPP(s)	Virtual Power Plant(s)
VPP(s)	Virtual Power System(s)
WP	Work Package