Ref. Ares(2021)2237798 - 31/03/2021

Virtual Power Plant for Interoperable and Smart isLANDS

VPP4ISLANDS

LC-SC3-ES-4-2020

GA 957852

Deliverable Report

Deliverable ID	D2.2	**Version**	0.5
Deliverable name	Analysis of Obstacles to Innovation in Islands		
Lead beneficiary	BUL		
Contributors	Robert Garner (BUL) Geert Jansen (BUL) Zahir Dehouche (BUL) Antonio Jesús Sanz Igual (FORM) Mehmet Koç (UEDAS)		
Reviewer	ALWA, CIVI		
Due date	31/03/2021		
Date of final version	29/03/2021		
Dissemination level	PU: Public		
Document approval	BUL	**Date**	31/03/21

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

Acknowledgement: VPP4ISLANDS is a Horizon 2020 project funded by the European Commission under Grant Agreement no. 957852. We would like to thank the island partners FORM and UEDAS for providing technical island grid data, along with descriptions of local obstacles and concerns within the project. We would also like to thank ALWA, AMU, FTK, and BC2050 for their input to the VPP4ISLANDS concept taxonomy.

REVISION AND HISTORY CHART

Version	Date	Main Author(s)	Summary of changes
0.1	15/03/21	Robert Garner, Geert Jansen, Zahir Dehouche	First version
0.2	19/03/21	Robert Garner, Geert Jansen, Zahir Dehouche	Added data from island partners (FORM and UEDAS) to assist in explaining technical obstacles. The key findings were clarified, and quantifiable outcomes presented.
0.3	26/03/21	Robert Garner, Geert Jansen, Zahir Dehouche	Updated sources and international standards relating to DER interoperability with the energy grid. Updated the obstacles flow diagram and defined the importance of the LLP in system reliability and the management.
0.4	29/03/21	Robert Garner, Geert Jansen, Zahir Dehouche	Taxonomy completed and included to highlight technical barriers relating to component interactions, reliability, and risk.
0.5	29/03/21	ALWA/CIVI	Deliverable review: updated table of contents and increased resolution of concept taxonomy diagram for readability

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

List of Figures

List of Tables

List of Abbreviations and Acronyms

Abbreviation	Meaning
BESS	Battery Energy Storage System
CC	Connected Community
CEC	Clean Energy Community
CHP	Combined Heat & Power
CVPP	Commercial Virtual power Plant
DER	Distributed Energy Resources
DLT	Digital Ledger Technologies
DRES	Distributed Renewable Energy System
DSO	Distributed Service Operator
DT	Digital Twin
DR	Demand Response
DUoS	Distribution Use of System
ESS	Energy Storage System
EV	Electric Vehicle
FESS	Flywheel Virtual Energy Storage

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

FIT	Feed in Tariff
HFC	Hydrogen Fuel Cell
HVAC	Heating, Ventilation and Air Conditioning
LCOE	Levelised Cost of Electricity
LLP	Loss of Load Probability
LV	Low Voltage
MV	Medium Voltage
PHES	Pumped Hydro Energy Storage
PPA	Power Purchase Agreement
PV	Photovoltaic
P2G	Power-to-Gas
P2P	Power-to-Power
RES	Renewable Energy System
RTU	Remote Terminal Unit
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
TSO	Transmission Service Operator
TNUoS	Transmission Network Use of System
VESS	Virtual Energy Storage System
VPP	Virtual Power Plant

List of Project Partners

Abbreviation	Meaning
ALWA	AlgoWatt
AMU	Aix-Marseille Université
BC2050	Blockchain2050
BORN	Bornholms Varme A/S
BoZI	Bozcaada Belediye Baskanligi
BUL	Brunel University London
CIVI	CIVIESCO srl
CSIC	Consejo Superior de Investigaciones Científicas
CU	Cardiff University
DAFNI	Network of Sustainable Greek Islands
FORM	Consell Insular de Formentera
FTK	FTK Forschungsinstitut fur Telekommunikation und Kooperation EV
GRADO	Commune di Grado
IDEA	Ingenieria Y Diseno Estructural Avanzado
INAVITAS	INAVITAS Enerji AS

LIS	Laboratoire Informatique des Systèmes
PVM	Protisvalor Méditerranée
RES	Renewable Energy System
RDIUP	RDI'UP
REGENERA	REGENERA LEVANTE
SCHN	Schneider Electric
TROYA	TROYA CEVRE DERNEGI
UEDAS	Uludag Electric Dagitim

TABLE OF CONTENTS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

1. EXECUTIVE SUMMARY

The market for distributed Renewable Energy Systems (RES) has been increasing considerably in recent decades due to several economic and climate related factors. The vision of the VPP4ISLANDS project is to develop novel and futuristic concepts for energy production, distribution, and monitoring on geographical islands, by promoting the use of RES. The Virtual Power Plant (VPP) would not be considered as a conventional power plant but as a modular green energy system that can store surplus energy and be explicitly controlled to support island growth and change in energy demand, climate, and electricity market. This report outlines and analyses the obstacles to successful implementation of the VPP system. The barriers have been identified based on preliminary research in addition to the produced *'Islands Technical Survey'* and analysis of the two lead island participants of Formentera and Gökçeada, as shown in Appendix 1.

1.1. PROJECT MOTIVATION

Conclusions from the European Council for climate action set out a target of at least 27% share of renewable energy usage within the EU by the year 2030, and a total 40% domestic reduction in greenhouse gas emissions compared to 1990 [1]. These energy targets were agreed upon to comply with the objectives of the 2015 Paris Agreement on Climate Change following the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change. This agreement aims to prevent global average temperatures from rising by 1.5°C, with a contingency aim of keeping well under 2°C compared to pre-industrial levels [2].

One of the biggest challenges in the decarbonisation of European countries is in the development of renewable energies on geographical islands. Island states of Malta and Cyprus have reported come of the highest energy and network costs [3] in Europe, likely due to the requirement for mainland energy trade and fuel imports. Cyprus also has one for the highest greenhouse gas emissions per capita, which is approximately 31% over the European average [4]. Energy security and reliability are becoming increasing important as the market share of small, distributed renewable energy systems increases. This is a particular problem of remote areas and geographical islands with limited resources, which have to often rely on a cable interconnector with limited power throughput. Moments of excess renewable energy will lead to generation curtailment and loss of income for the operators, whereas moments of unplanned RES deficit will create system instability, loss of energy, and the potential of blackouts. Non-dispatchable renewables such as wind and PV solar add an additional element of unpredictability to the power generation, further compounding the reliability problems.

The proposal of a VPP system will be used in this project to provide solutions to the energy grid problems on geographical islands, where they will be used as an experimental platform to assist in accelerating the European and global efforts to achieve a zero-carbon society.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

1.2. THE VIRTUAL POWER PLANT CONCEPT

The concept behind a VPP is to aggregate these distributed resources in such a way as to streamline the efficient and reliable use of the distributed renewable energies. The aggregation of these resources can be used in combination with novel demand forecasting technology and real time system modelling techniques. In this way, the virtual system acts as a single unit, providing flexibility to the grid and the ability to reduce emissions, cost, and increase reliability. In a situation where the non-dispatchable sources supply a surplus, a Virtual Energy Storage System (VESS) made up of batteries, fuel cells, as well as flexible loads can provide flexibility of services to the local grid. A simplified schematic of the VPP concept if shown in Figure 1.1.

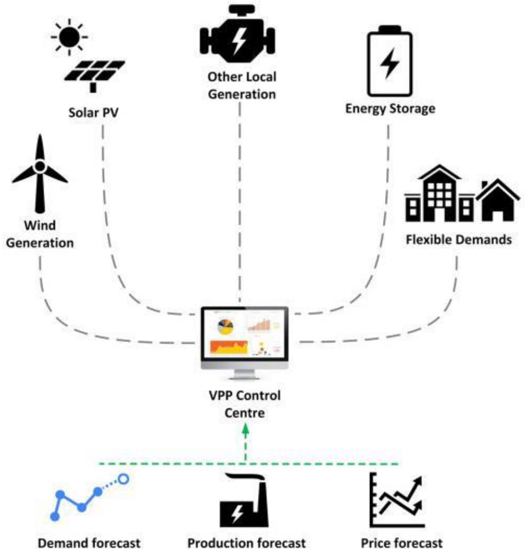


Figure 1.1: VPP concept schematic [5]

1.3. BARRIERS AND OBSTACLES

As mentioned, the barriers and obstacles collected within this report have been based on a number of resources. The methodology consisted of published research, international directives, environmental reports, as well as focus groups with island stake holders to identify and analyse relevant obstacles to the successful implementation of the VPP system. The island stake holders were presented technical surveys to access the technical grid structure, required services, and system resiliency. In addition, the environmental impacts of RES based VPP deployment were also reviewed, including the impact of energy generation activities, and relevant restrictions. From the generated results the barriers were derived and categorised into the three main sections, displayed in Figure 1.2.

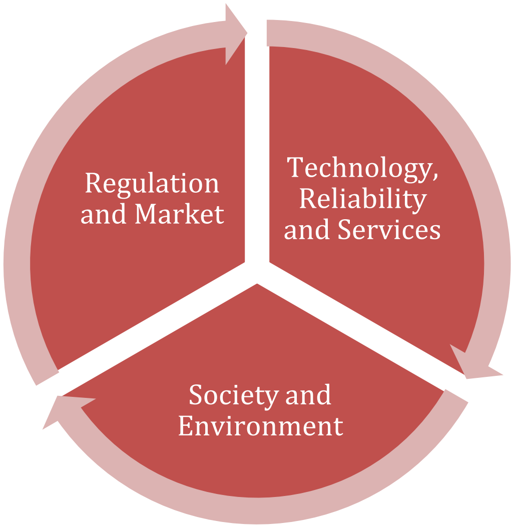


Figure 1.2: Categorisation of identified obstacles to innovation

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

The identified obstacles within these sections are explored in further detail, and case studies applying specifically to island settings are presented where available. The diagram in Figure 1.3 illustrates the structure of this report.

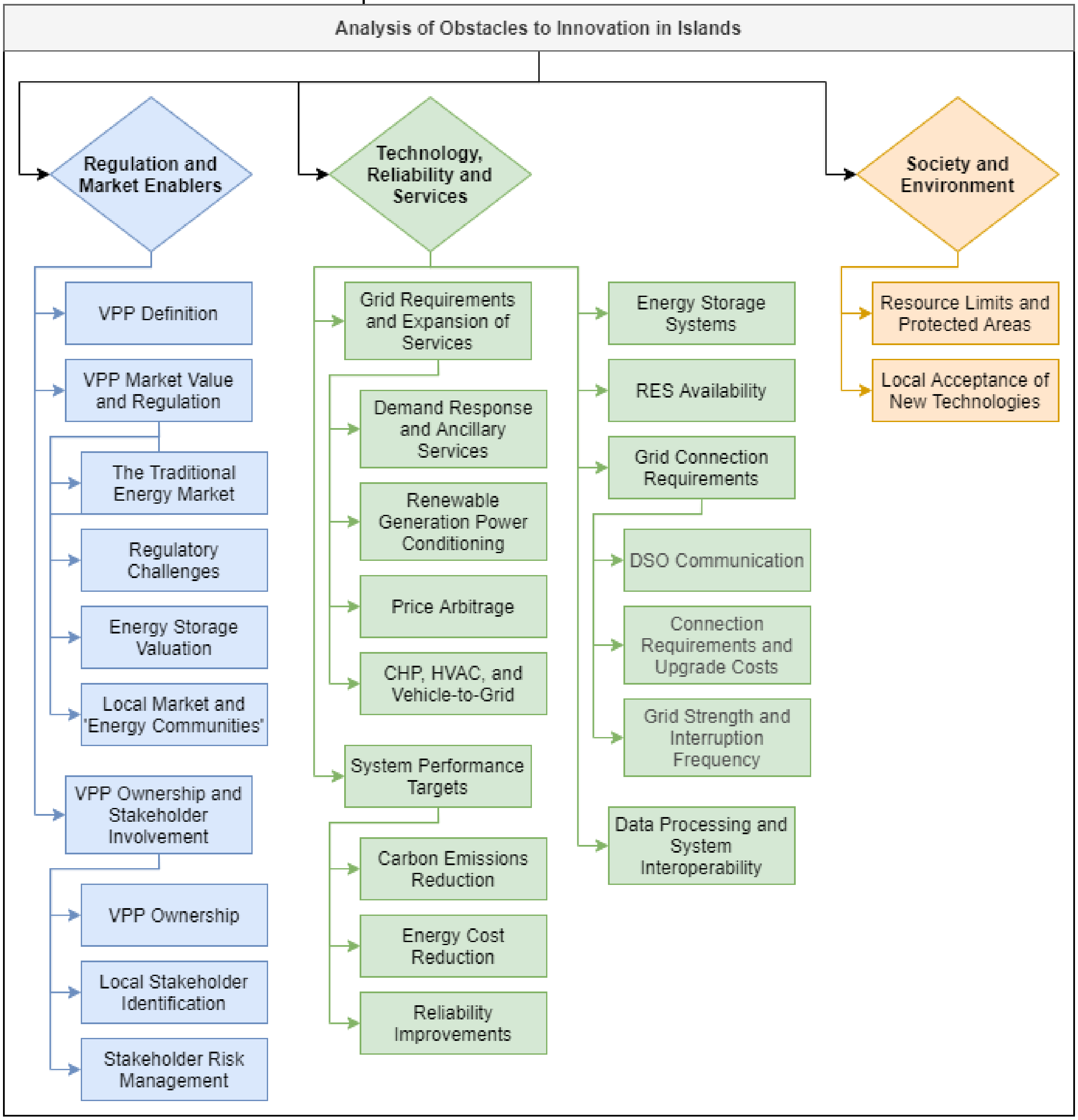


Figure 1.3: Schematic of the report structure with identified obstacles and barriers

A short summary of the content presented within each section of this report is shown below, and analysis of any relevant literary sources and data collected through island surveys.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

Regulation and Market

- Presents research and expands upon the currently documented barriers relating to regulatory and market enablers for the VPP system on islands.
- Defines the VPP as a disruptive technology that is in many ways different from the traditional energy market structure in Europe, and the definition varies depending on concept architecture and application.
- Explores VPP concepts such as aggregated generators, demand response, market arbitrage, and the use of fast reserve energy storage systems that have been considered for many years but have not been fully realised within the major European spot markets.
- Efforts to design a parallel local market to exploit the benefits of VPPs have also been presented, including peer-to-peer trading and local Distribution Service Operator (DSO) services fulfilment research with literature.
- This section analyses these frequent VPP market obstacles and presents a series of mitigation strategies supported by recent EU directives on the changing state of the energy market and regulation.
- This section also includes a brief analysis of common barriers relating to stakeholder interaction, risk mitigation, and the communication paths required for successful local partnerships.

Technology, Reliability and Services

- This section presents the obstacles of providing the proposed services through VPP implementation.
- The services discussed include demand response, market ancillary services (primary, secondary, tertiary reserve), price arbitrage, RES power generation conditioning, in addition to emerging and niche services such as district heating, smart EV charging, Power-to-Gas (P2G) and hydrogen energy.
- This section also considers the barriers of achieving the envisioned performance objectives of the island stakeholders, and the challenges of reducing the carbon impact given the location and energy needs of the island. A practical analysis of the RES availability on the island of Formentera was conducted, as this will ultimately dictate the ability to achieve low carbon operation.
- Includes an analysis of common ESS, their advantages, disadvantages, associated risk, and obstacles to implementation with VPP4ISLANDS.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

- Presents an analysis of grid interconnection obstacles and interoperability requirements with the DSO. Standards to consider include IEEE 1547-2018 and BS PD IEC/TS 62786:2017 describing the DER connection requirements for interoperation.
- Explores the challenge of internal interoperability between VPP actors, given the communication and data transfer requirements. An example of measurement error on the island of Formentera is used to display the barrier of error handling. This section discusses the benefits of using Distributed Ledger Technology (DLT) for enhanced security, traceability, and trust between actors.

Society and Environment

- The ultimate objective of the project is to provide increased welfare to the island community through reliability, environmental, and cost improvements to their energy supply. This section presents the challenges for the VPP relating to the location and resource limitations of geographical islands, and the potential environmental impacts.
- The social acceptance of the technology among early adopters is crucial to the VPP4ISLANDS business model, so understanding any public concerns and risks regarding reliability, security, and environmental welfare will also be critical challenges to implementation.

1.4. KEY FINDINGS AND CONCLUDING STATEMENTS

This report presents research into the state-of-the-art of current VPP concepts, and the notable barriers and obstacles that will affect the implementation on geographical islands. Each section is concluded with a short summary highlighting the key barriers that should be acted on during the development stages.

The conclusions from the report show that the regulatory and market enablers will likely prove to be one of the most challenging barriers to mitigate due to the disruptive nature of the VPP and the required modification of existing legislation or creation of new flexible market strategies for the concept to be fully realised. Recent EU directives highlight the requirement for energy market reform, so within the next years up to 2030 a shift in the nature of the market will occur. The market and regulation are driving forces for the many of the technical obstacles presented, such as services requirement and performance objectives. The technical barriers explored have been shown to largely depend on the current and future prediction of the island energy structure. The availability of RES, dedicated ESS, and flexible loads are crucial to the reduction in environmental impact of the island. Additionally, the requirement for real-time communication and control

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

between distributed actors within the system also presents itself as a common obstacle within literature. The use of DLT to ensure interoperability between all actors, as well as secure and tamper-proof data transfer will be crucial to successful operation of the VPP components.

The key findings have been summarised below:

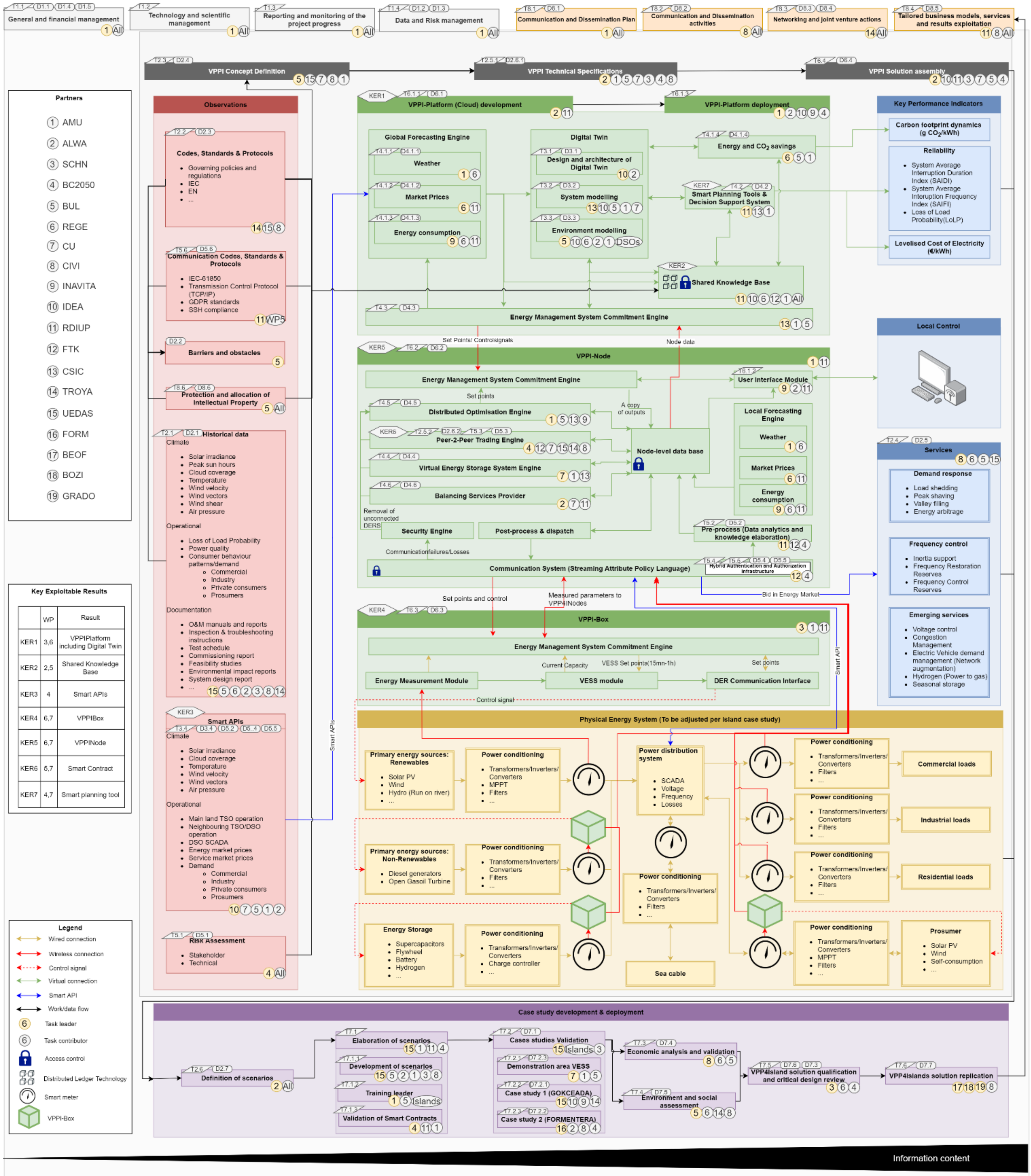
1. The current energy market regulations pose the largest challenge for the VPP concept within literature, as the traditional market is not designed to realise potential value of the VPP.
2. Developments in the EU energy market structure will influence the adoption and profitability of VPPs in the coming years (EU 2019/944).
3. Creation of a local services market will increase viability of the VPP on islands, along with the development of disruptive business strategies for creating revenue streams.
4. Identification of required local stakeholder involvement on islands and stakeholder risk will assist in the practical applications and requirements of VPPs on islands.
5. Identification of concrete services that can be provided through RES/ESS aggregation will mitigate the increased risk associated with the cost and reliability of the new system.
6. A dedicated ESS system will significantly improve system flexibility and services provision, in addition to RES and flexible loads.
7. The grid interruptions on Gökçeada around approximately four times higher than mainland Europe, which may cause VPP interoperability challenges for the DERs.
8. System interoperability with the current energy grid and TSO/DSO communication system will be required, as well as secure, trust-based data access protocols to mitigate control faults and errors.
9. Specific islands will have particular resources constraints, such as the wind deployment limitations on Formentera, that will inhibit expansion of RES within the VPP concept.
10. Local acceptance of the new technology must also be considered, which will foster development of the envisioned energy communities concept.

The initial data collection and identification of obstacles and challenges to the VPP implementation has already assisted in the creation of a preliminary VPP4ISLANDS concept definition. The taxonomy definition will be used to drive forward further technical discussion with consortium partners and innovation within the project. The diagram displays the inherent complexity of the VPP system, including the number of interoperating components and stakeholders, which presents itself as a technical obstacle to reliability and increased risk. As mentioned, the concept architecture in an iterative process, and will be presented in complete form with D2.4: Concept Definition. The concept architecture diagram is shown in

Figure 1.4.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852



Partners

1. AMU
2. ALWA
3. SCHN
4. BC2050
5. BUL
6. REGE
7. CU
8. CIVI
9. INAVITA
10. IDEA
11. RDIUP
12. FTK
13. CSIC
14. TROYA
15. UEDAS
16. FORM
17. BEOF
18. BOZI
19. GRADO

Key Exploitable Results

	WP	Result
KER1	3,6	VPPIPlatform including Digital Twin
KER2	2,5	Shared Knowledge Base
KER3	4	Smart APIs
KER4	6,7	VPPIBox
KER5	6,7	VPPINode
KER6	5,7	Smart Contract
KER7	4,7	Smart planning tool

Figure 1.4: VPP4ISLANDS Concept Design Architecture

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

Overall, this report presents an in-depth analysis of current obstacles to innovation affecting state-of-the-art VPP development and deployment in Europe, with the application focused to geographical islands. The outcomes will serve as a foundation for future project activities where obstacles will need to be addressed in further detail.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

2. REGULATION AND MARKET

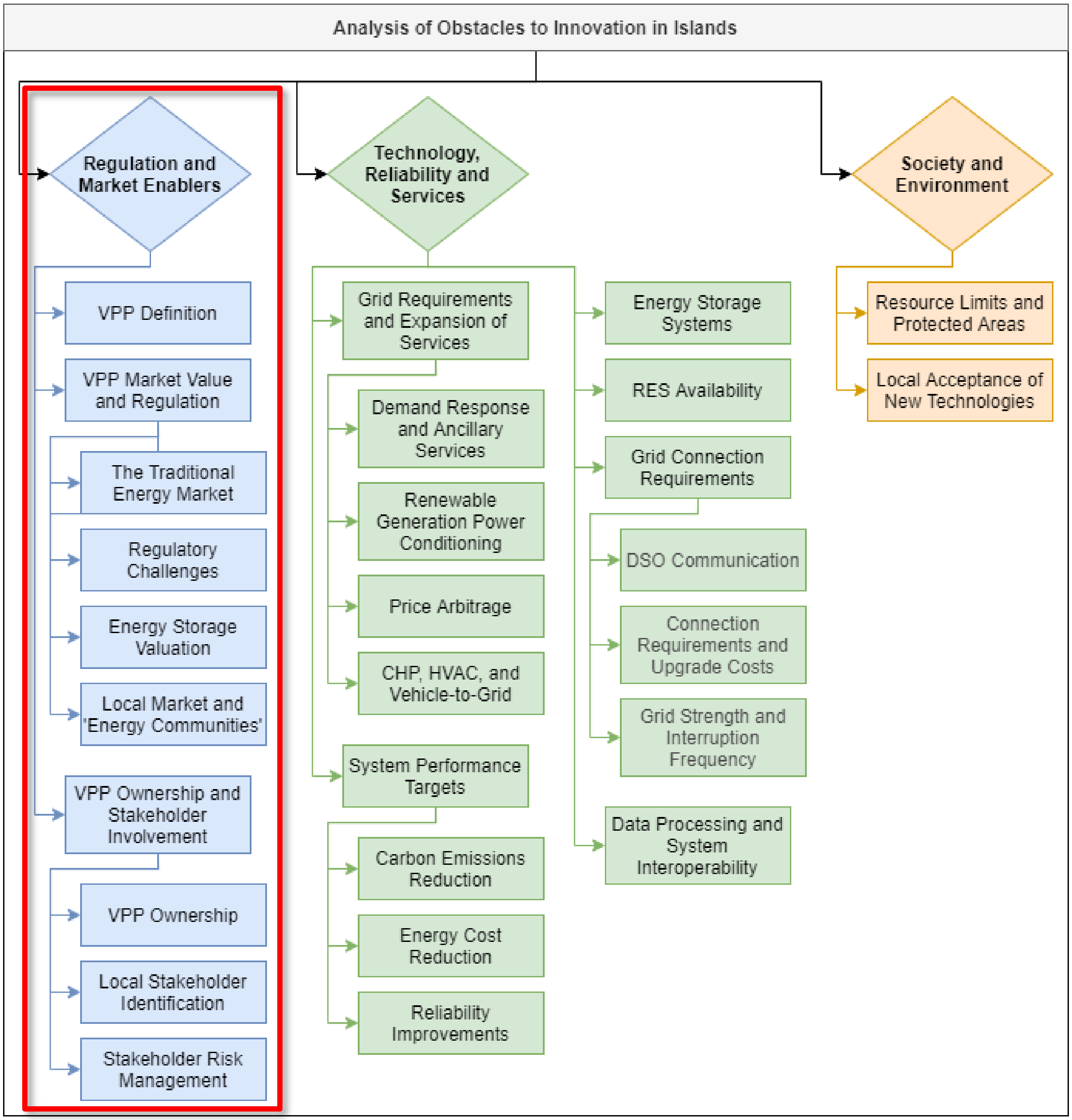


Figure 2.1: Report structure diagram highlighting the regulation and market obstacles.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

2.1. VPP DEFINITION

Before continuing to identify the key barriers and obstacles related to the integration of a VPP system, it is important to outline the VPP definition. The VPP is a relatively new concept, being the object of study for the past 15 to 20 years. Over time, different sources have expanded upon its potential uses within the energy grid, and as well as the many benefits. The definitions of the VPP therefore vary widely across the literary landscape, depending on the objectives of the system and the available resources. A generally accepted definition of the VPP is:

"A flexible representation of a portfolio of Distributed Energy Resources (DERs), not only aggregating the capacity of many diverse DERs, but also creating a single operating profile from a composite of the parameters characterizing each DER and incorporating spatial constraints" [6].

This definition, while including the fundamental structure of the VPP, does not include the additional information that defines the other complex operational aspects. It is important to note the emphasis on interoperability through the integration of information and data management systems to dispatch the available energy automatically and remotely at the optimal moment. The definition also needs to place importance on these virtual connections to ensure the successful interoperation between multiple distributed generators.

The VPP structure is often confused with the microgrid concept as both integrate a number of distributed generators. A microgrid, however, describes a physical system of connected generators such as PV solar, wind, and battery storage that can act as an isolated system to service a very localised area. A VPP however is much more reliant on a network of data connections and smart metering equipment to control the remote generators as a single entity, and to export this energy to the grid to serve a larger area than a traditional microgrid. The VPP should also be considered as a stochastic model, with the ability to constantly improve and optimise it dispatch processes through the use of environmental input data including past demand conditions, meteorological measures, and future forecasting variables. Artificial Intelligence (AI) algorithms such as Artificial Neural Networks (ANN) and Neural Fuzzy (NF) are becoming crucial to the performance of VPP concepts [7], so should also be incorporated into the VPP definition.

To overcome this potential barrier, a unifying definition of the VPP should be defined by the project so that the project can agree upon. Given the additional considerations, the following definition is proposed:

"A flexible and virtual portfolio of Distributed Energy Resources (DERs), Energy Storage Systems (ESSs), and flexible loads connected through the use of communication technology and

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

represented as a single power entity. The system utilises advanced learning methods to accurately forecast the optimal operation based on environmental conditions, required grid services and performance objectives".

2.2. VPP MARKET VALUE AND REGULATION

A key barrier identified within literature which hampers the successful implementation of the VPP is the position of the system within the structure of the energy market. The VPP needs to not only improve efficiency and the reliability of the system at a local level, but also be visible to the regulatory bodies such that it is able to provide energy trade and services on a distribution or national level. This is one of the key methods of generating revenue from the VPP.

The Traditional Energy Market

The price-based mechanisms that allow for profitability of DERs vary between technology and location. Most European countries adopted Feed-In Tariffs (FITs) set by the regulators such that the owner could receive remuneration for the energy generated by small scale DRES. The tariffs are often fixed values or are set as a percentage premium combined with the market value [8]. A common method for renumeration adopted by renewable energies on a larger scale is via Power Purchasing Agreements (PPAs), also sometimes referred to as bilateral contracts. A PPA is a long-term contract that a power generator has with a supplier or direct consumer to pay a certain fixed amount for that energy over the given period. PPAs are good for ensuring financial security for both the supplier and consumer, as both parties trade a fixed value for the energy over an extended period. This means that market participation is not required, negating the associated financial risk [9]. Both FITs and PPAs could work well as a preliminary mechanism for the VPP to receive value from the consumer, although they both limit the profitability of the RES by applying a rigid pricing structure. FITs were used originally by countries to increase RES usage, but with the disadvantage of devaluing the traditional energy generators required for frequency balancing as the RES share increases [10]. Eventually, countries such as Spain and more recently the UK have had to remove FITs from use. In January 2020, the UK replaced the FITs by the smart export guarantee (SEG) to encourage small scale, low carbon electricity generation [11].

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

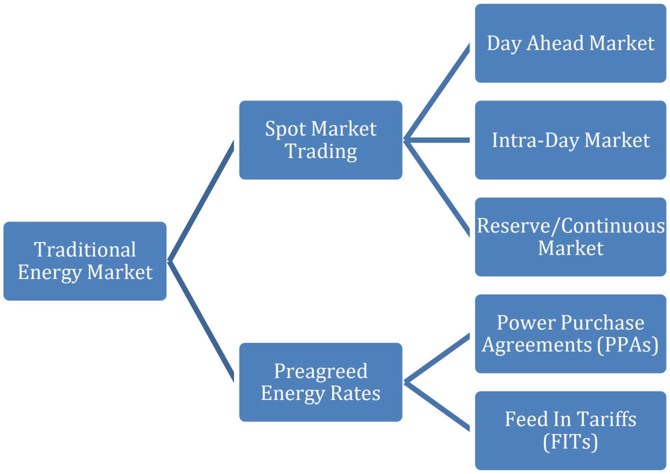


Figure 2.2: Traditional Energy Market Structure

The most common option used by large tradition power generators is to participate in the wholesale spot market. In most European markets, players can opt to take part in the day ahead, intra-day, and continuous markets. The day-ahead market consists of energy generators and suppliers placing bids to sell and buy electricity in EUR/MWh, after which the market operator calculates the Market Clearing Price (MCP) through a centralised clearing house such as European Commodity Clearing (ECC). The ECC manages the settlement process between traders and guarantees physical settlement through risk management. The intraday bidding then occurs in hourly or quarterly day intervals, with reserve markets responding to offers from minute responses to up to one hour to keep the system balanced [12]. Although these markets provide the majority of grid profits for suppliers, the process does not combine well with renewable energies due to their non-dispatchable and variable nature.

Analysis conducted in the EU project 'MASSIG' suggested that DER suitability for participation within the spot market relies heavily on whether they qualify for both the day ahead and reserve markets, and if the generation forecasting is accurate [13]. The traditional market also does not provide mechanisms that value the potential merits of a flexible VPP system at a local level, and any changes to the market would be a challenge due to regulatory barriers to be discussed. Moreover, some European countries such as Spain do not allow aggregated prosumers to participate in the balancing market, though this should change with the introduction of new directives in the coming years [14]. A number of studies have been conducted into the potential value to be gained by VPPs by participating in wholesale trade despite the current regulatory problems.

Most notably, [15] addresses an optimal bidding strategy for what is known as a Commercial Virtual Power Plant (CVPP) - considered as a separate entity to the actual aggregated VPP. The

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

key objective was to maximise profitability in trading, whilst minimising the required real-time generation and imbalance charges, and addressing the associated risk in market bidding in relation to forecasting accuracy. Although this displays a thorough investigation into potential revenue streams and risk minimisation through market strategy, the model also assumed all DERs when combined in the VPP are about to participate openly in all markets and that there are no minimum energy bid limitations, which as discussed in [16] and [17] is not strictly true for all European markets. The availability for these technologies to be able to interact with national markets on this level should therefore be considered on a case-by-case basis, and as regulatory bodies begin to modify entry requirements for small-scale aggregated generators.

Market Regulatory Challenges

Within a centralised energy grid market, large utilities and regulators have been in control of overseeing all aspects of the process from generation to consumption of electricity. Over many decades, additional layers of regulation and complexity have produced a market that is not designed with non-dispatchable generators such as RES, which should make up the majority of VPPs, to participate. As an example of this problem, it has been a challenge to implement a system of demand response capability – one of the key services offered by the VPP concept. The EU demand response policy report 2016 revealed that "*many national regulators see the process of opening markets to demand response as complex and confusing*" [18]. The regulation surrounding traditional energy generation is stifling growth and change within the industry, caused a reluctance on the side of the policy makers to provide the necessary building blocks for VPPs.

The regulatory issues are not only a significant challenge in Europe but in energy markets around the world. Research presented in [19] highlights the barriers to profitability of a VPP business model for sub-Saharan Africa, the outcomes of which indicate two fundamental challenges to the implementation of a successful model. Firstly, high capital and operational costs will impact economic scalability due to the increase in hardware requirements for smart control, as well as increasing RES and ESS share. Secondly, the lack of regulatory framework also produces an unclear understanding of how operational requirements and liabilities should be split between stakeholders, and how any financial risk is to be handled.

A method therefore needs to be devised for the regulatory bodies to recognise the additional value that the VPP can create within the energy system, without making a large quantity of reforms to the current national and international markets. A better suited system should include incentive-based solutions for the VPP that would provide additional services and value at the local Distribution System Operator (DSO) level [20]. A common service cited within the VPP capabilities is peak load management, in that any stored energy would be shifted and released during high

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

demand and inject additional voltage to keep the grid feeders energised and rebalance frequency fluctuations [21]. In this case, an incentive-based model where the VPP is valued based on the additional stability given to the DSO could provide profits over the traditional capacity and reserve markets currently used. A full review of the barriers to implementation of the specific grid services offered by the VPP concept are included in Section 3.

Energy Storage Valuation

A report on energy storage systems (ESS) within the EU from 2017 suggests although that the potential benefits of these technologies are being recognised, however the regulatory framework is largely not in place to support its flexibility of services and profits [22]. Different European countries also have differing definitions for what ESS is and what services can be provided. For most European energy markets, ESS is classified as a generation asset, which is not specific to the operation of the storage. This also creates a situation where ESS is undervalued given its potential services, and monetary rewards are low for implementation. There are even situations where the flexibility causes additional costs to be levied by the system operator. For example, the UK grid network consists of the Transmission Network Use of System (TNUoS) and the Distribution Use of System (DUoS) charges, for recouping the costs of system maintenance. Energy storages smaller than 100MW while exempt from the TNUoS, would still be charged for the DUoS tariffs [22]. Understanding whether these tariffs are used in the countries where the VPPs may be installed will be vital to analysing the true value of the ESS.

Certain countries also do not apply a value to ESS for their contribution to common ancillary services. In Spain, generators are obliged to provide voltage and primary frequency balancing services without renumeration [23]. ESS could react much faster on average than traditional balancing generators, which would benefit a local level strategy more than the national level but is a condition that is not recognised by the current market. In combination with the fact that the ESS needs to charge as well as release energy, a price arbitrage strategy may not be enough to overcome the additional grid charges and lack of service value. As this is considered a key market for ESS implementation, these considerations are certainly a barrier to wide scale ESS integration.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

Local Market and ‘Energy Communities’

It can be seen from the topics discussed that modifying existing regulation within the current energy market would be a technical challenge due to the number of stakeholders involved and would be largely outside of the scope of this project. A possible mitigation strategy is to operate a small-scale ‘deregulated’ market in parallel to the existing spot market, in which the local ancillary service benefits for the DSO can be made visible and renumerated appropriately. The Flexible Congestion House (FLECH) originally suggested by [24] stipulates a local energy market within the DSO level that specialises in the unique services offered by the VPP, including responding to voltage and frequency instabilities, storing excess RES, and supporting critical loads during interruptions. These services would need to be outlined in full and accepted by the appropriate regulating authority, and a full analysis of the monetary that would be gained by the DSO and utility contributed by the VPP. Additionally, [23] reviews the identified barriers commonly associated with the current ancillary services market design, given that it was initially formulated for traditional Synchronous Generators (SGs) and did not anticipate the growth of DRES. The review proposes a new set of ancillary services tailored to the strengths of DRES and the propagation of smart grids, microgrids, and VPPs. A number of other sources have suggested the development of a parallel or ‘micro’ market to realise the potential of distributed generation, notably by [25] and [26].

The parallel local market theory lends itself well to the applications on geographical islands, as the system is separated from the mainland transmissions network. The islands are usually connected through a single sea cable interconnector to the mainland, so any activity within the island can be monitored and controlled. These interconnectors are responsible of load balancing and auxiliary services as they are required. If the VPP was able to assist the interconnector with DSO grid services, the value of those services could instead be transferred to the VPP and redistributed among the aggregated generators.

On the ESS valuation side, it was highlighted that the DSO level would be the optimal installation level for this technology, as the services can be identified and delivered in a single operation without interaction between multiple stakeholders [22]. The definition of ESS also needs to be modified and the potential benefits over traditional spinning reserves fully understood. The DSO in most European countries is not able to own and operate their own generation or ESS system, so must use third parties to bid on the energy market on their behalf and share any profits, incurring participation charges [27]. A simplification of this system could be to allow the ESS to be operated by the third party and charge the DSO directly through a form of bilateral contract, instead of having to go through the energy market. The market barrier that appears frequently in both previously related projects and literature, notably in [10] and [28] is that the current energy

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

market is both outdated and unsuited for the services that distributed generation including VPPs can provide. The market largely favours traditional generation systems as the development occurred in parallel, and so regulatory changes are difficult due to the complexity and potential devaluation of existing balancing generators. The disruptive VPP technology could be paired with a purpose-built local service market independent of the national regulators, that works with the DSO and community to provide reliable, low cost, and low carbon electricity. The VPPI-Node concept also fits well into this concept, as local community 'clusters' of consumers and prosumers can interact through a peer-to-peer trading concept.

Local ancillary services markets have been explored with the use of peer-to-peer trading as presented in [29]. The research implements a novel bidding and optimisation strategy for a selection of 20 consumers and prosumers with varying PV installation and EV charging facility, which are also assumed to be equipped with smart metering. The results show that the creation of a local energy market where customers can participate in both community energy balancing and ancillary services has the ability to increase the individual profits considerably, as well as the social welfare of the customers. This methodology is similar to that of the parallel and micro-market strategies discussed, however the author notes that variables such as generation and demand forecasting, grid use payments and the technical aspects of variable ancillary services are not discussed. These potential obstacles could significantly affect the profitability of the market strategy, so must be considered before practical implementation. A summary of the local market concept is displayed in Figure 2.3.

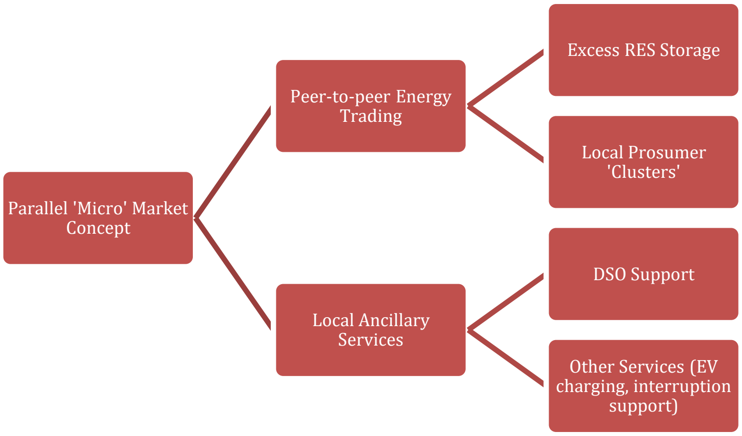


Figure 2.3: Parallel energy market concept for local services delivery

The concept of Clean Energy Communities (CECs) is a continuation and development of the local market theory. An exploration into the structure and challenges of CECs conducted by [30] states

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

that a CEC differs from a system of local DRES in that it describes the specific relationship between the end users and their energy management. All end users are considered key stakeholders in the development and management of the CEC to continuously promote and improve their sustainable energy usage. CECs can consist of several smart grid technologies such as microgrids and VPPs, as the specifics of the technical structure is not within the key definition. The revenue generated by the energy community activities such as providing ancillary services to the DSO and peer-to-peer trading is then fed back into the portfolio of community investments. The investments may include the installation of additional DRES and ESS to increase energy reliability and sustainability of the CEC. Similarly, Connected Communities (CCs) incorporate a central control to a number of community and residential buildings to optimise the dispatch and usage of energy. There are number of challenges associated with CECs that would also affect the overall operation of the VPP. Multiple ownership could complicate the organisation and coordination of energy scheduling activities, as well as allocating costs and benefits among all stakeholders. Additionally, the capital cost of shared systems and grid upgrade costs would also have to be shared among stakeholders. A method for financing the project would have to be defined between the shared owners [31].

The requirement for change in the tradition energy market structure is being recognised by the EU, who recently released regulation (EU) 2019/943 ‘on the internal market of electricity’ [14]. This amend highlights the state of the current energy market and how it is not suited to the fast-transforming nature modern energy generation of prosumer participation. Emphasis is placed on new technologies and services such as distributed generation, flexible generation, demand response, and energy storage, as well as how these should be incentivised further. Like the local parallel market theory, Article 24 of the document suggests the use of short-term markets to improve liquidity by allowing more participants within the market, which may reduce the entry requirements for small generators. The related directive (EU) 2019/944 also outlines the reforms that are required to move towards a decarbonised energy grid, and that the renewable energy targets would be most effectively met through the creation of *“a market framework that rewards flexibility and innovation”* [32]. The directive defined the new industry terms ‘active customer’, ‘citizen energy community’, ‘aggregation’, and ‘interoperability’. From these cases, it is clear that governing bodies recognise the current problems with energy regulation and are looking for methods of reform. The concept will also build upon the work completed in the MAGNITUDE EU project which aims to devise a business and market trading model flexibility in European energy, including electricity, gas, and district heat.

Many leading European energy companies are investing in VPP technologies seen as the future of the energy grid. The *European Virtual Power Plant Market Forecast to 2030* details the key market drivers and restraints that are influencing the current and future uptake of VPPs, as well as analysis of different business models and opportunities for growth [33]. As mentioned, the

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

market model would have to the purpose built for small island energy systems, and the types of local services that are required. The VPP concept devised within this project could be an excellent vessel to push forward these changes.

2.3. VPP OWNERSHIP AND STAKEHOLDER INVOLVEMENT

The modern energy grid can be considered as a single large and complex electrical machine, reaching continental sizes and serving several different countries simultaneously. Multi-layered communication is required to concisely regulate the generation, trading, transmission, distribution, sale, and consumption of electricity, due in part to the number stakeholders with individual roles and priorities interacting throughout the entire process. While the potential benefits of VPPs for use in geographical islands have been clearly outlined, the problem of ownership, stakeholder involvement, and liabilities needs to be considered as a potential barrier to implementation.

VPP Ownership

The first ownership obstacle that must be discussed is the definition for the 'fostering entity'. The fostering entity as described within [34] as the stakeholder with the responsibility of describing the objectives of the VPP and the level that the system is installed within the grid. This entity can be the existing local utility company or DSO, council or governing body, or a 3rd party investor that will ultimately oversee the function of the VPP once it is implemented. Given the various business objectives of these stakeholders, it is understandable that the performance objectives will vary depending on the type of entity. For example, the DSO or utility may want to maximise system stability and minimise interruptions to avoid penalisation from regulatory bodies, whereas 3rd party investors may want to maximise the green energy share to meet the investment objectives. In the case of the local council or governing body, the cost of energy may need to be minimised for the benefit of the local citizens. The first consideration after identifying the fostering entity is understand whether it is business, social, or environmentally oriented in terms of its objectives for the VPP. Under this business model, the fostering entity is ultimately liable for the operation and profits of the VPP, as well as the associated financial risks.

It is common for distributed generators to be owned and operated by utility companies or private prosumers. For the VPP to operate effectively, the operation of these generators needs to be monitored by the system. It is important that the generation stakeholders are involved in open discussion to gain access to their monitoring and control systems. Privacy issues that affect the access and distribution of generation information presents itself as another key barrier that will be discussed in Section 3.6. In addition, some renewable generators may also have PPAs in place, so would be unable to take part in the VPP due to contractual commitments. The commitments

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

and availabilities of private generators on the islands need to be fully communicated and understood within the project, as these will dictate the flexibility of the system.

Local Stakeholder Identification

For the community-based approach to be implemented within the VPP model, stakeholders within the local community need to be identified. The energy community would consist of the end-users (consumers and prosumers, commercial, industrial) and the local governing body or council with a vested interest in social welfare. The objectives of these stakeholders will be centred around the environmental and social welfare of the island, as well as ensure a fair cost of any services being provided. In the case of the VPP, the community stakeholder will likely have a vested interest in the public perception of the new system, and that any changes to the end-users' day-to-day lifestyle are received positively. Community engagement with the VPP concept through active energy structure and policy modification is a key performance indicator for the project. Implementing demand-side management incentives such as lower, capped, or time-of-day based energy usage may have a mixed reception, so this opinion will have to be considered.

The DSO (and TSO depending on the grid structure) will be present on the island. As the main technical contact, these stakeholders will have an interest in the services made available by the VPP, and potential revenue streams. The regulatory barriers discussed in the previous section apply primarily to the operation of the VPP at this system level, so it is key to identify these operational stakeholders at an early stage and ensure contact throughout every stage of the development process.

Stakeholder Risk Management

Stakeholder analysis will also be important in understanding the associated risk during the scheduling of VPP services. Uncertainties in energy and demand forecasts, fault occurrence, and grid interruptions could affect the delivery of the scheduled service by the VPP, therefore affecting the planning renumeration settlements between stakeholders. In European energy trading, the ECC trading house has a collateral system that all buyers and sellers pay into as an entry requirement for participation [35]. A similar system of emergency financial settlement will likely be required for the VPP, such that revenue can be transferred to the alternative balancing provider to cover the service non-delivery. This would mitigate the financial risk to stakeholders within the VPP.

Research in [36] highlights a lack of stakeholder analysis with regards to the VPP, specifically consideration potential risks and benefits to stakeholders that are naturally part of or are joining

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

the VPP system. To produce an effective VPP product, the development will benefit from communication and information from key stakeholders who will ultimately work with the completed system when implemented. Identifying these stakeholders early in the project will assist in data collection for the services requirement, performance objectives, and potential revenue streams for the system.

2.4. REGULATION AND MARKET: SUMMARY

The definition of the VPP has gone through many iterations since it was first conceptualised. The increase in renewable energies and distributed generation has increase the number of potential services that could be provided. In addition, advanced AI controls, Big Data, Internet of Things (IoT), and high-speed internet connectivity have allowed for the prospect of a virtually connected array of RES. The performance of this system is then specifically optimised for the requirements of the local energy system. These additional developments in the VPPs capability should be reflected in its definition.

The regulation and market barriers have been noted by many similar projects and literary sources as one of the main hurdles when it comes to successful installation of disruptive technologies such as VPPs, particularly when deployed on islands. Progress is being made by governing and regulatory bodies in identifying and amending the shortcomings within the current energy market that are hampering the development of distributed generation. The reformation of the liberalised energy markets presents an enormous challenge and cannot yet be transformed for the benefit of renewable energy, as devaluing traditional balancing generators will cause problems for energy sector.

The concept of a community energy market that is independent of the larger spot markets is an intriguing prospect, as power is placed in the hands of local distributed generators to provide the DSO with balancing and ancillary services. This concept would be ideal for geographical islands as they can act as an autonomous community, calling on services from the sea cable interconnector when required. This concept would undoubtedly be met with regulatory challenges, but the concept of starting with a small-scale parallel market for distributed services rather than attempting to make changes on a national or international scale may be simpler for regulatory and governing bodies to implement. The concept can be realised with peer-to-peer technologies and Distributed Ledger Technology (DLT), that allow for quick and secure monitoring and energy trading between participants for the benefit of the community.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

Appropriate identification and analysis of local stakeholders will assist greatly in opening communication pathways on the island and gain a great understanding of the requirements and challenges faced by the community.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

3. TECHNOLOGY, RELIABILITY AND SERVICES

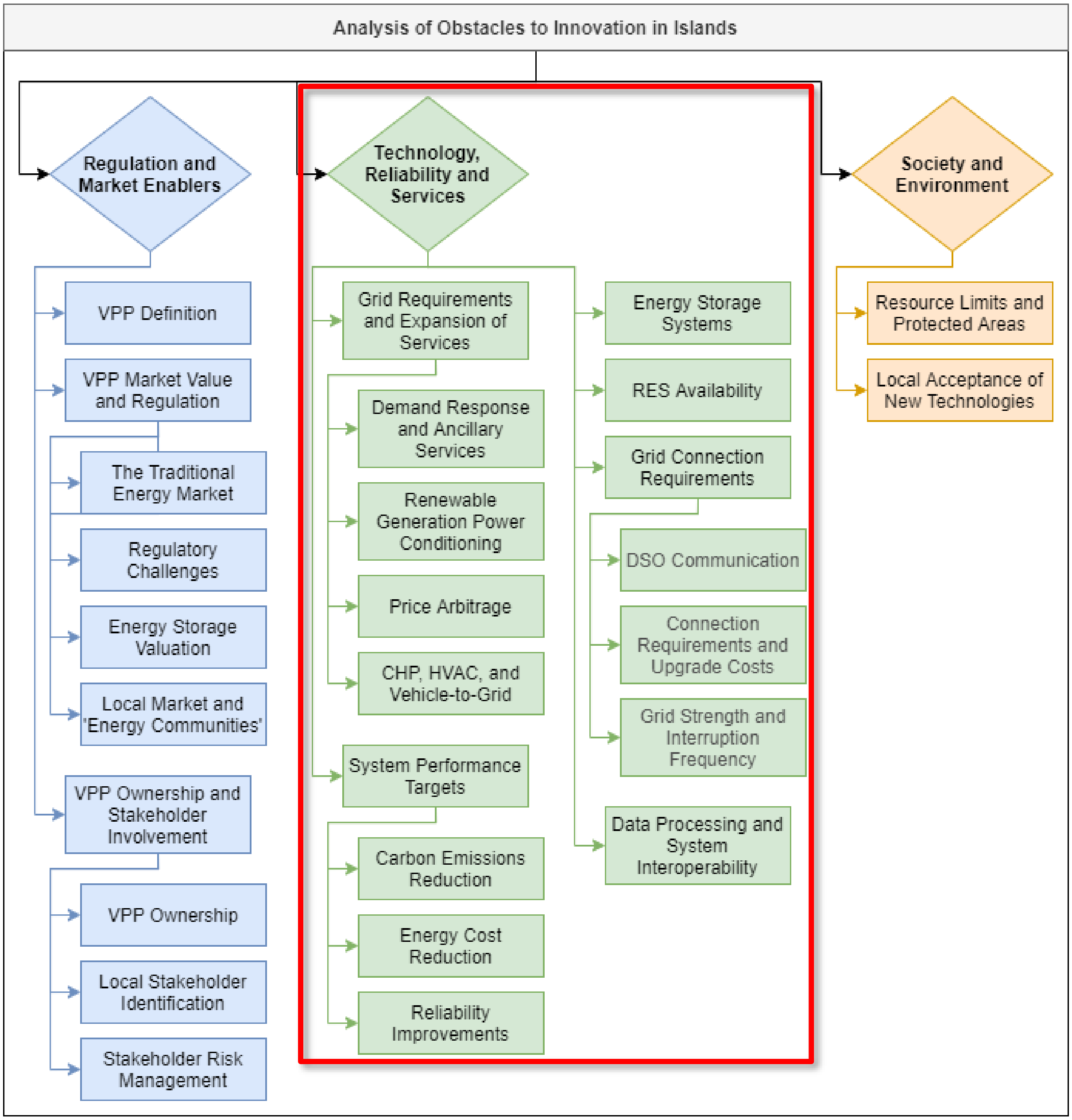


Figure 3.1: Report structure diagram highlighting the technology, reliability, and services obstacles.

3.1. GRID REQUIREMENTS AND EXPANSION OF SERVICES

The potential services made available by the VPP concept is the key attraction of the technology within the energy industry. The increase in small-scale distributed generation has had a dramatic effect on the energy landscape and has produced a potential market for equally local ancillary services and renewable energy grid support. The regulation and market barriers discussed in section have a considerable effect on the variety of services that can be implemented, as well as their value added to the VPP concept. This section focuses on the technical barriers that face the different services successful use with the VPP4ISLANDS project. A review of ESS service barriers presented in [27] provides an excellent foundation, from which an extension into VPP services is discussed.

Demand Response and Ancillary Services

Demand Response (DR) has been noted as one for the key services to be provided by VPPs. DR can be seen as a competitor to the traditional reserve markets, except that it can be effective at a community level. Due to the increase in distributed generation, it is becoming increasing important to respond to sudden supply changes and consumer demand. DR concepts, for example those presented in [37] and [38], consist of an aggregated grouping of small renewable generators, a consumer fixed load, consumer variable load, and an ESS. These models consider the optimal approach to controlling the VPP energy community to meet the DR objectives in the most robustness and cost-efficient manner. A potential technical barrier with the DR method is in understanding the range of operating conditions and connection requirements of the distributed resources, and how to coordinate the appropriate response to the grid. This barrier can be grouped under the larger ICT considerations to be applied to the VPP such as sensing, computing, and communication of the DR assets [39]. Unfortunately, the route to inclusion of DR within the European energy market is currently unknown, as noted in section 2.

The VPP concept will also have ability to assist the DSO and local community with emergency response service in the event of a planned or unplanned interruption. Depending on the local and variety of the interruption fault, the VPP could have a contingency mode that acts quickly to protect and supply the most crucial loads with power. Most critical loads including hospitals and airports have diesel generators that are activated in the event of a fault, which will increase the carbon impact of the island. A potential service would be to provide reserve power to the critical load instead of relying on back-up generators. Another service discussed for this situation is that the VPP could also act to store excess renewable energy that is currently disconnect from the load. The stored energy could then be released to either power critical loads if a connection is available or assist the DSO in reenergising the grid after the fault has cleared. Like DR, a barrier with these

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

services is the data and communication required to make decisions and control the energy flow on the grid, particularly when critical loads are to be handled.

Renewable Generation Power Conditioning

It is known that unpredictable behaviour is one of the key problems facing the mass installation of renewable generations such as Photovoltaic (PV) solar and wind turbines. Sudden changes in power output particularly within a small grid system like those on islands could significantly affect stability and robustness, leading to large voltage and frequency fluctuations. Research conducted in [40] and [41] both recognise the importance in smoothing the power fluctuations in distributed generators. PV curtailment control is a common method of controlling the output power by modifying the Maximum Power Point Tracking (MPPT) set point of the system. This smoothing method cannot account for situations like sudden power derate from partial covering, and ultimately causes a power loss in the PV system. An alternative would be to allow peak power fluctuations to be stored, then reinjected when required. Similarly, wind turbines can suffer from variations in output through changing weather conditions. In an island environment with a large renewable energy share, these changes would be challenging to control. The use of a coupled ESS or through VPP communication could provide smoothing assistance to the output and reduce possible system interruptions. Although this service appears promising for increasing grid reliability for the islands, there are obstacles to consider. The first is that the energy storage would have to be situated on site or near to the renewable generator to benefit from the power fluctuations. The second obstacle, like with DR and price arbitrage, is that although this technology is alleviating problems and therefore incentivising new RES, the overall carbon emissions would be increased due to the installation and use of the storage. Although there are clear reliability benefits to this service, the value added to the energy grid is also not fully understood, so would have to be analysed in more detail.

Price Arbitrage

The potential flexibility of the VPP concept combined with an appropriate ESS could take advantage of price variations on the energy spot market, as known as price arbitrage. Price arbitrage is the practice of buying energy from the grid while the price and demand are low, such as at night or earlier afternoon, and selling on when the price and demand are high. This process also complements DR as the use of arbitrage can produce excess stored energy that can be made available for other services. As mentioned in the previous section, the practicality of price arbitrage would depend on whether small-scale, aggregated generators qualify for participation on the national spot market, which is known to vary between EU countries. While providing potential profits from promoting renewable energies, price arbitrage will likely increase overall

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

carbon emissions in the system due to efficiency losses in operating an ESS. Research presented in [42] analyses the prospect of market price arbitrage participation for individual prosumers with small Battery Energy Storage Systems (BESS). A forecasting sensitivity analysis and its effects on the scheduling performance is also modelled in detail, and outcomes show that the profits using this method rely heavily on the quality and accuracy of the forecasting technique. Most notably, arbitrage can have a negative effect on both the price and environmental sustainability of the stored energy if forecasting is proven to be inaccurate. As a mitigation strategy, analysis of the capital and maintenance of the ESS should be considered when calculating market arbitrage viability, as well as the risks associated with generation forecasting.

CHP, HVAC, and Vehicle-to-Grid

The attraction of VPPs is not only in the potential grid support services, but also for auxiliary services that will become increasing important in the coming years with changes to consumer habits. The services can also be used to supplement other community energy systems and industries.

Electric Vehicles (EVs) have been discussed at length for their involvement in VPPs for the benefit of both the EV owner and the grid operators. The Danish EDISON project was set up to aggregate EVs to provide support and flexibility to DERs. Due to DER intermittency, the EV batteries provided a beneficial method of supporting the local grid through charging and discharging, increasing grid reliability. The EDISON project also provides time-coupled metering methods, in which the EV owners would receive renumeration for their participation, incentivising others to join [43]. The EDISON is based on the island of Bornholm, a follower island within the project. Participants in this initiative should therefore be contacted to understand more about the technical aspects and barriers of integrating EVs into the VPP.

Combined Heat and Power (CHP) and Heating, Ventilation and Air Conditioning (HVAC) are commonly discussed within VPP concepts to increase system efficiency by scavenging excess heat of generation and storage processes to direct into a useful process. CHP has long been considered a natural component in the VPP structure due to its community-based district heating design, and as discussed in [44], can mitigate some of the inherent financial risks associated with the concept system. CHP plants can also be used as one of the few low carbon dispatchable resources to assist in the flexibility of the VPP. If residential heating is challenging or not required as frequently due to the local climate, CHP can be used to provide low, medium or high-grade heat for industrial processes [45]. By support industry, CHP can be used to reduce grid stress as well as natural gas usage, further reducing the carbon emissions of the island.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

Although these potential auxiliary services are intriguing prospects that have detailed research and proof of concept, a potential barrier to their implementation is in understanding whether there is a market requirement specific to the island. Most smart EV-charging concepts have been designed for implementation in Scandinavian countries and Germany, where EV ownership is high. According to EU data on new car registrations in 2020, Norway registered 23 times more plug-in EVs per capita than Spain [46], even though the latter has the fifth largest economy in Europe. Similarly, the potential for CHP on geographical islands is strongly linked to the inhabitants' requirement of the heating that is provided, such as cold weather climates. These requirements and constraints should therefore be analysed in depth for each island, providing a concrete business case with evidence of utilisation, as well as cost and energy usage reductions.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

Services Summary

In addition to services mentioned in this section, a list based on information provided in [47] has been provided in Table 3.1. It can be noted that the individual services have different temporal resolutions and require synergies with other stakeholders both local to the island and nationally. Although these services have been suggested for use within local energy scenarios such as VPPs, limited research has been conducted on the practical implementation of such a storage system, particularly when applied to ancillary services and local energy trading.

Application Time Frame	Services for Flexible VPP Dispatch		
0-30 Seconds	Voltage and frequency control	Voltage/VAR support	Power quality
3 Minutes	Spinning reserve	RES generation smoothing	
	Voltage sag		
	Rapid demand support		
	Real-time energy balancing		
20 Minutes	RES ramp and voltage support		
	Back-up power	Blackout support	
2 Hours	Peak load shaving	Consumer incentives for quick load reduction	Energy cost management
	Congestion relief	RES energy store during interruption	
8 Hours	Time-shifting	Price arbitrage	Consumer time-of-use incentives
Days	Weekday-weekend load smoothing and carry over		
Weeks	Smoothing weather and environmental conditions		
Seasonal	RES seasonal storage	Annual load smoothing	
Years	Outage mitigation	Grid upgrade deferral	Reliability improvements
Other Energy Services	Smart EV-charging	CHP district heating and industrial processes	
Data mining and sharing	Shared energy data could be used for grid performance improvements	Transparency with 3rd parties to increase project visibility and investment	Shared with communities to create additional cost saving measures and carbon emissions reductions

Table 3.1: Potential services implementation through the VPP (modified from [47])

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

3.2. SYSTEM PERFORMANCE TARGETS

The system performance targets for the VPP will provide crucial objectives and constraints for the conceptual design and specification. As mentioned in the previous section, the performance objectives will vary depending on the objectives of the ‘fostering entity’ - the stakeholder who is responsible for the practical investment and integration of the VPP systems into the community grid.

It has been noted previously that this fostering entity can be a variety of potential stakeholders, such as the local DSO, community governing council, private investor, or groups of private prosumers. For each of these cases the objectives and constraints will be different, as well as the costs and benefits of the VPP. It should also be noted that the objectives defined may conflict with each other, so must be considered as a multi-objective optimisation problem. The performance objectives can be approximately grouped into three categories. Developing communication paths and joint ventures with other projects and improving the collective knowledge of VPP potential are other performance indicators will also have a major influence on the success of the VPP.

Carbon emissions reduction: Given the current climate situation, and stress placed on national energy bodies to reduce the climate impact of the distribution grid, this will be one of the key performance objectives for most fostering entities. Considering the local governing body, they may have incentives placed on them by national government to provide evidence of emissions reduction with the community, as well as penalisation to those who do not participate. The same carbon levies may not apply to local DSOs, who also may not have as much of an interest in carbon emissions reduction over other prioritised objectives. The VPP concept presents a method of curbing carbon emissions from energy production in a local area with a large amount of RES generation capacity. RES that must be curtailed due to over-production or sudden generations peaks would be ideal to exploit in this scenario, either through export to the grid, local energy trading, or ancillary services supply.

Energy cost reduction: the reduction of electricity cost for the participants with the VPP is one of the key motivators with research. A number of methods have been presented, such as [17], [25], [26] and [29] that consider the economic impacts and potential benefits of the aggregation of DERs into a VPP-style system. Cost reduction is seen as a major future driving force to the implementation of such futuristic and disruptive technologies, even more so that the other objectives discussed. Cost reduction also applies to the widest audience of potential fostering entities, as all will look to reduce the operational cost and even produce a profit from the implementation of a VPP. It can be noted, however, that increasing cost effectiveness may conflict with the objective of carbon reduction, as it may be most beneficial economically to operate a

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

system that produces increased emissions. When the previously discussed example service of price arbitrage is considered, it has been shown to increase profits for an installed ESS, but the disadvantage is that efficiency losses which will inevitably increase the carbon impact, even before the manufacture and lifespan of the ESS is considered.

Reliability improvements: the reliability of the local energy system is closely linked to the ultimate cost of operation and maintenance, as the TSO and DSO are both rewarded and penalised based on the reliability performance within which they operate. Reliability can also consider the quality and comfort of the energy consumers, which can be approximated with the reliability indexes System Average Interruption Duration Index (SAIDI) and the System Average Interruption Frequency Index (SAIFI). Loss of Load Probability (LLP) is also used to define the fraction of time which loss of load may be expected to occur during a period in the future [48], usually expressed as hours or days of the year or a percentage. The LPP equation is shown below:

$$LLP = \sum_{j=1}^{N} P_j t_j$$

Where P_j is the normalised lost capacity due to an outage in line the probability density function, and t_j is the normalised outage duration. The probability density function is determined based on data from previous plant outages, which can then be used to estimate when a power station will experience an outage and how much capacity is lost.

As discussed previously, geographical islands are generally connected to the mainland or another island through a single medium voltage sea cable and may not have additional ancillary services on the island to respond to demand variation. The introduction of ancillary balancing services through the VPP may have the ability to considerably increase the robustness of the system. These reliability improvements, however, may again conflict with the other objectives of cost and emissions reductions. For example, peer-to-peer energy trading may be more profitable in some markets than providing ancillary services and may increase carbon emissions through efficiency losses.

The key barrier to implementation of system performance targets is in understanding the objectives, services, and constraints for each island individually. The concept design would then need to generalise this rationale such that any number of specification combinations can be handled by the proposed system. This generalised concept can be modelled in principle and has shown to be effective within research [20], but the nuances specific to the local area and governing

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

regulations produces a performance optimisation problem that is complicated by multi-inputs, multi-objectives and non-linearities.

3.3. ENERGY STORAGE SYSTEMS

An Energy Storage Systems (ESS) is defined as the conversion of electrical energy into another energy form for later conversion back in electricity. In this way, it can perform temporal shifts in electrical consumption, providing additional flexibility of services to the energy grid. The regulatory barriers of integrating ESS into the traditional energy structure, considering the requirements of the energy market and related governing policies, have been discussed in the previous section. It is widely accepted by most literary sources that there is a lack of direct policy and frameworks with respect to ESS that enhance the benefits that could be provided to the energy grid. This means that the technology currently has a limited number of exploitable revenue streams, as it is challenging to compete with the traditional capacity reserve markets on a national level.

The previously conducted regulatory analysis does not consider the technical barriers and challenges that will also affect the successful implementation of ESS on geographical islands. In this section, a variety of different ESS technologies were considered, as well as their advantages and disadvantages. ESSs come in many forms and adopt varying methods of electric energy capture and storage, which in turn dictate the storage and discharge capacity. Examples are displayed in Figure 3.2.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

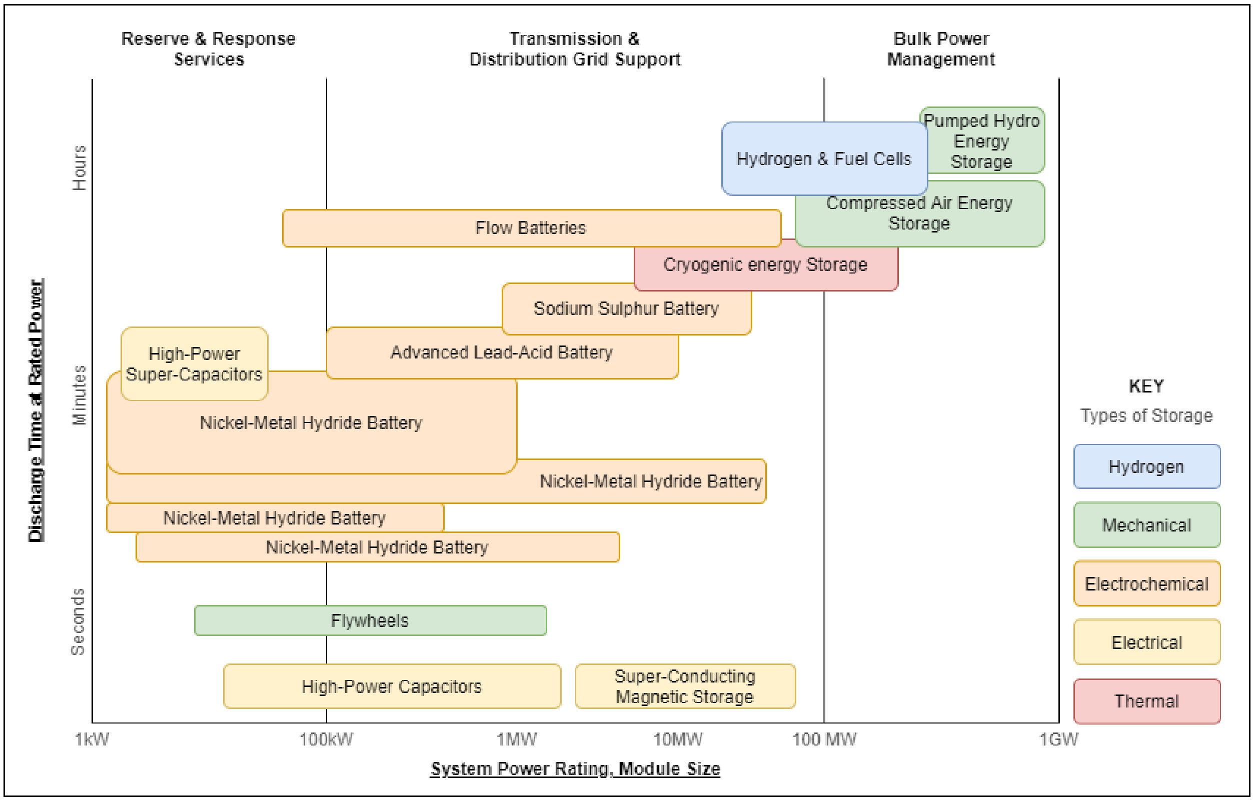


Figure 3.2: Comparison of ESS in terms of storage capacity and discharge duration [49]

Battery Energy Storage

BESS are the most common form of ESS currently being explored for implementation within VPPs. Fast maturing, future oriented energy services industries such as the battery EV market have sped up the development of lower cost batteries. Companies have also had to scale up the manufacture of large capacity batteries to keep up with demand. This produces a low cost and widely available technology that is well understood from a technical perspective, so could theoretically be implemented into the VPP system. The deficiencies identified that are associated with limited lifespan and safety issues relating to BESS are being continuously remedied [50]. The extensive development and manufacturing of BESS means that it has a lower inherent risk associated with its usage.

While the benefits of BESS are many, there are also some challenges to consider with this technology before implementation on geographical islands. It can be seen in Figure 3.2 that battery systems common discharge at nominal power output in the temporal range of seconds to

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

minutes, and usually have a lower system power rating than other storage systems. This indicates that BESS have a limited temporal range in which they can operate most effectively. When considering the services outlined in Table 3.1, while provisions for services occurring within the first seconds to minutes range such as voltage/frequency control, power quality, and RES generation smoothing can theoretically be handled by BESS, other long-term services cannot. The ability to provide hourly and daily energy shifting for arbitrage services, and seasonal storage for long term energy transfer would be a challenge for BESS, not least because of the natural current leakage that occurs within chemical batteries. While the problem of services delivery may limit its effectiveness to capture additional revenue streams, the benefits including the technology readiness, continual cost reduction and vast commercialisation favour BESS considerably.

Flywheel Storage

Flywheel Energy Storage Systems (FESS) function simply by storing electrical energy with the use of a motor connected via the output shaft to a rotating mass. The electrical energy is converted within the electric motor, increasing the rotational velocity of the flywheel. Power can then be drawn from the rotating mass when required, slowing its rotational velocity. The FESS is coupled to the grid via a DC link converter similar to a wind turbine, which controls the injected AC frequency. The flywheel itself is suspended on magnetic or mechanical bearing and contained within a vacuum to minimise frictional losses. Flywheel can also accelerate to speeds of 50,000rpm so has be contained within a protective structure in case of failure and potential explosion [51].

There are many advantages to the use of FESS over other ESS. The high energy stored in the form of inertial energy can be injected quickly back into the grid, so would be ideal for applications like RES generation smoothing and primary reserve response. The technology is simple in design when compared to electro-chemical storage and has a theoretically infinite lifespan with regular maintenance [51].

There are also barriers associated with the implementation of FESS, most notably the frictional losses that occur during operation that would limit the round-trip efficiency. The inertial energy must be used quickly after it is stored to limit losses, so FESS is not suitable for long term storage [52]. Overall, the implementation could be an interesting prospect to assist in the generation smoothing of RES, but the applications are limited due to efficiency losses and technology readiness level. FESS has a higher overall associated risk in implementation due to the factors described.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

Pumped Hydro Storage

Pumped Hydro Energy Storage (PHES) is one of the oldest forms of energy storage, so has many documented cases of opportunities and barriers that may influence its implementation. Energy is stored simply by pumping water from a low to a high elevation with the use of natural lakes, reservoirs, and dams, increasing its gravitational potential energy. When power is required, the water is released from the high elevation and the gravitational potential is converted back into electricity. Approximately 300 PHES plants had been installed worldwide as of 2015 [53].

PHES is a mature technology that has proven reliability and longevity in many European countries, and with an efficiency of 65-85% it has a relatively high efficiency when compared to other ESS technologies [54]. Other advantages include the long lifespan and ability to store a provide very high quantities of energy for industrial applications and provide a response within the seconds to minutes time frame. Given the large potential storage capacity, PHES can be operated from hours to months. The use of PHES combined with RES has be proven, for example in Portugal where a 220MW hydro storage system is used to support and counteract peaks and valleys in wind power generation [55]. The smoothing of wind and PV production has been considered on large islands with the use of PHES, such as the Greek island of Crete, where the projected increase in wind turbine installations may require energy storage to smooth out generation peaks and valleys, as well as providing additional system measures, control enhancement, and preventative actions [56].

A key disadvantage of PHES is that it has geographic requirements such as elevation change to provide the gravitational potential. Natural lakes are also an advantage, but dams and artificial reservoirs can be constructed. Sub-terranean reservoirs can also be built [57], but at an additional cost to the system, as well as a negative effect on the total environmental impact. The damage to ecological systems is also a commonly cited problem among the sustainability analysis of PHES, in particular the effects on wildlife including fish and waterfowl that rely on the use of natural waterways and lakes [58]. The increased noise and activity can also drive away wildlife and reduce biodiversity to critical levels. It is unlikely within the scope of this project that PHES will be included within the VPP concept, but future implementation should be considered has the future construction of the technology increases.

Power-to-Gas and Hydrogen Storage

Power-to-Gas (P2G) is the process of converting excess electrical power in hydrogen or natural gas to be used as an energy vector. The gas can then be fed into the natural gas distribution grid and consumed within homes or industrial processes. Research conducted in [59] analysed the

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

feasibility of a regional G2P multi-domain VPP situated in south-west Germany. The analysis concluded that P2G would be a possible option given the forecasted increase in energy generation from wind power in the area and would reduce operational losses in the system whilst providing additional energy flexibility to the local area. This model, however, was based on a prediction up to the year 2040, as it was concluded early in the research that the current day profitability from P2G is too low to be exploitable, even if an energy generation cost of zero is assumed. The model also does not consider the systems required to feed gas into the network, and the appropriate metering equipment. Analyses of a combined P2G system with coupled Closed Cycle Gas Turbine (CCGT) considered in [60] come to a similar conclusion, in that with the current 'Business as Usual' RES scenario P2G is unlikely to be a viable system without specific incentives from regulators.

An alternative to the P2G system is generating energy with a Hydrogen Fuel Cell (HFC). HFCs only produce water as a by-product, so are a cleaner source of energy than gas turbines. Although the concept of fuel cell energy storage has been explored for a number of decades, few practical examples exist of HFC usage as an energy storage for the grid. A comprehensive review of the role, cost, and value that HFCs may be able to provide as a grid ESS is provided in [47] Electrolysis can provide a number of resources in addition to hydrogen, like district heating and oxygen for potential medical applications. Power-to-power (P2P) systems such as HFCs could also provide seasonal storage due to the low self-discharge rate of hydrogen storage. Countries with a large amount of PV solar production can have considerable variation in RES generation between summer and winter, so the ability to store excess production to then use at another time of year could be hugely beneficial. It is important to note that HFC system would work best when there is a large amount of excess or curtailed RES load, as the round-trip efficiency is less than that of batteries and other ESS. Price arbitrage would also be more challenging to produce a profit due to the lower efficiency. The creation of a hydrogen economy is considered not an alternative but a complementary technology to batteries and other energy storages [61] to balance the strengths and weaknesses. The services requirement of the island would therefore have to be analysed in depth, and confirmation of excess RES generation would likely be required for this technology to be successfully implemented.

ESS Hybridisation

It can be seen from the selection of common ESS described that each system has its own set of advantages and disadvantages in terms of services and processes that can be provided. For example, BESS can provide a fast response to changes in VPP operation, but with a limited storage capacity it cannot be used for long term ancillary services support between charges. By

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

contrast, HFCs can provide energy over long periods of time and be used for seasonal storage but are not as suitable for quick response services.

In this scenario, it may be beneficial to use a hybrid system approach to combine the advantages of multi ESS technologies, whilst simultaneously reducing the number of obstacles and disadvantages during operation. Exploration into the benefits of ESS hybridisation within the energy grid are limited within research, but sources indicate that cost reduction and increased storage lifetime is achievable. For example, outcomes from [62] strongly indicate that the use of a hybrid battery and fuel cell system in combination with a PV solar array can significantly reduce the Levelised Cost of Electricity (LCOE) of the power system for off-grid applications.

3.4. RES AVAILABILITY

The requirement for a VPP system is due to the increased penetration of decentralise RES generation within distribution grids. It is the case in some European countries such as Germany that excessive RES supply causes the generators to be curtailed above a certain limit. This is a problem for several reasons, not least that it applies a limit to the amount of carbon reduction that can occur within the grid. Energy production in excess can also devalue the supply, producing negative market prices, as well as adding additional stress to the grid infrastructure. Through the aggregation of these resources, the VPP would be able to properly forecast and schedule the power production from RES, as well as store any energy that is not used. This process is only possible if RES energy is being produced in excess of the demand, otherwise while scheduling and storing energy may increase profitability and reliability, the adverse effect of increasing the carbon impact due to efficiency losses. Like the performance objectives discussed, the inherent trade off may not favour emissions reduction in this case.

As a simple case study, the island of Formentera can be used as an example. The island consists of a 2MW PV solar farm, in additional to 18MW diesel generators and a 13MW gasoline turbine to serve as back-up supply. Any additional demand for the island, including balancing services, is handled through a series of sea cable interconnectors within the Balearic Islands that eventually reach the mainland peninsular of Spain. The island had a minimum and maximum demand in 2019 of 2.5MW and 19.5MW, respectively. By comparing the PV solar generation with the minimum demand requirement, it can be seen that there is not a moment on the island that RES energy is available in excess of demand. To store energy and provide balancing reserves through the VPP, a proposed ESS would have to store RES energy that could otherwise be used to serve the island during normal operation, and in the process would increase the carbon impact of the island through efficiency losses. Another option is to store energy arriving from the mainland to be used for the VPP services discussed. The Spanish mainland has low levels of carbon in the

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

generation mixture due to a large quantity of wind power present. However, as the connection passes through other Balearic Islands such as Mallorca and Ibiza, the presence of gas and coal fired power stations increases the carbon impact considerably. Initial studies conducted on this generation data conclude that storing interconnect energy in Formentera would negate the benefits for reduced diesel generator usage, even before the round-trip efficiency is considered. This presents itself as a major barrier to carbon emissions reduction on the island.

This problem will likely be present until RES integration surpasses supply in Formentera and other geographical islands. It has been noted through interviews with Formentera partners that there is an aim to have 70% renewable generation on the Balearic Islands by 2030. Bornholm, by contrast, already produces RES in excess of its supply and is able to export the energy to Sweden through a 50kV interconnector. This is the ideal scenario for a geographical island as excess RES can be stored and its low carbon impact kept on the island. The VPP concept should therefore be designed to promote the increased integration of RES with cost and reliability incentives, as this will naturally reduce the carbon impact over time as uptake increases. The promotion of local distributed system will also decrease grid losses, as energy does not have to be transmitted over long distances to reach the consumer.

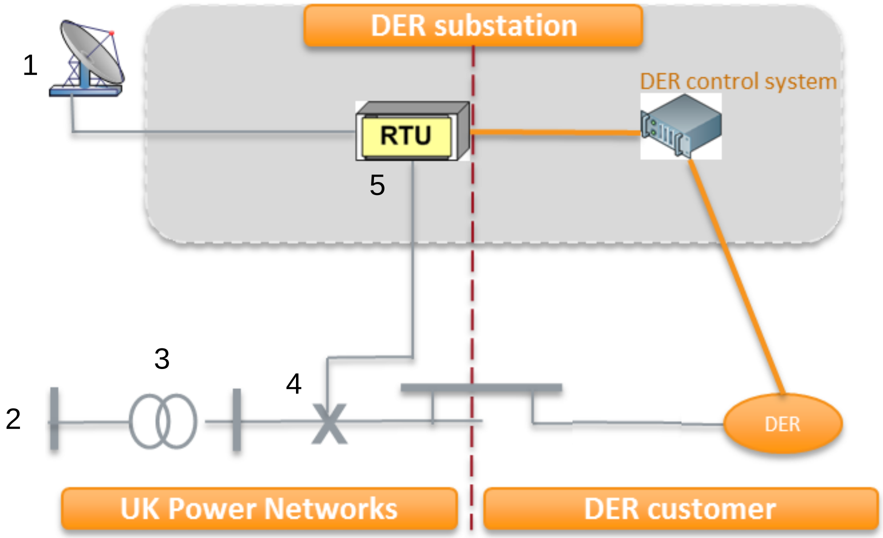
3.5. GRID CONNECTION REQUIREMENTS

An important aspect of the VPP is that it takes advantage of the increasingly distributed nature of the energy grid system. Not only does the VPP require a high level of DER integration in order to operate, but it also promotes the continual increase in production capacity at a decentralised level. The traditional energy grid was designed such that energy was generated from a single source and transmitted from high voltage lines to low voltage feeders to serve the end users, so connection requirements for traditional generators are well understood. The IEEE 519 documentation provides a guideline for setting limits on the voltage and current distortion effects on the grid due to linear and non-linear loads with power quality constraints [63]. These guidelines also influence the design of the transmission and distribution infrastructure. DERs on the other hand have much different requirements to operate and interact with the energy grid. In the UK, the DSO UK Power Networks sets out the DER technical requirements as part of the Power Potential project trials [64]. Power Potential is a new initiative to increase visibility and capabilities of DERs in the UK using a unified system of control and communication. The aims and objectives of the project are similar to that of the VPP concept, so the DER requirements can be used to give a preliminary understanding and analysis of challenges.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

DSO Communication

The UK Power Networks report outlines the required system architecture and the responsibilities of the key stakeholders (TSO and DER operator). Communication with the DSO is vital in providing the correct services to the grid. The DER substation must be fitted with a control system and Remote Terminal Unit (RTU) that will communicate directly with the DSO through Distributed Network Protocol 3 (DNP3) or similar [64]. The simplified substation diagram is shown in Figure 3.3. The red dotted line signifies the divide between the DSO managed infrastructure and the DER operator managed infrastructure. The system design will vary depending on country and region of installation, so understanding the requirements of the communication system is important. Within the VPP concept, a key challenge will be to ensure these communication pathways between the DSO are available such that the services requests and scheduling can be received.



No	Component
1	DSO communication
2	DSO grid
3	Secondary transformer
4	DSO side measurement
5	DSO side RTU

Figure 3.3: UK Power Networks DER substation communication requirements [64]

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

Connection Requirements and Upgrade Costs

The rapid adoption of small-scale PV solar has led to the requirement for new approaches in assessing the cost, grid conditions, and requirements for connecting to the grid [65]. For example, the hosting capacity may limit the VPPs effectiveness in islands. Hosting capacity is the maximum quantity of distributed generators such as PV solar and ESS that can be installed before distribution grid parameters are violated and require additional upgrades. Given that islands generally have a weak distribution network, the availability to install more RES may be limited before the DSO has to invest in high power feeder lines and transformer stations.

The use of ESS can further complicate the local grid requirements. As mentioned in the previous section, ESS can act as both a generator and a consumer of electricity, so energy will flow in both directions within the local grid. The location of the ESS installation for the VPP should therefore be considered carefully as the connection will need to be capable of both importing and exporting energy to the grid. If it is decided that an upgrade needs to occur, there is a problem which stakeholder is responsible for the cost to the system. The US, electric utilities have deployed a cost envelope which limits the amount that a DER operator must pay the DSO for the required upgrades, as estimated by the utility. The exact regulation surrounding cost envelopes varies between states, but in general the DER operators is liable to pay a certain amount towards any required upgrades, after which the utility who produced the estimate is also liable [65]. If additional DER is to be installed with the VPP, the challenge and costs of preparing the local grid needs to be considered as an obstacle within the system.

The increase in share of distributed RES comes increased concerns over grid reliability problems such as congestion due to unplanned generation. Several US states have begun to develop standards to take advantage of the increasing functionality of advanced inverters. Inverters are used by PV solar arrays to converter the DC output to 50Hz AC at a constant voltage to be used by the grid. The advanced inverters can perform several additional functions including voltage and frequency ride through and reactive power support to enhance the local island grid reliability and improve the coordination of services between DSO and DER operators [65].

There are international standards and guidelines to follow when considering new DER connections to the grid. The IEEE 1547-2018 is a technical specification for the interconnection and interoperability between electrical utilities such as the TSO and DSO, and DERs. This document provides information relevant to the performance, operation, testing, safety considerations, and maintenance of the interconnection [66]. Similarly, the BS PD IEC/TS 62786:2017 provides principles and technical requirements for DERs that are connecting to the distribution network, including planning, design, operation and connection of the DER. The

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

standard also specifies the operating range, active and reactive power responses, response to frequency deviation and voltage changes, Electromagnetic Compatibility (EMC) and power quality [67]. It is vital to address the requirements mentioned within the DER connection standards, particularly those relevant to the control and response to distribution grid signals within the planning and scheduling of the VPP services.

Grid Strength and Interruption Frequency

Geographical islands are typically connected to the mainland via one or more sea cable interconnectors, which naturally limits in the power throughput available. For example, the island of Gökçeada is connected through a 35kV AC cable to the Turkish mainland and is used to balance the power output from the RES generation available on the island. This can often lead to additional grid stress when demand is high or unpredictable, causing an increase in interruptions. In 2016, the System Average Interruption Duration Index (SAIDI) for unplanned disruptions did not exceed 400 minutes for all European countries and has generally displayed a stable decline in the years leading up [68]. Gökçeada, by contrast, recorded a SAIDI of 764 minutes 2019, which is if assumed to be similar for three years prior is nearly four times higher than mainland Europe. The island also has a planned interruption SAIDI of 1590 (2019), compared to an EU maximum of 400 (2016).

The reasons for the increase in grid interruptions on the island include bird touches, box dislocation, current, voltage transformer, cutting trees, disconnector damage, LV box problem, LV connector damage, LV cable damage, and MV insulator damage, surge arrester damages, and MV overhead line maintenance [69]. These interruptions could present a significant barrier for the implementation of a VPP. Figure 3.4 below is an example of the Gökçeada energy flow, with the sea cable, total renewable generation, and approximate demand shown. Two large interruptions can be observed with the graph from 08:00-17:00 and again from 10:43-12:58 the following day. Although these interruptions are planned, it can be observed in the first case that both the sea cable and RES generation are paused, even though meteorological data showed a wind speed of 10m/s. This would cause a problem if a VPP system relied on these two energy sources to schedule energy services to the grid. It is vital to identify grid weakness and interruption occurrences on the island, such that VPP down time and risk of non-delivery of grid services can be minimised.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

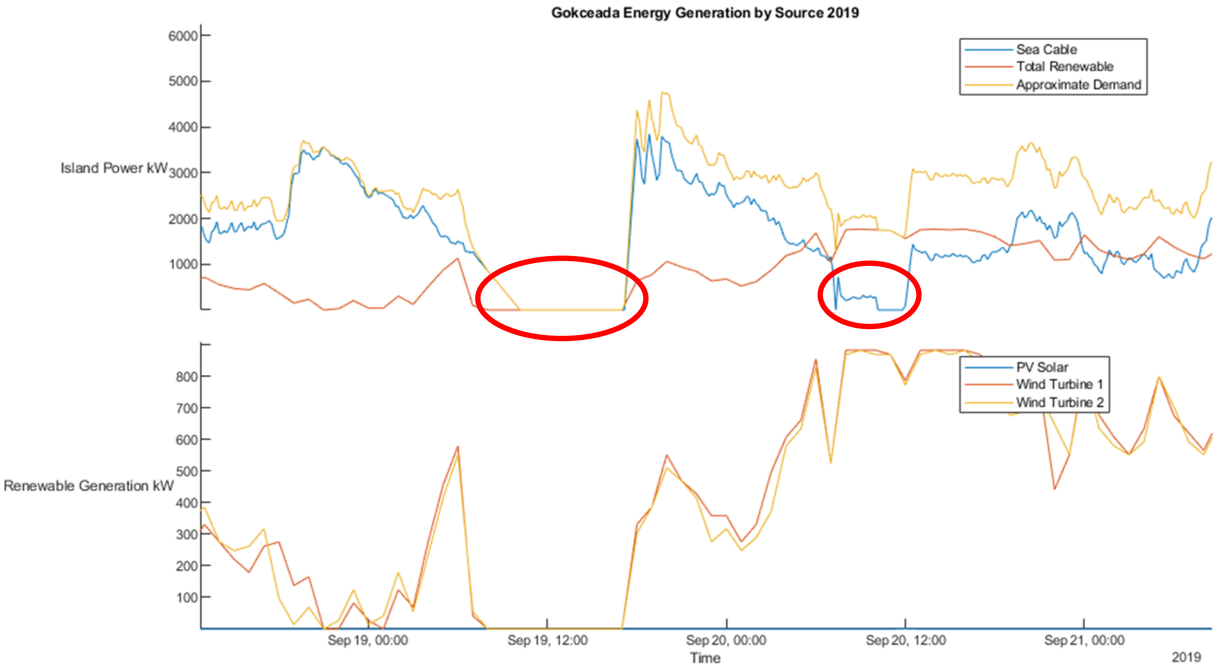


Figure 3.4: Gokceada demand interruptions example data

3.6. DATA PROCESSING AND SYSTEM INTEROPERABILITY

The premise of the VPP requires an ecosystem of interconnected measuring and control equipment for optimal decision making. In additional to the practical barriers of connecting DER to the existing grid, this section will cover the technical obstacles to transition from the tradition grid control methods to the digital and autonomous communication standard of an interconnected smart grid.

Many consider the key technology to unlocking the excess of peer-to-peer communication with distributed energy systems such as VPPs is in the use of Distributed Ledger Technology or Blockchains. A blockchain is a digital data structure containing a continuously increasing number of records, where each record can include information like transactions, recorded data, and control history. The difference is that there is no centralised authority controlling each record, as any transaction is requested, authorised, and validated by the participants of the peer-to-peer network. An in-depth review of the challenges and opportunities of Blockchain within the energy sector was conducted in [70]. The review highlights the uses that DLT could serve within a local community energy setting, including billing and tendering, data access and transfer, autonomous control, and other grid applications. Again, these process all rely on a network of smart meters connected to each peer node in order to control the communication signals effectively. Also

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

highlighted were the benefits of this technology when compared to a traditional centralised energy economy, such as increased security and identification, transaction transparency, and speed of transactions [71]. Although the number of potential benefits exist for blockchain within the VPP concept, there are also technical barriers that have been highlighted. Given the number of potential actors and customer/prosumer interactions that would occur at every time-interval, coordinating, recording, and responding to specific scenarios is seen as a common problem with concept systems. Organising complex and stochastic optimisation routines to run within the required timeframe may also be computationally expensive.

It is possible during the operation of the VPP that measurement errors will occur within the actors involved. An example observed within initial research of the lead islands is an error present in the measurement of the PV solar farm generation on the island of Formentera, as shown in Figure 3.5. According to the TSO, Red Eléctrica de España (REE), a quality code error forces the Supervisory Control And Data Acquisition (SCADA) system to stop receiving measurement data from the local transformer. The error code could have been caused by component malfunction, unexpected maintenance, or another data handling problem. The presence of measurement errors in the VPP system could greatly influence the performance output and could cause additional grid instability. An analysis of the current and potential measurement errors within the system needs to be performed, so the mitigation strategies and alternative algorithms can be performed during such an event. These mitigation strategies need to be designed to protect the system from any adverse effects, such as loss of revenue, power, and reliability. These errors could also manifest as security threats, that cyberthieves could take advantage of and exploit for other purposes.

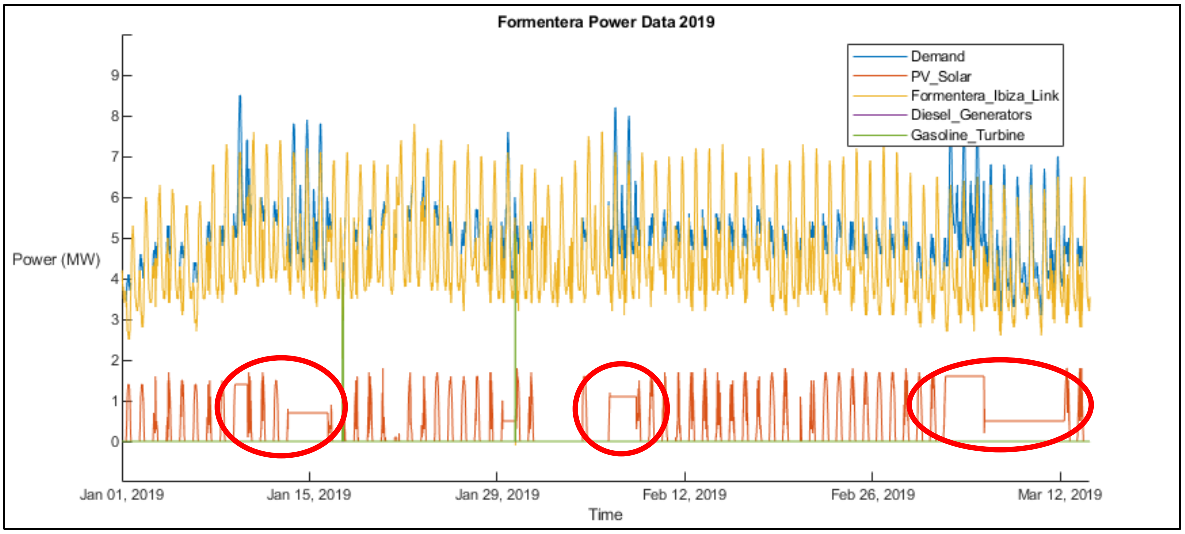


Figure 3.5: Formentera power generation data with observed PV solar measurement errors (source: REE)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

The problems presented relating to peer-to-peer interoperability and error handling could be solved with trust-based algorithms, which can be implemented through blockchain technology into the Digital Twin. The concept of a 'trust-based digital ecosystem' is described by [72] is an ecosystem of interconnected actors where trustworthiness is computed rather than granted by default. This can be considered an extension of the distributed consensus methods built into DLT, in that different nodes have to prove alliance with the prerequisites of the data transaction, and the total fault tolerance is above the predefined limit [70]. By the inclusion of the digital twin, the measurement data and processes can also be validated numerically, adding an additional layer of robustness to the data management system.

3.7. TECHNOLOGY, RELIABILITY AND SERVICES: SUMMARY

To meet the requirements of a low carbon society, the increase of decentralised and distributed energy resources is inevitable. There needs to be a strong technical foundation for how components will communicate to provide the energy and services required. The reliability of these communication systems will also indicate the perceived risk by potential adopting parties. In this section, a brief review of the technical barriers to the operation of the VPP concept on geographical island is presented, and potential mitigation strategies.

Through analysis of the Island grid structure, demand, and performance, as well as considering the vision and objectives of the fostering entity, the potential grid services need to be identified. Assessing the feasibility of these services through an extended cost-benefit analysis will also be required before a decision can be made on the VPP conceptual design. A socio-economic analysis of the benefits for the local community would be crucial to persuading potential scepticism of the new system. A discussion of public opinion and community sentiment in relation to RES is included in the next section. Appropriate ESS consideration will have to take in account the technology readiness level, levelised cost, commercial maturity, as well as the ability to provide a variety of potential services to the fostering island.

One of the main topics of research relates to the communication and interconnection of the technologies within the VPP. Blockchain technology has the potential to be very successful in dealing with some of the key obstacles due to its decentralised nature, increased security, and trust-based algorithms. This will be very important as the risk of measurement errors will be increased with the number of distributed nodes within the VPP. These errors would need to be identified and removed before having an adverse effect on the VPP control scheduling.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

4. SOCIETY AND ENVIRONMENTAL

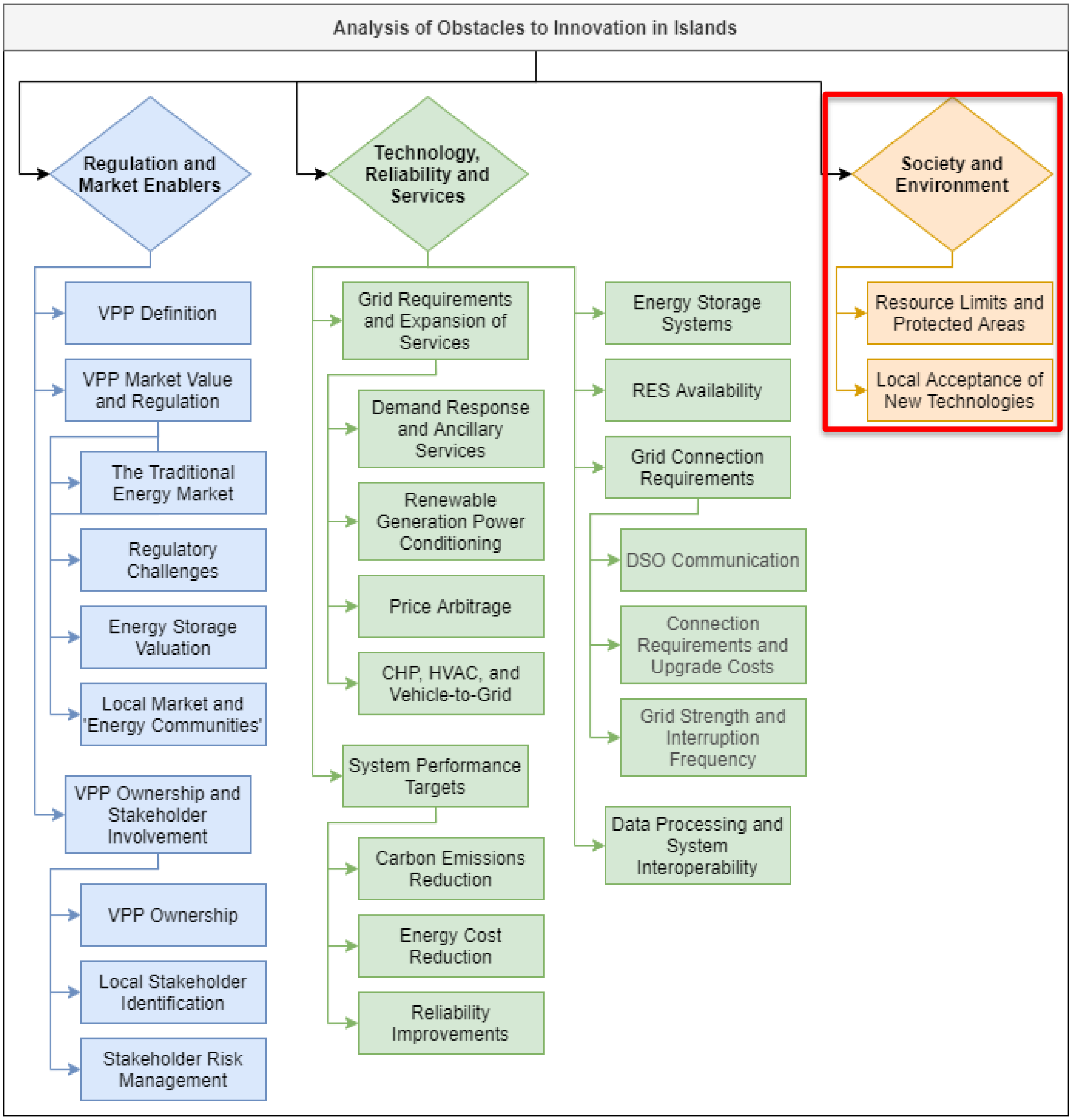


Figure 4.1: Report structure diagram highlighting the societal and environmental obstacles.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

4.1. RESOURCE LIMITS AND PROTECTED AREAS

The objective of a VPP system is to not only provide additional efficiency and flexibility to the local energy system, but also promote increased installation of distributed RES. For this reason, it is important to consider limitation to the physical implementation of VPP components including future potential energy generation.

Geographical islands will have space and resource limitations that could stifle future growth of certain RES. Resource limitations include absence of dependable solar hours, wind strength, and water reserves for PV, wind turbines, and hydro power, respectively. For example, European nations further north will experience fewer Sun Peak Hours (SPH) than in the south and Mediterranean. For example, Denmark has less than one tenth of the PV solar generation in 2019 when compared to Spain. Different resource availabilities of the different island will change the RES generation mixture, capabilities, and therefore flexibility of services offered through the VPP.

Protected areas are also an important barrier to consider when discussing RES installation. Geographical islands may have laws and regulations that restrict the building of renewable systems in certain locations or the entire island. In Formentera, local governing regulation does not allow the installation of wind turbines anywhere on the island. This is due to wildlife protection laws relating to the migration of local bird species. Natural reserves and parks have similar laws prohibiting the implementation of RES. This barrier is another important consideration for the VPP, as it will again limit the amount of DER that is permitted. Hydro power and the requirement for building dams and reservoirs can also pose a significant threat to freshwater species such as fish and waterfowl [58]. The dammed rivers can also limit communities' access to fresh water further downstream. This would be a particular problem for geographical islands as fresh water will be natural limited. Other location-based restrictions could include built up urban centres, airports, and military bases.

4.2. LOCAL ACCEPTANCE OF THE NEW RES AND VPP SYSTEMS

Although public opinion on new RES technology is generally positive, there may also be both public and regulatory concern over the implementation of a VPP. The local acceptance of the VPP within the community, in addition to adoption of the new technology and additional RES will be key to its success. The acceptance of new technologies can be categorised into two main categories: community impact and reliability concerns.

While specific analysis of public sentiment towards VPP systems is few due to the novelty of the technology, the impact that RES technologies on the local environment have been researched at

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

length since the introduction of large-scale wind and solar generation. Since a main objective of the VPP is to facilitate the increase in distributed RES, any related barriers need to be considered. The continuation of generalised public antipathy as documented in [73] has become less of a concern than it was a decade previously, but still affects the installation of RES in certain locations. As an example, the island of Formentera was considering the addition of a new 2MW PV solar farm south-east of the main town of, under the project name ‘Posidonia’ [74]. After initial environmental analysis it was deemed unsuitable for the island, due in part to the space consumed by the farm, and the environmental concerns raised by the local people. The current 2MW solar installation on island had public aversion during construction due to the requirement to flatten natural areas of tree and wildlife, which held sentimental value among the community. For geographical islands with strong community values towards the aesthetics of their local area, particularly among more conservative citizens, there will be a degree of public opposition to the implementation of new RES technologies.

The reliability of new RES and VPP systems is not only a concern for grid operators and regulatory bodies, but also the local government and citizens. The new concept needs to prove to these stakeholders that the overall reliability and security of supply will not be affected, particularly when faults occur. Reliability concerns can raise political debate over the usage of RES, with traditional non-renewable generation stakeholders to encouraging distrust of the new technology within the public. These reliability concerns are multiplied when extreme weather events such as extreme heat or cold occur (which are set to increase with climate change), particularly in emergency scenarios. In February 2021, an arctic storm swept through the US Midwest, with temperatures as low as -18°C in the state of Texas. This extreme weather incident sparked discussion over the reliability of the wind farms in the state, which were frozen and unable to function [75]. This was commented on by conservative energy stakeholders and political figures as a disadvantage of RES over traditional non-renewable fuels. These sources do fail to note that around double the generation capacity from non-renewable resources was lost compared with RES during the incident. Although this is an extreme case, reliability concerns will certainly be a barrier to persuading the local public to adopt the VPP and increased RES technologies, particularly when political power can be used to dissuade potential adopters. Particularly when considering the concept of energy community development, the promotion of active investment and ‘prosumerism’ will require a level of trust between operators end users that any adverse effects will not affect their security of supply. A system of communication and transparency with adopters should therefore be set up, where any reliability and cost concerns can be raised by all stakeholders.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

4.3. SOCIETY AND ENVIRONMENT: SUMMARY

The social and environmental benefits are two of the many predicted benefits of a successful VPP implementation. The concept of relocating the power of energy security and generation from a centralised regulation and governing to a local level ecosystem has the potential to transform the community views of energy consumption and handling. There are, of course, a number of barriers to overcome in order for energy communities to be accepted by local stakeholders.

The space and regulatory limits on geographical island may limit certain aspects of RES expansion that are to be promoted through VPP implementation. This may limit the overall future effectiveness of VPP as the number of participants and services requirement increases of time.
The local acceptance of the RES and VPP technology is also a key obstacle, because of aesthetics, noise, wildlife effects, and possible reliability concerns for end users. Research has shown a very strong correlation between socio-political factors such as age, social class, and political alignment with sentiment towards renewable technologies [76] [77]. Since these factors will be a major obstacle to adoption of the new technologies, it may be beneficial to understand the public view towards the VPP technologies within the islands. Conducting open discussion and surveys of potential adopters will also assist in mitigating this barrier.

5. CONCLUSION

This report reviews the key barriers and obstacles that have been identified through both published research and interviews with consortium members representing the two lead islands of Gökçeada, Turkey, and Formentera, Spain.

The first section presents a breakdown of the key regulatory and market challenges facing the implementation of a VPP on geographical islands. It has been projected that the current limitations and incompatibilities between the tradition energy market structure and the flexibility of services offered by the VPP will be a considerable barrier in the coming years. Disruptive elements such as aggregated generation, demand response, price arbitrage, and flexible energy storage have been cited within research as some of the main critical services for a VPP that currently do not have a concrete definition within the large energy spot markets of Europe. Recent EU directives have noted these problems and set out processes to introduce policy to allow for future flexibility and enhanced revenue streams for distributed generation, but also relies on the uptake of these policies on an individual country or regional level. The regulatory barriers could be seen as the most important to discuss as they dictate the practicality of many other technical properties and aspects of the VPP concept. The market and regulation are the driving forces for the many of the technical obstacles presented, including the noted services requirements and performance

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

objectives. Through the identification and mitigation of these challenges, the overarching aim of reduced environmental impact and increased energy security on geographical islands can be fully released.

The technical barriers explored have been shown to largely depend on the current and future prediction of the island energy structure. The availability of RES in addition to dedicated ESS are crucial to the reduction in environmental impact of the island. This section highlights the number of potential services that could be enabled with the introduction of a flexible VPP concept, with varying temporal ranges to suit individual island requirements, as well as expressing current technical obstacles to their future implementation. The requirement for real-time communication and control between distributed actors within the system also presents itself as a common obstacle within literature. The use of DLT to ensure interoperability between all actors, as well as secure and tamper-proof data transfer will be a major element of this project.

One of the key strategic objectives of the VPP4ISLANDS project is to engage with local island stakeholders to promote community energy initiatives. It is therefore vital that the societal and environmental obstacles to innovation are documented. In this section the restrictions on RES implementation are explored for the lead islands, in addition to public sentiment towards disruptive and community involved technologies that increases the inherent investment and reliability risks. Allowing transparency in VPP operation and a robust data access control scheme will assist in mitigating these problems.

The VPP4ISLANDS project envisions a method for developing an energy production, distribution, monitoring, and control system tailored specifically for use on geographical islands. In this report, a structured view of the obstacles to implementing disruptive VPP concepts is presented. Conclusions from research into state-of-the-art VPP systems, as well as surveys with the island partners from Formentera and Gökçeada have allowed for the identification and critical evaluation of these obstacles and barriers. While mitigation strategies have been discussed for many of the identified obstacles, work completed by the consortium will have to consider further strategies for overcoming the economic, technical, and environmental challenges. Overall, this initial analysis of obstacles to innovation on islands will serve as a reference to ensure that further deliverables are aware of the challenges and risks faced in this project.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

6. REFERENCES

[1] The European Parliament, “Directive (EU) 2018/2021: On The Promotion of the Use of Energy from Renewable Sources,” *Official Journal of the European Union,* vol. 328, pp. 82-209, 2018.

[2] United Nations, “The Paris Agreement,” United Nations, Paris, France, 2015.

[3] European Commission, “Prices and Costs of EU Energy,” Ecofys, Netherlands, 2016.

[4] Eurostat, “Greenhouse Gas Emissions per Capita,” Eurostat, 2020.

[5] G. Gharehpetian and S. Mousavi Agah, Distributed Generation Systems: Design, Operation and Grid Integration, Butterworth-Heinemann, 2017.

[6] D. Pudjianto, C. Ramsay and G. Strbac, “Virtual power plant and system integration of distributed energy resources,” *Renewable Power Generation, IET,* vol. 1, no. 1, pp. 10-16, 2007.

[7] A. Marinescu, C. Harris, I. Dusparic, V. Cahill and S. Clarke, “A hybrid approach to very small scale electrical demand forecasting,” in *ISGT 2014*, Washington, DC, 2014.

[8] A. Pyrgou, A. Kylili and P. Fokaides, “The future of the Feed-in Tariff (FiT) scheme in Europe: The case of photovoltaics,” *Energy Policy,* vol. 95, pp. 94-102, 2016.

[9] Public-Private-Partnership Legal Resource Center, “Power Purchase Agreements (PPAs) and Energy Purchase Agreements (EPAs),” 22 March 2020. [Online]. Available: https://ppp.worldbank.org/public-private-partnership/sector/energy/energy-power-agreements/power-purchase-agreements. [Accessed 01 February 2021].

[10] P. Rovekamp, M. Schopf, F. Wagon, M. Weibelzahl and G. Fridgen, “Renewable electricity business models in a post feed-in tariff era,” *Energy,* vol. 216, p. 119228, 2021.

[11] OFGEM, “About the Smart Export Guarantee (SEG),” OFGEM, 1 January 2020. [Online]. Available: https://www.ofgem.gov.uk/environmental-programmes/smart-export-guarantee-seg/about-smart-export-guarantee-seg. [Accessed 24 March 2021].

[12] European Parliment, “Understanding electricity markets in the EU,” EU Parliment, 2016.

[13] A. Andersen, T. Erge, C. Sauer, T. Siewierski and G. Romanovsky, “MASSIG: 'How to start entering the big markets as a small player',” EU-project MASSIG, 2010.

[14] EU Commission, “Regulation (EU) 2019/943 'on the internal market for electricity',” *Official Journal of the European Union,* vol. 158, pp. 54-124, 2019.

[15] E. Kardakos, C. Simoglou and A. Bakirtzis, “Optimal Offering Strategy of a Virtual Power Plant: A Stochastic Bi-Level Approach,” *IEEE Transactions on the Smart Grid,* vol. 7, no. 2, pp. 792-806, 2016.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

[16] M. Barbero, C. Corchero, L. Canals Casals, L. Igualada and F.-J. Heredia, “Critical evaluation ofEuropean balancingmarketsto enable the participation of Demand Aggregators,” *Applied Energy,* vol. 264, p. 114707, 2020.

[17] D. Schwabeneder, C. Corinaldesi, G. Lettner and H. Auer, “Business cases of aggregated flexibilities in multiple electricity markets in a European market design,” *Energy Conversion and Management,* vol. 230, p. 113783, 2021.

[18] P. Bertoldi, P. Zancanella and B. Boza-Kiss, “Demand Response status in EU Member States,” *JRC Science for Policy Report,* 2016.

[19] S. K. Venkatachary, J. Prasad and R. Samikannu, “Challenges, Opportunities and Profitability in Virtual Power Plant Business Models in Sub Saharan Africa - Botswana,” *International Journal of Energy Economics and Policy,* vol. 7, no. 4, pp. 48-58, 2017.

[20] G. Plancke, K. De Vos and R. Belmans, “Virtual Power Plants: Definition, Applications and Barriers to the Implementation in the Distribution System,” in *International Conference on the European Energy Market*, 2015.

[21] A. Oudalov, D. Chartouni and C. Ohler, “Optimizing a Battery Energy Storage System for Primary Frequency Control,” *IEEE Transactions on Power Systems,* vol. 22, no. 3, pp. 1259-1266, 2007.

[22] G. Gissey, P. Dodds and J. Radcliffe, “Market and regulatory barriers to electrical energy storage innovation,” *Renewable and Sustainable Energy Reviews,* vol. 82, pp. 781-790, 2018.

[23] K. Oureilidis, K.-N. Malamaki, K. Gallos, A. Tsitsimelis, C. Dikaiakos, S. Gkavanoudis, M. Cvetkovic, J. M. Mauricio, J. M. M. Ortega, J. L. M. Ramos, G. Papaioannou and C. Demoulias, “Ancillary Services Market Design in Distribution Networks: Review and Identification of Barriers,” *Energies,* vol. 13, p. 917, 2020.

[24] C. Zhang, Y. Ding, N. C. Nordentoft, P. Pinson and J. Østergaard, “FLECH: A Danish market solution for DSO congestion management through DER flexibility services,” *J. Mod. Power Syst. Clean Energy,* vol. 2, no. 2, pp. 126-133, 2014.

[25] A. Paladin, R. Das, Y. Wang, Z. Ali, R. Kotter and G. Putrus, “Micro market based optimisation framework for decentralised management of distributed flexibility assets,” *Renewable Energy,* vol. 163, pp. 1595-1611, 2021.

[26] J. Guerrero, D. Gebbran, S. Mhanna, A. Chapman and G. Verbic, “Towards a transactive energy system for integration of distributed energy resources: Home energy management, distributed optimal power flow, and peer-to-peer energy trading,” *Renewable and Sustainable Energy Reviews ,* vol. 132, p. 110000, 2020.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

[27] F. Castellano Ruz and M. Pollitt, “Overcoming barriers to electrical energy storage: Comparing California and Europe,” *Competition and Regulation in Network Industries,* vol. 17, no. 2, pp. 123-149, 2016.

[28] R. Schulte and F. Fletcher, “Why individual electric utilities cannot achieve 100 % clean energy,” *The Electricity Journal ,* vol. 34, p. 106909, 2021.

[29] Y. Zhou, J. Wu, G. Song and C. Long, “Framework design and optimal bidding strategy for ancillary service provision from a peer-to-peer energy trading community,” *Applied Energy,* vol. 278, p. 115671, 2020.

[30] E. M. Gui and I. Macgill, “Typology of future clean energy communities: An exploratory structure, opportunities, and challenges,” *Energy Research & Social Science,* vol. 35, pp. 94-107, 2018.

[31] V. Olgyay, S. Coan, B. Webster and W. Livingood, “Connected Communities: A Multi-Building Energy Management Approach,” National Renewable Energy Laboratory, Golden, CO, 2020.

[32] EU Commission, “Directive (EU) 2019-944 on common rules for the internal market for electricity and amending Directive 2012/27/EU,” *Official Journal of the European Union,* vol. 158, pp. 125-199, 2019.

[33] Research and Markets, “The European Virtual Power Plant (VPP) Market to 2030,” Frost & Sullivan, 2020.

[34] E. Lerch, M. Bokhari and F. Jennrich, “A Framework for Developing VPP Conceptual Models: From Multiple Dimensions and Stakeholders, Towards a Unified Perspective,” in *ICVE on Green Energy for Sustainable Development*, Phuket, Thailand, 2018.

[35] Epexspot, “Basics of the Power Market,” Epexspot, 2021. [Online]. Available: https://www.epexspot.com/en/basicspowermarket. [Accessed 26 March 2021].

[36] C. Liu, R. Yang, X. Yu, C. Sun and P. Wong, “Virtual power plants for a sustainable urban future,” *Sustainable Cities and Society ,* vol. 65, p. 102640, 2021.

[37] P. Li, Z. Wang, N. Wang, W. Yang, M. Li, X. Zhou, Y. Yin, J. Wang and T. Guo, “Stochastic robust optimal operation of community integrated energy system based on integrated demand response,” *International Journal of Electrical Power and Energy Systems ,* vol. 128, p. 106735, 2021.

[38] Y. Xia, Q. Xu, H. Qian, W. Liu and C. Sun, “Bilevel optimal configuration of generalized energy storage considering power consumption right transaction,” *International Journal of Electrical Power and Energy Systems,* vol. 128, p. 106750, 2021.

[39] N. Good, K. Ellis and P. Mancarella, “Review and classification of barriers and enablers of demand response in the smart grid,” *Renewable and Sustainable Energy Reviews,* vol. 72, pp. 57-72, 2017.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

[40] N. Jayalakshmi, D. Gaonkar, R. Karthik and P. Prasanna, “Intermittent power smoothing control for grid connected hybrid wind/PV system using battery-EDLC storage devices,” *Archives of Electrical Engineering,* vol. 69, pp. 433-453, 2020.

[41] W. Ma, W. Wang, X. Wu, R. Hu, F. Tang and W. Zhang, “Control Strategy of a Hybrid Energy Storage System to Smooth Photovoltaic Power Fluctuations Considering Photovoltaic Output Power Curtailmen,” *Sustainability,* vol. 11, p. 1324, 2019.

[42] D. Kiedanski, M. Umar Hashmi, A. Busic and D. Kofman, “Sensitivity to Forecast Errors in Energy Storage Arbitrage for Residential Consumers,” in *2019 IEEE SmartGridComm*, Beijing Shi, China, 2019.

[43] C. Binding, D. Gantenbein, B. Jansen, O. Sundstrom, P. Andersen, F. Marra, B. Poulsen and C. Træholt, “Electric Vehicle Fleet Integration in the Danish EDISON Project - A Virtual Power Plant on the Island of Bornholm,” in *IEEE PES General Meeting*, Minneapolis, MN, USA, 2010.

[44] S. Ghavidel, L. Li, J. Aghaei, Y. Tao and J. Zhu, “A Review on the Virtual Power Plant: Components and Operation Systems,” in *2016 IEEE International Conference on Power System Technology (POWERCON)*, Wollongong, NSW Australia, 2016.

[45] M. Alipour, B. Mohammadi-Ivatloo and K. Zare, “Stochastic riskconstrained short-term scheduling of industrial cogeneration systems in the presence of demand response programs,” *Applied Energy,* vol. 136, pp. 393-404, 2014.

[46] ACEA, “Fuel types of new cars: electric 10.5%, hybrid 11.9%, petrol 47.5% market share full-year 2020,” 04 February 2021. [Online]. Available: https://www.acea.be/press-releases/article/fuel-types-of-new-cars-electric-10.5-hybrid-11.9-petrol-47.5-market-share-f. [Accessed 08 February 2021].

[47] D. Parra, L. Valverde, J. Pino and M. Patel, “A review on the role, cost and value of hydrogen energy systems for deep decarbonisation,” *Renewable and Sustainable Energy Reviews,* vol. 101, pp. 279-294, 2019.

[48] G. Calabrese, “Generating Reserve Capacity Determined by the Probability Method,” *Transactions of the American Institute of Electrical Engineers,* vol. 66, no. 1, pp. 1439-1450, 1947.

[49] P. Taylor, R. Bolton, D. Stone, X.-P. Zhang, C. Martin and P. Upham, Pathways for Energy Storage in the UK, York: Centre for Low Carbon Futures, 2012.

[50] G. Blomgren, “The Development and Future of Lithium Ion Batteries,” *J. Electrochem. Soc,* vol. 164, no. 1, pp. 5019-5025, 2017.

[51] S. Salkuti, “Energy Storage Technologies for Smart Grid: A Comprehensive Review,” *Majlesi Journal of Electric Engineering,* vol. 14, no. 1, pp. 39-48, 2020.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

[52] A. Olabi, C. Onumaegbu, T. Wilberforce, M. Ramadan, M. Abdelkareem and A. Al-Alami, “Critical review of energy storage systems,” *Energy,* vol. 214, p. 118987, 2021.

[53] J. Deane, B. Gallachoir and E. McKeogh, “Techno-economic review of existing and new pumped hydro energy storage plant,” *Renewable and Sustainable Energy Reviews,* vol. 14, no. 4, pp. 1293-1302, 2015.

[54] P. Lund, J. Lindgren, J. Mikkola and J. Salpakari, “Review of energy system flexibility measures to enable high levels of variable renewable electricity,” *Renewable and Sustainable Energy Reviews,* vol. 45, pp. 785-807, 2015.

[55] T. Ackermann, Wind power in power systems, John Wiley & Sons, Ltd, 2005.

[56] E. Karapidakis, “Hydro Pump Storage Energy Units in Crete’s Power System,” in *Deregulated Electricity Market Issues in South Eastern Europe*, 2015, pp. 106-110.

[57] C.-J. Yang and R. Jackson, “Opportunities and barriers to pumped-hydro energy storage in the United States,” *Renewable and Sustainable Energy Reviews,* vol. 15, no. 1, pp. 839-844, 2011.

[58] S. Cafasso, “Hydropower dams threaten fish habitats worldwide,” Stanford University, 03 February 2020. [Online]. Available: https://earth.stanford.edu/news/hydropower-dams-threaten-fish-habitats-worldwide#gs.wht1wd. [Accessed 18 March 2021].

[59] R. McKenna, Q. Bchini, J. Weinand, J. Michaelis, S. Konig, W. Koppel and W. Fichtner, “The future role of Power-to-Gas in the energy transition: Regional and localtechno-economic analyses in Baden-Württemberg,” *Applied Energy,* vol. 212, pp. 386-400, 2018.

[60] G. Guandalini, S. Campanari and M. Romano, “Power-to-gas plants and gas turbines for improved wind energy dispatchability: Energy and economic assessment,” *Applied Energy,* vol. 147, pp. 117-130, 2015.

[61] R. Moliner, M. Lazaro and I. Suelves, “Analysis of the strategies for bridging the gap towards the Hydrogen Economy,” *International Journal of Hydrogen Energy,* vol. 41, no. 43, pp. 19500-19508, 2016.

[62] G. Jansen, Z. Dehouche and H. Corrigan, “Cost-effective sizing of a Hybrid Regenerative Hydrogen Fuel Cell Energy Storage System for Remote & Off-Grid Telecom Towers,” *International Journal of Hydrogen Energy,* vol. 46, no. 22, 2021.

[63] PE/T&D - Transmission and Distribution, “IEEE 519-2014 - IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems,” IEEE, 2014.

[64] Uk Power Networks, “Power Potential: DER Technical Requirements,” National Grid.

[65] R. McAllister, D. Manning, L. Bird, M. Coddington and C. Volpi, “New Approaches to Distributed PV Interconnection: Implementation Considerations for Addressing Emerging Issues,” National Renewable Energy Laboratory, Golden, CO, 2019.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

[66] SASB/SCC21, “IEEE 1547-2018 - IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces,” IEEE, 2018.

[67] British Standards, “PD IEC/TS 62786:2017: Distributed energy resources connection with the grid,” British Standards Institution, 2017.

[68] Council of European Energy Regulators, “CEER Benchmarking Report 6.1 on the Continuity of Electricity and Gas Supply,” CEER, Brussels, Belgium, 2018.

[69] UEDAS, “VPP4islands Project Report T2.1,” VPP4islands, 2021.

[70] M. Andoni, V. Robu, D. Flynn, S. Abram, D. Geach, D. Jenkins, P. McCallum and A. Peacock, “Blockchain technology in the energy sector: A systematic review ofchallenges and opportunities,” *Renewable and Sustainable Energy Reviews,* vol. 100, pp. 143-174, 2019.

[71] PWC, “Blockchain – an opportunity for energy producers and consumers?,” 2015. [Online]. Available: https://www.pwc.com/gx/en/industries/assets/pwc-blockchain-opportunity-for-energy-producers-and-consumers.pdf. [Accessed 12 February 2021].

[72] E. Cioroaica, S. Chren, B. Buhnova, T. Kuhn and D. Dimitrov, “Towards the Creation of A Reference Architecture for Trust-based Digital Ecosystems,” in *ECSA*, Paris, France, 2019.

[73] J. West, I. Bailey and M. Winter, “Renewable energy policy and public perceptions of renewable energy: A cultural theory approach,” *Energy Policy,* vol. 38, pp. 5739-5748, 2010.

[74] J. R. Martínez Trueba, “Parque Solar Fotovoltaico "Posidonia",” Enerland Group, Formentera, Islas Baleares, 2019.

[75] BBC News, “Texas weather: Are frozen wind turbines to blame for power cuts?,” BBC News, 17 February 2021. [Online]. Available: https://www.bbc.co.uk/news/world-56085733. [Accessed 18 February 2021].

[76] C. Tatchley, H. Paton, E. Robertson, J. Minderman, N. Hanley and K. Park, “Drivers of Public Attitudes towards Small Wind Turbines in the UK,” *PLoS one,* vol. 11, no. 3, p. e0152033, 2016.

[77] L. Hamilton, J. Hartter and E. Bell, “Generation gaps in US public opinion on renewable energy and climate change,” *PLoS one,* vol. 14, no. 7, p. e0217608, 2019.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

7. Appendix 1

7.1. Formentera Technical Survey

STANDARDISED SURVEY FOR TECHNICAL DATA & BARRIERS TO INNOVATION*

This survey is intended to perform the task of critical preliminary data collection in line with the objectives of T2.1 and will be incorporated into the later VPP conceptual models. Related barriers and obstacles to innovation on the islands have also been identified (D2.2). Also noted is the additional deliverable D2.3.1: identifying VPP system taxonomy, to be delivered by M3. We will also be evaluating market exploitation routes beyond VPP implementation (T8.4).

Please provide the information below in necessary formats, add file names to the list and check the boxes when completed. If a response to a particular factor is unavailable or does not apply to the participating island, please give reasoning in the ‘enclosed file’ box.

Preliminary Energy Data Confirmation

Formentera

- 257.8TWh (2019) annual energy production in **Spain**
- 2MW PV solar power capacity
- 37kW PV solar (hospital), grid connected, export capability
- Schools, football stadium has combined PV solar, 20.16kW peak output – grid connected
- PV grid exported at low value/free
- 0.17-0.24EUR/kWh average
- Island peak power demand 11MW in winter to 20MW in summer
- Wind turbines are prohibited due to existing local laws and regulation regarding wildlife protection
- 2x30kV sea cable from Ibiza
- AC current, additional 2x132kV sea cable not before 2024.
- 70% renewable energy mix from sea cable
- Open gasoil turbine with 11.5MW capacity
- Annual usage of the GT
- 8x diesel generators
- 24.2MW total generation
- Confirm turbine manufacturer/model for performance specification as function of the load
- TSO identified as Red Eléctrica de España

***Technical Survey incomplete for Formentera at time of deliverable.**

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

7.2. Gökçeada Technical Survey

STANDARDISED SURVEY FOR TECHNICAL DATA & BARRIERS TO INNOVATION

This survey is intended to perform the task of critical preliminary data collection in line with the objectives of T2.1 and will be incorporated into the later VPP conceptual models. Also noted is the additional deliverable D2.3.1: identifying VPP system taxonomy, to be delivered by M3. We will also be evaluating market exploitation routes beyond VPP implementation (T8.4).
Please provide the information below in necessary formats, add file names to the list and check the boxes when completed. If a response to a particular factor is unavailable or does not apply to the participating island, please give reasoning in the 'enclosed file' box.

Preliminary Energy Data Confirmation

Gökçeada

- 308.5 TWh (2019) annual energy production in **Turkey**
- Island has 1.8MW installed renewable capacity from 2x900kW turbines and 210kW PV solar.
- 4x770kVA (~616kW) diesel generators as standby power (emergency cases), emergency power for approx 1 week.
- States 93,089 MW of total installed power production in **Turkey**
- Island has 6MW peak power (summer season – June to August)
- 50kW (100kWh storage capacity from Lithium battery – 2 hours discharge capacity) ESS required for grid stability and monitoring upgraded to 1MWh, based on approval from regulatory)
- Will the discharge remain the same when storage is increased?
- What is the sea cable capacity, 120mm^2 CS, ~20MW, 50Hz AC, 36kV
- Medium voltage transmission 15kV

Performance

No		**Criteria/Factors**	Name of enclosed file	**Check**
1	End users energy demand (load profiles) and context	• Hourly change • Summer weekday • Summer weekend • Winter weekday • Winter weekend	1b-End_User_2017-2020_Hourly_Consumption 1c-End_User_2017-2020_Yearly_Consumption 2a-GOKC_Power_Emissions_Data (approximate total island demand)	☐

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

		• Electricity/heat demand bias • Standby energy		
2	Local power generation	• Breakdown of individual power generators • Load factor (number of hours the generators and services are in operation) • hourly change • seasonal peaks • Historic data if available	2a-GOKC_Power_Emissions_Data 2b-Kumlimanı TM Gökçeada Feeder 2c-TUZLA IM WPP FEEDER 2d-Gökçeada Producer Monthly	☐
3	Any planned expansion to current island power systems	• Date due • Roadmap • Expected impacts	3a-Planned_Expansion 3b-Expansion Plan	☐
4	Island power grid map	• Detailing electrical grid • Display cable capacities and distances • Locations of power systems and substations • CHP/HVAC system • Renewables grid penetration	Available through UEDAS GIS VPN software 4a-Gokceada_Grid_Map 4b-TUZLA IM SCADA Single Line 4c-Island_Map	☐
5	Grid Resiliency	• Failure rate of grid • Resiliency to certain extreme weather conditions (storms, warm weather) • Blackout length and recovery time • Loss of load probability by sector (residential,	5a-Gökçeada Interruption Detail 2019 5b-All Table-5 GÖKÇEADA 2019 5c-SAIDI SAIFI Gökçeada (interruptions)	☐

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

		commercial, industrial, critical)		
6	Mainland Connection	• Current grid connection • Rated voltage • Rated power • AC or DC connection	See opening remarks for island	☐
7	Wind capacity data	• Transient • Daily and seasonal changes • Power curve and hub height of any installed turbines • Wind shear factor •	7a-ENERCON_Product_Sheet 7b-Daily Average Windy Direction and Speed 7c-Daily Maximum Windy Direction and Speed	☐
8	Generator/Turbine Data	• Power-load efficiency • Generator/turbine manufacturer or operator	8a-Local_Generator_Information 8b-Mecc_Alte_Gen_Spec	☐

Environmental Impacts

		Criteria / Factors	**Name of the file enclosed**	**Check**
9	Emissions of the island and total for country - kgCO2eqv/kWh	• Transient data • Historic data if available • Individual energy components (sea cable, PV solar, wind turbines etc) • Mix fuels CO2eqv factor	2a-GOKC_Power_Emissions_Data	☐
10	Local restrictions for RES/ESS installation	• Any resource or local policy restrictions that would impact installation • Military presence, urban areas, wildlife, national parks etc • Local people's acceptance of RES	No regulations relating the resource limits have been identified at this time	☐

Local Energy Market

		Criteria / Factors	**Name of the file enclosed**	**Check**

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852

11	Local energy price transient data	• For renewable systems and 'mainland' • Historical data • Purchase and export energy cost rates • Incentives and taxes • Feed in tariffs for RES	Turkish Energy Exchange (EPIAS) has information in the country's energy markets, and an API for accessing data. It is not known if local energy market prices deviate from these values. Follow link to EPIAS transparency portal: https://seffaflik.epias.com.tr/transparency/	☐
12	Design and Valuation of ancillary services market	• Demand Response • Valuation of the frequency balancing services • Seasonal shifting • Local permissions to allow for the development of small-scale services and technologies	It is not known if specific ancillary services apply to the island of Gokceada at this time, more information on the national ancillary services market is available through EPIAS. 12-EMRA Electricity Market Development Report (002)	☐
14	Levelised Cost of Electricity (LCOE) data (cost per kWh)	• From currently installed RES if available	The local levelized cost of electricity is to still to be confirmed. Approximate LCOE as published by Fraunhofer are 4.0-8.2 and 7.5-13.8 euro cent per kWh for onshore and offshore wind, respectively. PV solar is estimated at 600-1400 euro per kWp.	☐
15	Identify TSO and DSO	• At local and national level	UEDAS is the DSO at the local level, and state company Turkish Electricity Transmission Corporation (TEİAŞ) is the TSO	☐

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n°957852