energies

Article

Scalability and Replicability for Smart Grid Innovation Projects and the Improvement of Renewable Energy Sources Exploitation: The FLEXITRANSTORE Case

Georgios Fotis [1], Christos Dikeakos [1], Elias Zafeiropoulos [2], Stylianos Pappas [2] and Vasiliki Vita [2,3,*]

[1] IPTO (Independent Power System Operator), Dyrrachiou 89 & Kifissou, 10443 Athens, Greece; gfotis@admie.gr (G.F.); c.dikeakos@admie.gr (C.D.)
[2] Institute of Communications and Computer Systems, School of Electrical and Computer Engineering (ECE), National Technical University of Athens (NTUA), 9 Iroon Polytechniou Street, 15780 Athens, Greece; eagle74@gmail.com (E.Z.); steliospappas74@gmail.com (S.P.)
[3] Department of Electrical and Electronics Engineering Educators, ASPETE—School of Pedagogical and Technological Education of Athens, Stathmos "ISAP", 14121 N. Heraklion, Greece
* Correspondence: vasvita@aspete.gr; Tel.: +30-210-289-6955

Abstract: In this paper, detailed scalability and replicability plans have been developed to facilitate the adoption of innovation technologies in the pan-EU market. Smart grid development must enable both information and power exchange between suppliers and customers, thanks to the enormous innovation in intelligent communication, monitoring, and management systems. Implementing physical infrastructure alone is not enough, but a smart grid must include new business models and new regulations. In recent years, the number, participants, and scope of smart grid initiatives have increased, with different goals and results. FLEXITRANSTORE project integrates hardware and software solutions in all areas of the transmission system and wholesale markets, unleashing the potential for full flexibility of power systems and promoting the penetration of renewable energy sources and pan-EU markets. Full deployment of these demonstrated solutions requires a reasonable level of scalability and replicability to prevent project demonstrators from continuing local experimental exercises. Scalability and replicability are fundamental requirements for successful scaling-up and replication. Therefore, scalability and replicability enable or at least reduce barriers to the growth and reuse of project demonstrator results.

Keywords: smart grid; scalability; replicability; FLEXITRANSTORE

check for updates

Citation: Fotis, G.; Dikeakos, C.; Zafeiropoulos, E.; Pappas, S.; Vita, V. Scalability and Replicability for Smart Grid Innovation Projects and the Improvement of Renewable Energy Sources Exploitation: The FLEXITRANSTORE Case. *Energies* **2022**, *15*, 4519. https://doi.org/10.3390/en15134519

Academic Editor: George S. Stavrakakis

Received: 1 June 2022
Accepted: 20 June 2022
Published: 21 June 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

1.1. Smart Grids and Renewable Energy Sources

Smart grid technology is enabling the effective distribution and management of Renewable Energy Sources (RES) such as wind, solar, and hydrogen. Renewable energy integration aims to improve the electric grid's system design, planning, and operation in order to reduce carbon emissions and other air pollutants by increasing the use of renewable energy, storage systems, and other clean distributed generation.

A great variety of distributed energy resource assets are connected to the power grid via the smart grids. Utilities can rapidly detect and manage service issues by leveraging the Internet of Things (IoT) to collect data on the smart grid [1–3]. This self-healing capability is critical to the smart grid because utilities no longer rely on customers to report problems. Wind farms, for example, rely on mechanical gears with several sensors in each connection. Every sensor can record current weather and ambient conditions. These data are then promptly routed through the grid to alert the utility of any problems, improving both service quality and safety.

Electric vehicles, storage systems, and distributed generation of RES are transforming distribution grid characteristics around the world [4,5]. Under certain operational settings, these novel components could create bidirectional energy flows. This has an impact on grid planning since they are optimized for one direction flows. In these conditions, even if the existing processes for organizing distribution networks on radial layouts are very straightforward and extensively verified, they cannot be implemented holistically.

FLEXITRANSTORE (An Integrated Platform for Increased FLEXIbility in smart TRANSmission grids with STORage Entities and large penetration of Renewable Energy Sources) contributes to the development of a pan-European transmission grid with high flexibility and high interconnection [6]. This will accelerate the transformation of the current energy production mix by increasing the share of renewable energy sources. In order to bring flexibility to the European power system, new control and storage methods, smart grid technologies, and new market approaches will be developed, installed, and demonstrated.

1.2. Smart Grids and FLEXITRANSTORE

Currently, most smart grid projects are still in the phase of Research and Development (R&D) or demonstration. In [7], it is confirmed that regardless of how quickly various utilities embrace smart grid concepts, technologies, and systems, this massive transformation is inevitable, and at the same time, many researchers across the globe are working to make this transition by developing the next-generation technologies required to realize the smart grid easier. Working on this direction in March 2011, the European Commission and the European Free Trade Association (EFTA) issued the Smart Grid Mandate M/490 which requested CEN, CENELEC, and ETSI to develop a framework to enable ESOs to perform continuous standard enhancement and development in the smart grid field [8]. Research work in [9] analyses the state-of-the-art of smart grids, in their technical, management, security, and optimization aspects, providing also a brief overview of the regulatory aspects involved in the development of a smart grid, mainly from the viewpoint of the European Union.

In [10], the smart grid development in Brazil is performed, presenting the policy and regulation efforts beyond investments, taking into account a pattern for smart grid development, since the smart grid implementation is very high. Moreover, in [11] a review of the current research on smart grids is carried out, shedding light on the development of smart grids in China, which is then analyzed to identify the obstacles and barriers in the development process. Reference [12] presents a survey of smart grid projects in Europe bringing together input and feedback from a variety of stakeholders through a cooperative and transparent process. D. Novosel makes clear in [13] that smart grid technologies are required to manage grid complexity, addressing a holistic smart grid approach and experiences with deploying smart grid projects. Research work in [14] indicates that demand response services or vehicle-to-grid and grid-to-vehicle services will be offered in conjunction with the supply of RES.

The work in [15] deals with the assessment of the flexibility benefits coming from smart grid innovations, developed in the H2020 project FLEXITRANSTORE. The project includes pilots in various sites across the Europe, where appropriate technologies have been developed in an effort to enhance the flexibility of the systems examined in the context of the project. Research work in [16] demonstrates the trading and flexibility of services amongst TSOs, DSOs, and Prosumers in a transparent, secure, and cost-effective manner using Blockchain-based TSO-DSO flexibility marketplace. In [17] a flexibility adequacy assessment of the countries of South-East Europe is presented, and in [18,19] a novel technology integration is considered in order to provide more flexibility resources to the power system to absorb more renewable energy.

In [20] a flexibility-oriented day-ahead market model that accounts for renewable sources and storage units where no incentive is provided to the renewable sources is developed, and its results demonstrate how a system can cope with renewable sources with no incentive in the presence of storage. Moreover, in [21] a detailed survey conducted during FLEXITRANSTORE on identifying stakeholders' opinion on electricity networks' challenges is presented and commented and in [22] grid flexibility solutions for transmission networks with increased RES penetration are examined.

The operational flexibility potential of individual power system assets and their aggregation at the system level is examined in [23] and a similar work in [24] present a methodology to assess the flexibility of a power system while explicitly considering the limitations of the transmission network. Researchers in [25] evaluate the operational flexibility for power system with energy storage, while in [26] a framework to efficiently characterize the available operational flexibility in a multi-area power system is presented and in [27] the flexibility of a test system with increasing penetrations of variable generation is assessed.

Electricity, natural gas, water, and district heating/cooling systems are predominantly planned and operated independently. The work presented in [28] centers on residential city districts as source of flexible electrical energy demand and generation, while [29] presents an integrated optimization and control of such systems at multiple spatiotemporal scales that can bring significant socioeconomic, operational efficiency, and environmental benefits. In [30], an in-depth review of the modeling and implementation of flexible ramping products that have been proposed in the industry to improve the availability of ramp capacity is presented.

The European Commission in its effort to speed the clean energy transition supports the development of flexible energy efficiency and renewable financing platforms at national or regional level [31]. In [32], the Smart Grids Task Force reviews the value which demand side flexibility could be able to bring to the energy system and its possible impact to the future market development in Europe.

Due to a lack of practical experience, the outcome of implementing smart grids on a large scale remains questionable. Many projects have been launched around the world to evaluate various smart grid solutions in real-world systems [33–36]. These projects provide extremely significant information, but the findings obtained are dependent on the precise setting in which the tests are carried out. As a result, the testing conclusions may not be immediately applicable to the deployment of the same solutions on a bigger scale or in other regions. To understand the impact of the context on the outcomes of deploying a smart grid solution, a thorough investigation must be undertaken. It is required to assess the effects of various smart grid systems on existing networks in greater scale for various DEMOs, and this is the main goal of the current work.

FLEXITRANSTORE develops a next-generation Flexible Energy Grid (FEG) that will be integrated into the European Internal Energy Market (IEM) through the flexibility services [15–32]. The project includes pilots in various sites across Europe, where appropriate technologies have been developed in an effort to enhance the flexibility of the systems examined in the context of the project. The work presented here takes both national and regional approaches and recognizes the need to seamlessly integrate the national markets. Networks in Southeast Europe, in particular, do not yet have the high levels of interconnectivity that other European networks have. Full deployment of the tested solutions requires a reasonable level of scalability and replicability to prevent the project demonstrator from continuing local experimental exercises. This paper focuses on analyzing the scalability, replicability, and implementation conditions of the FLEXITRANSTORE concept.

This FEG supports the capabilities of power systems to maintain continuous operation in the face of rapid and large fluctuations in supply or demand. Therefore, as shown in Figure 1, within this integrated FEG, new business models and a wholesale market infrastructure must be upgraded to network players, providing incentives to new ones to participate. Moreover, it will demonstrate new energy trading and business perspectives for cross-border resources management.

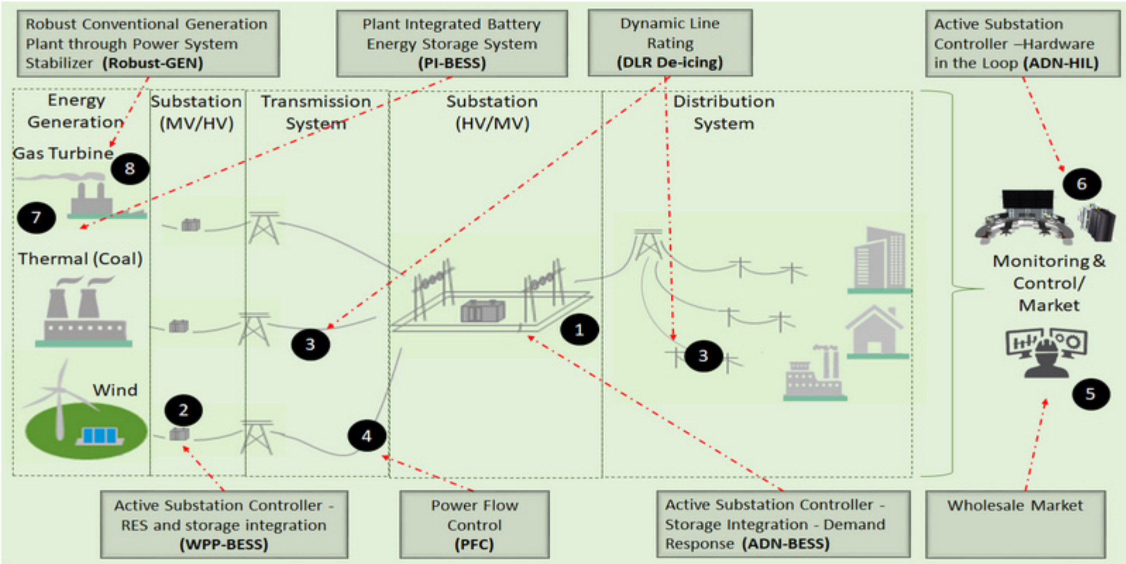

Figure 1. How the European Power System will be transformed by FLEXITRANSTORE through interventions targeting the whole Energy Value Chain [6].

The ability of a process, network, or system to respond to the growth in demand by increasing respectively its scope range or size is called scalability [33–35,37,38]. For FLEXITRANSTORE scalability is crucial, since in different demonstration sites, with different technical requirements development, implementation and validation of several demos have been carried out. The first step to deploy the technological innovation on a large-scale of the FLEXITRANSTORE project in order to meet growing volumes of demand is the scalability analysis. The ability of a process, network, or system to be duplicated in another time or location is called replicability [33–35,37,38]. The replication ability of the FLEXITRANSTORE technological innovations has been studied due to the application of different technologies and costs for different countries.

The focus of this work is to evaluate the experience and the demonstration results, gathered during the period of research, implementation, and testing in order to develop at EU level a detailed scalability and replicability plan. In order to find the practical problems and major benefits of the proposed actual field technical innovations, the results need to be evaluated. Moreover, it is extremely important to find how these innovations meet both the challenges of the variable integration of renewable energy sources and the interconnection of production capacity by increasing the awareness of the grid's flexibility. Two sets of questionnaires one for scalability and the other for replicability have been developed. The project partners are the responders of this survey, who have been involved as a team leader or contributors in the development of functionalities.

FLEXITRANSTORE provides technical innovations that are weighed against the EU energy targets and specific scalability and replicability factors. These factors affect the following four common areas of interest: regulatory, economic, technical, stakeholder acceptance. Replicability factors are: Network configuration, Standardization, Macroeconomics, Interoperability, Market design, Business model (economic factors), Regulation, and Acceptance. Scalability factors are: Modularity, Technology evolution, Software integration, Existing infrastructure (technical factors), Interface design, Economy of scale, Profitability (economic factors), Regulation, and Acceptance.

2. The European Commission Bridge—Scalability and Replicability Analysis (SRA)

BRIDGE is a European Commission initiative that integrates the Horizon 2020 Smart Grid and Energy Storage Projects to structure cross-cutting issues that arise in demonstration projects and can be barriers to innovation [39]. The BRIDGE process facilitates ongoing knowledge exchange between projects and draws conclusions and recommendations regarding future use of project results through four different Working Groups representing the main areas of interest: Business Models, Data Management, Consumer Engagement, and Regulations.

In BRIDGE, several Task Forces (TF) were created to address topics that could be horizontal to more than one of the above-mentioned working groups. A specific TF was created to investigate how different projects approached the Scalability and Replicability Analysis (SRA) of different project results.

The first objective of the TF was the development of common guidelines for performing SRAs, and the second one the development of ideas on the definition of the scope and implementation of a toolbox/repository of necessary data, best-practices, and past experiences. The steps to perform an SRA of a smart grid project are depicted in Figure 2 and have been followed in the analysis of this work and for each DEMO. The overall approach has five stages, with each stage having several steps. The definition of the SRA methodology and how to carry out the SRA are the most complex stages. These five stages are briefly described below.

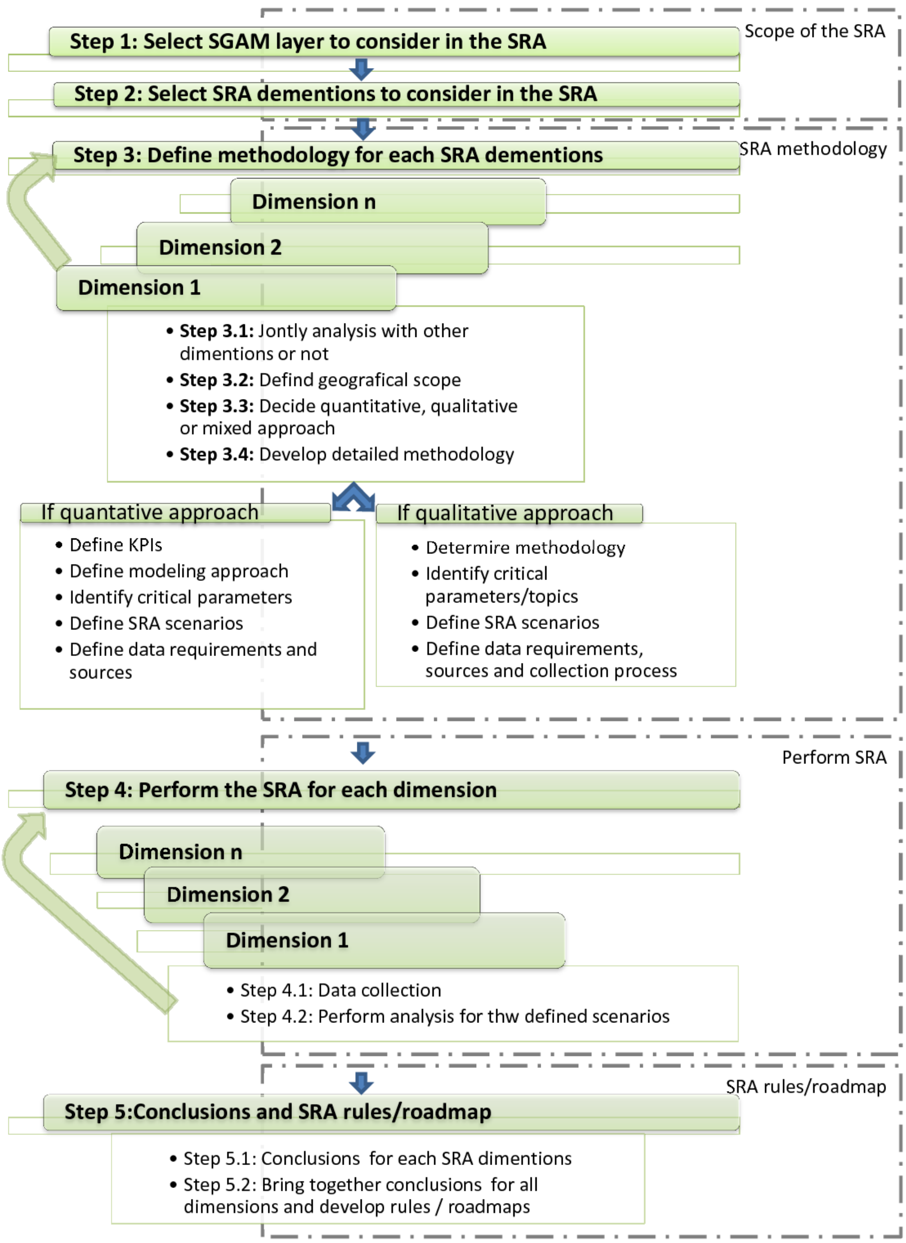

Figure 2. SRA guidelines [39].

Step 1 Definition scope of the SRA: Selection of the SRA dimension or dimensions that will be assessed in the Smart Grid Architecture Models (SGAM) layers and within each SGAM layer.

Step 2 Selection of the SRA dimensions: After the definition of the methodology, SRA developers perform the corresponding qualitative/quantitative analyses for the previously defined scenarios and collect the required input data. During this stage progression it may be necessary to go back and re-assess some aspects of the methodology initial described.

Step 3 Definition of the methodology for each SRA dimension selected: this third stage requires the definition of the methodology for each of the dimensions previously selected. It is recommended to rely on best practices from previous projects, in order to make informed decisions at each one of these steps. SRA developers have to take this into consideration, during the development of quantitative analyses. The proper definition of the relevant Key Performance Indicators (KPIs) and simulation scenarios focusing on the most critical parameters affecting the scalability and replicability is extremely important. In order to avoid delays in the execution of the SRA, an early definition of the input data is required.

Step 4 Performance of the SRA for each dimension: This stage consists of, first, analyzing the results obtained in the SRA for each dimension individually and, then, trying to correlate the results for the various dimensions if relevant.

Step 5 Conclusions and SRA rules/roadmap: The derivation of a set of SRA rules is allowed by this analysis. This can be defined as a conclusion on the most important aspects that affect the scalability and replicability of the technology or solution under investigation. SRA can also be used to provide an implementation roadmap. This can include timelines and milestones for the implementation and/or use of the technology or solution being evaluated.

It must be mentioned that H2020 projects, even if they all address new solutions related to smart grids and storage, are very diverse and consider a wide range of functionalities and technologies at different Technology Readiness Levels (TRLs). Consequently, in this work, the proposed common SRA methodology was applied ensuring that the proposed set of steps can support and speed up the delivery of a high-quality SRA. These steps were as a checklist to ensure that any aspect included or not in the SRA methodology selected by a project has been carefully considered. In any case, there is much room for those in charge of performing the SRA to implement and adapt the proposed guidelines as required by the characteristics of their project.

3. Scalability and Replicability Analysis Approach

Scalability of a system is understood as a set of elements interacting with each other, with similar boundary conditions. In a more restrictive formulation, scalability works to maintain system performance and function, retaining all its required properties when scaling up without correspondingly increasing system complexity [33,40].

Scalability analysis is extremely important for the FLEXITRANSTORE project to do the following:

i. Apply the technical innovations on smart storage and transmission on a large-scale deployment.
ii. Provide the appropriate business models and market strategies.
iii. Integrate flexibility assessment into system planning and power system research.

Replicability refers to the ability of a system to be replicated at another point in time [30]. Due to the difference in proposed technology and cost, replicability of FLEXITRANSTORE (the ability to duplicate the technical innovations in another location) is investigated. Each demo has been implemented, installed, and tested in different locations in the Southeast European (SEE) region, and typically has different technical requirements related to national regulations.

Scalability and replicability are fundamental to successful scaling and replication. Therefore, scalability and replicability enable or at least reduce barriers to growth and reuse of R & D and demonstration project results. This is important for businesses and utilities because scaling and replication offer significant benefits such as cost-effective deployment to a larger customer base and cost-effective reuse of proven solutions.

By examining the scalability and replicability factors that affect the scalability and replicability of FLEXITRANSTORE, scalability and replicability are analyzed, and potential barriers to large-scale deployments are identified.

Specifically, the factors extracted from the literature review were categorized into four main categories.

- Technical factors that determine whether the developed solution in a specific project is inherently scalable and/or replicable, i.e., whether it is feasible for scaling up and/or to replicate.
- Economic factors that reflect whether scaling or replication is feasible. This important step in investing analysis (internal rate of return, net present value, etc.) and ensuring that the business model applies on a larger scale or in different settings than in the original case is often ignored and poses a major barrier.
- Factors related to acceptance and regulation of stakeholders such as authorities, regulators, end users, etc., reflect the extent to which the social environment and current regulatory is willing to respond to an expanded version of the project or whether a new environment is suitable for receiving a project.

According to [33,35], in Tables 1 and 2, the scalability and replicability factors are summarized, relating to the economic, technical, regulatory, and stakeholder acceptance categories. Each of these are further categorized in order to identify the remaining/potential issues and to capture specific project achievements that can limit scalability and replication. Moreover, the main limitations and barriers that have an impact on scalability and replicability are identified. The identified issues already describe necessary conditions for scaling-up and replication, and they represent somehow rules to be contemplated for scalability and replicability.

Table 1. Scalability factors.

Area	Sub-Areas	Factors	Limitation Issues
Technical	Technology	Modularity	Communication capacities Computation memory
		Technology Evolution	Expected equipment costs IT/data security Missing standardization of control signal and information flow from/to distributed generation Big data
	Control and communications Interface	Interface design	Depends on nature of the project and focus
	Infrastructure	Software tools integration	Big data
Economic	Economy of scale	Economies of Scale	No detailed cost-benefit analysis
		Profitability	Uncertainty remuneration Focus on feasibility
Regulatory and Stakeholder	Regulation	Regulatory Issues	Data confidentiality Lack of rules to provide service Lack of rules for interaction
	Consent by users, local authorities and public	Acceptance	Change customer behaviour Stakeholder opposition or hesitancy

Table 2. Replicability factors.

Area	Sub-Areas	Factors	Limitation Issues
Technical	Technology	Standardization	New non-standardized services Proprietary standards Ability for standard-conform implementation
		Interoperability	Customized (project/equipment) implementation Provider-specific applications New non-standardized services
	Control and communications Interface	Standardization Interoperability	Depends on nature of the project and focus
	Infrastructure	Network Configuration	Focus/dependency on resource Load/generation mix and situation Infrastructure need Demographics
Economic	Business Model	Business model	Uncertainty remuneration Lack of rules to provide service
	Profitability Analysis	Macro-economic factors Market Design	Lack of analysis on macro-economic factors Lack of plans to export solution
Regulatory and Stakeholder	Regulation	Regulatory Issues	Non-existing or strongly varying regulatory and legal framework
	Acceptance	Acceptance	Change customer and operator behaviour

4. Scalability Factors

The different scalability factors are analyzed in the following subsections below [33–35,38–40].

4.1. Technical Factors

Modularity is a necessary requirement for scaling up. It refers to whether a configuration can be divided into forbidden components or not. A solid layout will be appropriate for larger-scale execution. On the other hand, well specified (and isolated) constituent elements provide the flexibility needed in ordering the setup to be transferred to a larger scale. Consequently, this factor investigates to what extent a solution is modular (e.g., how simple it is to include new components or whether there are limits on including components).

The number of interactions between components is addressed via interface design. If they grow more than linearly, the scaled-up solution may become overly complex and redundant at the target scale, limiting the scaled-up solution's performance. The extent to which interactions between components are managed locally or centrally is investigated through interface design.

Except for the solution's complexity, the software tools required to deploy it (such as simulation models, databases, and so on) must be able to handle the increased size. Note that a favorable technical progress can offset this impact. When the solution size grows, this factor influences how much the performance of software tools is affected.

The solution's compatibility with the technological environment in which it will be implemented, as well as the interaction between its components and the outside world, is taken into account during the compatibility analysis.

4.2. Economic Factors

A project can only be expanded up if it is viable at the required scale. This implies that both costs and income must be improved. This effectively means that the marginal cost and revenue functions of a solution will determine whether scaling-up is possible or not. The variation of the marginal cost curve according to the number of deployed units is particularly noteworthy in this situation, since the most obvious patterns influencing scalability are rise, drop, or stepwise development.

The percentage increase in costs equals at most the percentage increase of the project size. The significance of project size varies greatly depending on the undertaking (e.g., the number of meters, the amount of managed active power, the number of customers, the number of distributed generation units, etc.) This factor then specifies how much costs increase as the solution size grows.

Similarly, the rise in benefits should be proportional to the increase in project size. This is reflected in the profitability factor. This component asks and defines how much advantages grow as the solution size grows.

4.3. Regulatory and Stakeholder

Regulation establishes the framework for transmission, distribution, generation, and supply activities, outlining how the various agents involved (investors, consumers, etc.) behave and interact. The roles and responsibilities of agents, the rules, and requirements for providing services, the rules for remunerating regulated activities, and the rules for agent interaction are all defined by regulation. Regulation is understood in terms of its impact on the size and scope of the project when it comes to scalability. Scalability is usually influenced by the regulations and requirements for providing specific services. The factor regulation then evaluates whether there are any regulatory constraints to the solution's size and scope.

Acceptance refers to the willingness of stakeholders such as regulators, policymakers, and end users to accept an expanded project. It is vital to examine if the concerned stakeholders will accept the proposed changes. Although a project's solution may have overcome regulatory and legal constraints (for example, by changing the regulatory framework), it is critical that other stakeholders accept the solution. This element decides if stakeholder acceptance has been explored and if any challenges are anticipated.

5. Replicability Factors

The different replicability factors are analyzed in the following subsections below [33–35,38–40].

5.1. Technical Factors

The standardization process and the proper collection of standards by projects are complicated by the large number of players, the required speed, the numerous worldwide activities, and the constantly changing solutions. The standardization factor investigates and determines how standard-compliant the solution is and/or how readily it can be made standard-compliant.

Solutions must also be interoperable. Given the numerous standards available, it is theoretically feasible to have anything standardized that is incompatible with a specific system or environment (that operates according to a different standard). The ability of two or more networks, systems, devices, applications, or components to communicate, exchange, and use information to accomplish essential functions is referred to as interoperability. The factor interoperability determines how interoperable or plug-and-play solutions and their components/functions are.

Within the scope of a project, network configuration refers to aspects that are predetermined and cannot be changed (e.g., climate conditions such as temperature, wind, precipitation levels, terrain conditions, demographics, local generation mix, etc.) This component investigates how dependent the solution is on available resources and infrastructures.

5.2. Economic Factors

The project's solution must be tested in the context of a distinct business model. The original project's business model is unlikely to stand up in a new setting—at least not without modification. However, not all European countries have policies that promote loss reduction, thus a solution that is viable due to loss reduction in one host area may not be desirable in another. The factor business model determines how thoroughly the solution's viability has been investigated and/or whether the solution is viable in various scenarios (e.g., another EU member state).

In addition, a macroeconomic analysis is required to determine whether the proposed solution is (still) profitable in other European countries. This is usually accomplished by doing a brief scenario study on a few key target countries. Inflation carbon cost and interest rates all affect project costs and viability. The factor macroeconomics examines how dependent the answer is on specific macroeconomic factors (e.g., discount rate, inflation rate, etc.)

Additionally, another determining factor is the market design. The definition of products and services, bid or offer requirements, and pricing and financial settlement regulations are all part of market design. It also refers to the responsibilities and roles of various market actors, as well as the interactions among them. This includes questions about the market model utilized, the tariff structure in place, who the players are, how they interact, and whether there are any additional restraints such as taxes or subsidy schemes. The factor market design then indicates how dependent the solution is on a certain market design.

5.3. Regulatory and Stakeholder

It is critical for successful replication that regulation in the intended host area allows the project's deployment to be replicated. Regulation is defined broadly in terms of agent roles, rules for providing services, rules for remunerating regulated agents, and rules for agent interaction. Because the project demonstrator works under various regulatory frameworks, the definition is intentionally kept generic and does not focus on a specific regulatory framework. The factor regulation investigates how much the solution depends on current national or local regulation to be feasible and viable, and whether barriers arise because of this dependency.

Furthermore, the solution must be accepted by key stakeholders. This could imply a more fundamental agreement than is required for scalability. After all, stakeholders must be willing to accept something completely new, which may be more challenging than accepting a larger version of what already exists. The factor acceptance inquires and investigates the extent to which acceptance issues are to be expected when exporting solutions to other countries.

6. Scalability and Replicability Analysis

In the following subsections, the key points from each demonstration's scalability and replicability analysis are highlighted. The various factors were quantified into numbers ranging from zero to three in order to conclude how scalable or replicable each solution is, with zero representing the lowest score and three representing the highest [33–35,38–40].

6.1. DEMO 1: Active Substation Controller—Demand/Response and Storage Integration (ADN-BESS)

The Battery Energy Storage System (BESS) unit power rating (1 MW) meets the requirements for a simple grid connection. However, the increase in BESS unitary size is limited in order to avoid large power cable sizes that would make grid connection difficult. To achieve larger plant sizes, several BESS units can be combined to achieve the desired plant size. On the other hand, technological conditions may lead to smaller rack sizes, but system redesign may be required due to technological advances in the short to medium term [41,42].

The standard sizes of the containers that house the batteries limit the size of the BESS. Furthermore, as the total BESS plant size increases, so does the external plant substation, requiring more layout space. To add a new utility, modifications will be required; therefore, some architecture simplification is recommended to facilitate integration in the substations and systems of the Distribution System Operators (DSO) and Transmission System Operators (TSO).

In terms of the cost-benefit ratio, it is expected that short to medium-term changes will be beneficial. However, in order to accommodate the development of BESS, additional mandatory standard compliance should be completed. Adaptation to specific standards in each country must be considered, and BESS grid services must specifically meet the requirements of the country's Grid Code.

In recent years, the Energy Storage market has accelerated along with a significant increase in the production of electric vehicles, potentially affecting the availability of batteries for BESS applications. It is recommended to encourage agreements between BESS developers and battery suppliers, as well as battery recycling policies, to reduce the risk of shortages and reliance on imports. Finally, there are regulatory barriers to replicability that could affect the solution, specifically compliance with country grid code in each project.

The following Figure 3 shows the overall scalability and replicability assessment. Moreover, in Tables 3 and 4, the main remarks regarding the scalability and replicability analysis, respectively, for DEMO 1 are presented in detail.

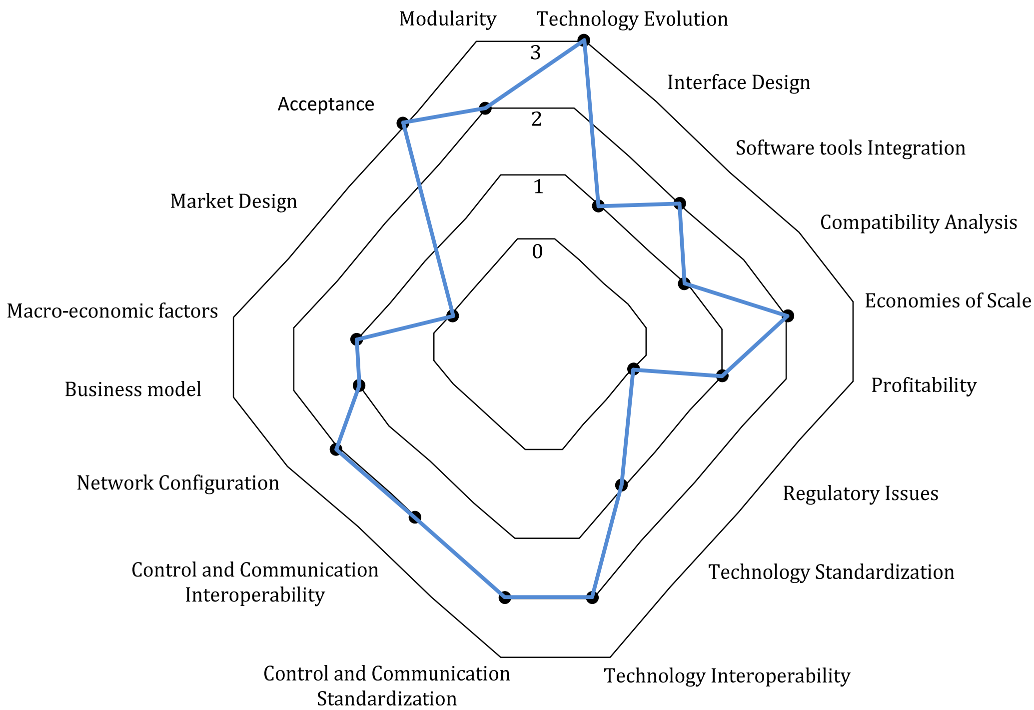

Figure 3. Scalability and replicability assessment DEMO 1: Active Substation Controller.

It can be concluded that DEMO 1: "Active Substation Controller" receives a medium overall score, with strong points for stakeholder acceptance as a key technology for future power grids, as well as the positive impact of technology evolution. The regulatory barriers and market design that do not adequately remunerate the services provided by the Active Substation Controller appear to be the weakest points at this stage.

Table 3. Scalability factors analysis for DEMO 1.

Area	Sub-Areas	Factors	Achievements	Issues
Technical	Technology	Modularity	Independent functional units clearly defined. BESS unit power rating (1 MW) suits the requirements for an easy connection to the grid.	Increase in BESS unitary size is limited to avoid great power cables sizes which would make difficult the connection to the grid. Greater plant sizes are achievable by combining several BESS units to attain the desired plant size.
		Technology Evolution	Technological conditions allow increasing the solution size.	Redesign in the system may be needed due to technological advances in the short to medium term. Some simplification in the architecture would be advisable to facilitate the integration in the substation and DSO/TSO systems. Advances in battery technology could lead to smaller sizes of racks.
	Control and communications Interface	Interface design	Centralized and decentralized.	Modification will be needed for a new utility system to be added.
		Software tools integration	The design of software permits the integration of more elements.	Integration to different operational and market platforms to be further analyzed.
	Infrastructure	Compatibility analysis	Limited physical size limitations.	BESS size is limited by the standard sizes of containers that house the batteries. Increase in total BESS plant size also involves that the external plant substation is also greater thus requiring more space for the layout.
Economic	Economy of scale	Economies of Scale	Evolutions in the short to medium term will have a positive influence on the cost-benefit ratio.	If the size of the solution increases cost and benefit would increase.
		Profitability	The economic indicators of the demo case show that the business model is viable enough to scale up.	Further analysis in business models could be carried out, including scenarios with BESS units supporting wind/solar plants.
Regulatory and Stakeholder	Regulation	Regulatory Issues	Regulation changes under development.	Regulation barriers currently in place.
	Consent by users, local authorities and public	Acceptance	Increasing consent.	Suggested to become more familiar.

Table 4. Replicability factors analysis for DEMO 1.

Area	Sub-Areas	Factors	Achievements	Issues
Technical	Technology	Standardization	The solution is partially standard compliant.	Further mandatory standard compliant should be done. Adaptation to standards particulars in each country needs to be considered Provision of grid services by BESS must specifically match the requirements of the country Grid Code.
		Interoperability	There is the ability to share data via software and hardware.	-
	Control and communications Interface	Standardization	The solution is partially standard compliant (standard communication protocols are used).	Further mandatory standard compliant should be done.
		Interoperability	There is the ability to share data via software and hardware (standard communication protocols are used).	-
	Infrastructure	Network Configuration	The solution is partially standard compliant, by using standard networking devices.	Further mandatory standard compliant should be done. Adaptation to standards particulars in each country needs to be considered.
Economic	Business Model	Business model	Business model exist that could be deployed in different environment.	Some investment would be needed to deploy it in different environment.
	Profitability Analysis	Macro-economic factors	Different options (locations, network topology etc) have been evaluated before the implementation.	Further analysis to study the influence of economic factors on the replicability capacity needed.
		Market Design	Solution can be easily (economically and technically) compliant with a defined different set of standards.	Markets for ADN-BESS currently not existing in many countries.
		Delivery time and availability of batteries suppliers	In the last years Energy Storage market is moving very fast together with a substantial increase in the production of electric vehicles, which could cause affect the availability of batteries for BESS applications.	Encourage agreements between BESS developers and battery suppliers and battery recycling policies to minimize the risk of shortages and reducing the dependence on imports.
Regulatory and Stakeholder	Regulation	Regulatory Issues	Regulation is expected to change that will make the solution feasible and viable.	There exist regulatory barriers with respect to replicability that could affect the solution, regarding specifically compliance with country grid.
	Acceptance	Acceptance	Stakeholders have shown great interest.	The stakeholder acceptance is important regarding replicability potential.

6.2. DEMO 2: Wind Power Plant Connected to Active Substation

The regulatory and institutional environments have a significant impact on the estimation of BESS's potential replicability and scalability. Some countries that have not developed the network codes for the regulation of the integration of BESS systems in their networks are now starting to adapt their regulatory frameworks to the new system needs and generation paradigm.

If the BESS is small in comparison to the size of the grid into which it discharges, detailed power system and production cost models are not required. Large-scale systems, on the other hand, have more data to consider, and the control processes and algorithms include more variables, making the control systems more complex. The task of preparing a BESS economic analysis for appraisal faces two major challenges: (a) the scale of the investment project under consideration influences this; (b) it is necessary to have a sufficient understanding of the unique technical aspects of BESS (technical aspects of battery design, sizing, performance etc.) Overall, there is still a lack of economic experience.

Concerning interoperability, the European Commission (EC) is enabled to develop interoperability standards for communication and control, between different distributed resources. This is in accordance with the delegated act on interoperability published by the EC, in application of the provisions of Directive (EU) 2019/944 [43].

BESS are typically capital-intensive projects, and their viability may necessitate additional assistance. As a result, the existence of financing instruments, both at the European and national levels, aimed entirely or partially at promoting the development of projects and technologies, will play a critical role in scalability.

The following Figure 4 shows the overall scalability and replicability assessment. Moreover, in Tables 5 and 6 the main remarks regarding the scalability and replicability analysis, respectively, for DEMO 2 are presented in detail.

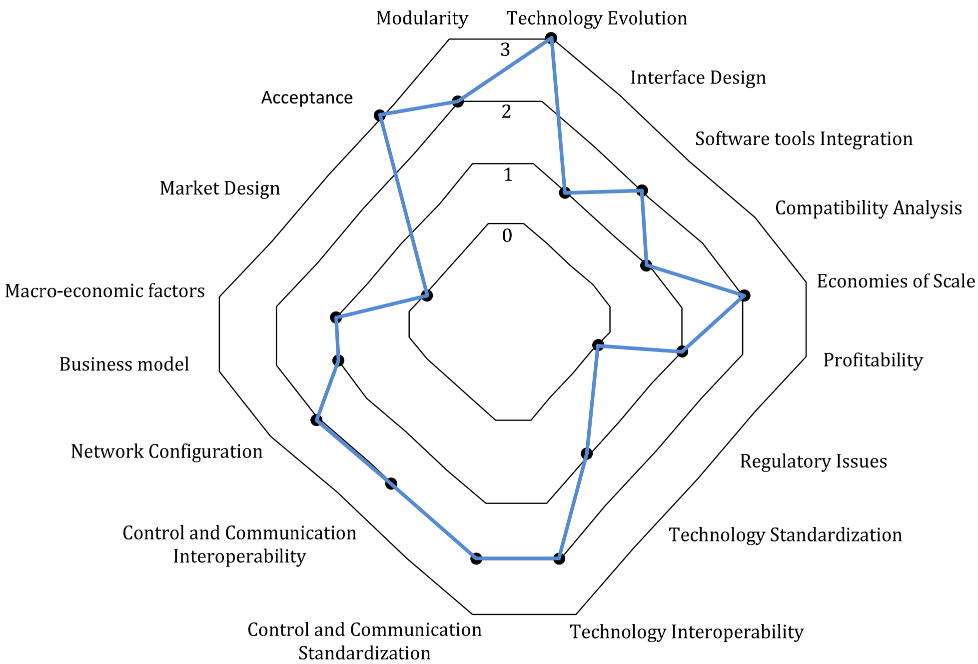

Figure 4. Scalability and replicability assessment DEMO 2: Wind Power Plant connected to Active Substation.

Table 5. Scalability factors analysis for DEMO 2.

Area	Sub-Areas	Factors	Achievements	Issues
Technical	Technology	Modularity	Independent functional units clearly defined.	Some changes would be needed to add components to the solution to increase its size.
		Technology Evolution	Technological conditions allow increasing the solution size.	Redesign in the system may be needed due to technological advances in the short to medium term.
	Control and communications Interface	Interface design	Centralized and decentralized.	Modification will be needed for a new utility system to be added.
		Software tools integration	The design of software permits the integration of more elements	Integration to different operational and market platforms to be further analyzed.
	Infrastructure	Compatibility analysis	Limited physical size limitations.	Some compatibility issues exist.
Economic	Economy of scale	Economies of Scale	Evolutions in the short to medium term will have a positive influence on the cost-benefit ratio.	If the size of the solution increases cost and benefit would increase.
		Profitability	The economic indicators of the demo case show that the business model is viable enough to scale up.	Further analysis in business models could be carried out.
Regulatory and Stakeholder	Regulation	Regulatory Issues	Regulation changes under development.	Regulation barriers currently in place.
	Consent by users, local authorities and public	Acceptance	Increasing consent.	Suggested to become more familiar.

As with DEMO 1, DEMO 2: "Wind Power Plant Connected to Active Substation" receives a medium score, with strong points for stakeholder acceptance as a key technology for future power grids, as well as the positive impact of technology evolution. The regulatory barriers and market design that do not adequately remunerate the services provided by the BESS connected to active substation with wind power plant appear to be the weakest points at this stage.

6.3. DEMO 3: Increase Resilience of the Cross-Border Lines with Sensors for De-Icing Solutions

The Dynamic Line Rating (DLR) [44,45] expert system has several subsystems, including line rating calculation, ice forecasting, sag simulation, and conductor temperature tracking. With model fine-tuning, fractional implementation of the various subsystems is possible. Each subsystem has its own display tab, and each power line necessitates new expert system implementation and adaptation. Furthermore, the incorporation of new sensors into the system increases the number of data records, resulting in increased computational capacity.

Table 6. Replicability factors analysis for DEMO 2.

Area	Sub-Areas	Factors	Achievements	Issues
Technical	Technology	Standardization	The solution is partially standard compliant.	Further mandatory standard compliant should be done.
		Interoperability	There is the ability to share data via software and hardware.	-
	Control and communications Interface	Standardization	The solution is partially standard compliant.	Further mandatory standard compliant should be done.
		Interoperability	There is the ability to share data via software and hardware.	-
	Infrastructure	Network Configuration	The solution is partially standard compliant.	Further mandatory standard compliant should be done.
Economic	Business Model	Business model	Business model exist that could be deployed in different environment.	Some investment would be needed to deploy it in different environment.
	Profitability Analysis	Macro-economic factors	Different options (locations, network topology etc) have been evaluated before the implementation.	Further analysis to study the influence of economic factors on the replicability capacity needed.
		Market Design	Solution can be easily (economically and technically) compliant with a defined different set of standards.	Markets for ADN-BESS currently not existing in many countries.
Regulatory and Stakeholder	Regulation	Regulatory Issues	Regulation is expected to change that will make the solution feasible and viable.	There exist regulatory barriers with respect to replicability that could affect the solution.
	Acceptance	Acceptance	Stakeholders have shown great interest.	The stakeholder acceptance is important regarding replicability potential.

The cost–benefit ratio is determined by the number of integrated sensors and the extra transmission capacity gained. Furthermore, the achieved surplus transmission capacity is dependent on the technical parameters of the line, substation elements, and weather conditions along the line. The demo demonstrated the viability of each subsystem, and the system could be more profitable if used on more power lines.

The technology is widely accepted, and there are no regulatory barriers to scalability or replicability that could jeopardize the solution. However, the TSO's internal regulatory regarding capacity management should be adjusted to the system's dynamic output. The expert system promotes the implementation of the EU's internal electricity market on a market basis.

Finally, sensor communications are standardized, and sensor manufacturers provide standard compliant Supervisory Control and Data Acquisition (SCADA) integration solutions. The interface and overall system communication, however, are dependent on the customers' requests and the system's adaptation to the given TSO's IT security requests for each demonstration.

The following Figure 5 shows the overall scalability and replicability assessment. Moreover, in Tables 7 and 8 the main remarks regarding the scalability and replicability analysis, respectively, for DEMO 3 are presented in detail.

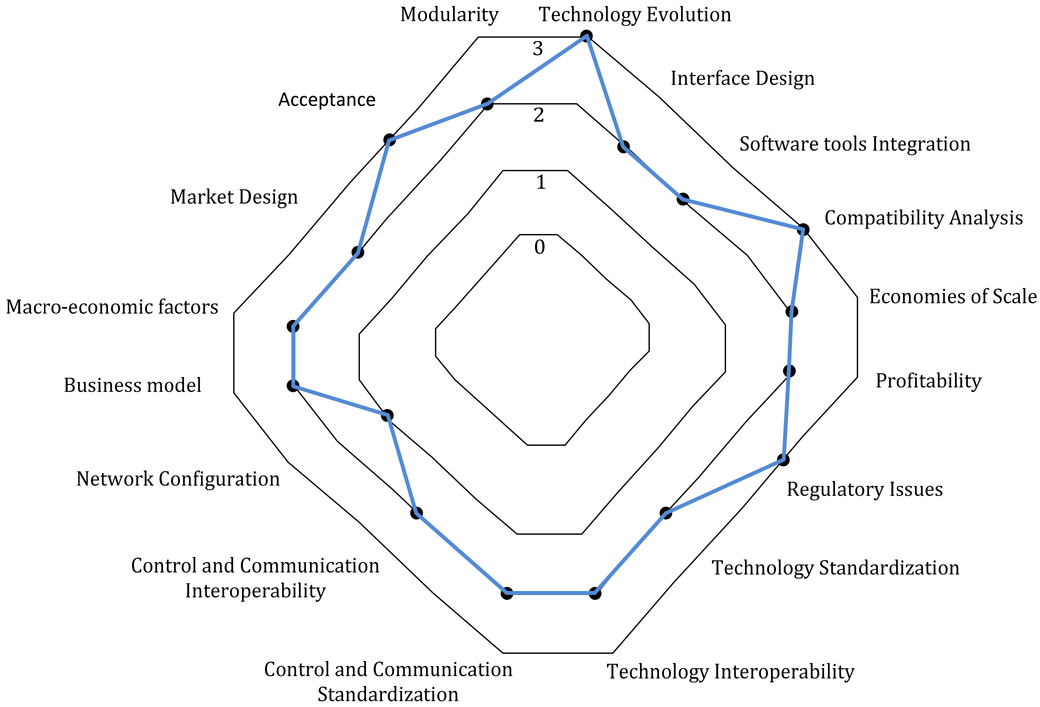

Figure 5. Scalability and replicability assessment DEMO 3: Increase resilience of the cross-border lines with sensors for de-icing solutions.

DEMO 3: "Increase resilience of the cross-border lines with sensors for de-icing solutions" achieves a good score in most of the scalability and replicability factors. There are no significant regulatory barriers, and the expert system can be adapted to any transmission line by knowing its technical parameters, which are both positive aspects of this technology. On the other hand, standardization could be improved further, particularly in terms of TSO security standards.

6.4. DEMO 4: Improve Transfer Capacities and Clean Electricity Flows through Power Flow Control Solutions

The solution can be scaled up or down in response to future changes in system needs. When need is driven by new generation, the solution can be scaled up as more generation connects to the network. As a result, if more generation applies to connect than was originally intended, it is still possible to use the assets and simply increase the impedance as needed. The modularity of this technology is a strong point, with individual units per phase and the ability to scale up and down the number of devices to meet the needs of the network. The ability to control the number of devices connected while in operation is also advantageous because it allows the TSO to scale up and down the functioning deployment as real-time demands change.

Table 7. Scalability factors analysis for DEMO 3.

Area	Sub-Areas	Factors	Achievements	Issues
Technical	Technology	Modularity	The DLR-based expert system includes different subsystems such as line rating calculation, conductor temperature tracking, sag simulation, and ice forecasting subsystems.	-
		Technology Evolution	Fractional implementation possibility for the different subsystems with fine-tuning of the models.	-
	Control and communications Interface	Interface design	Each subsystem has its own display tab.	-
		Software tools integration	The software is implemented on Matlab basis with MS SQL connection.	Each power line requires new implementation of the expert system.
	Infrastructure	Compatibility analysis	The expert system can be adapted to any transmission line by knowing its technical parameters.	Each power line requires new implementation of the expert system.
Economic	Economy of scale	Economies of Scale	Cost-benefit ratio depends on the number of integrated sensors and the gained surplus transmission capacity.	The achieved surplus transmission capacity depends on the technical parameters of the line, substation elements, and prevailing weather conditions along the line.
		Profitability	Quantifiable by the achieved capacity gain/congestion management.	-
Regulatory and Stakeholder	Regulation	Regulatory Issues	Internal regulatory of the TSO regarding the capacity management should be adjusted to the dynamic output of the system.	-
	Consent by users, local authorities, and public	Acceptance	The technology is generally accepted.	-

If the original need is reduced or eliminated, the Power Flow Control (PFC) devices can be easily redeployed to another part of the grid. Because the solution is not tied to the original location, this flexibility allows for a no-regrets investment decision. Because these devices are voltage agnostic, they can be redeployed onto different voltage lines without requiring any changes to the device hardware.

By moving the devices and redeploying them onto the Bulgarian network, the demo demonstrated the replicability of the project deployed in Greece. This could be redeployed to another network with a different voltage level without requiring any changes to the PFC devices. This also demonstrated the deployment's communication interface's ability to integrate into different countries' systems.

The following Figure 6 shows the overall scalability and replicability assessment. Moreover, in Tables 9 and 10, the main remarks regarding the scalability and replicability analysis, respectively, for DEMO 4 are presented in detail.

Table 8. Replicability factors analysis for DEMO 3.

Area	Sub-Areas	Factors	Achievements
Technical	Technology	Standardization	A DLR sensor testing protocol is standardized in the framework of the project.
		Interoperability	The measured field data and the calculated results are stored in the same database.
	Control and communications Interface	Standardization	The sensor communications are standardized; sensor manufacturer offers standard compliant solution regarding SCADA integration.
		Interoperability	The measured field data and the calculated results are stored in the same database.
	Infrastructure	Network Configuration	The system adopted to the given TSO's IT security requests.
Economic	Business Model	Business model	The demo proves the viability of each subsystem.
	Profitability Analysis	Macro-economic factors	The expert system implemented on the most critical power line (from icing and congestion point of view).
		Market Design	The expert system promotes the implementation of internal electricity market at EU level.
Regulatory and Stakeholder	Regulation	Regulatory Issues	No regulatory barriers with respect to replicability that could affect the solution.
	Acceptance	Acceptance	The technology is generally accepted.

It is clear that the highest score is obtained in terms of modularity. Technology evolution ranked high as well, as Smart Wires has evolved this technology further with higher capacity devices with greater controllability, being able to push and pull power from the line by increasing or decreasing the effective impedance rather than simply increasing as was the case with this demo. Because the solution design is determined by the type of transmission lines and towers, compatibility receives a lower score. The business model is viable, but it will vary by network, so individual cases must be investigated. Finally, acceptance could be improved by raising awareness of the devices and their benefit to the network.

6.5. DEMO 5: New Wholesale Market Approach with Flexibility Services

The delivered solution is a new market structure that makes it easier to integrate new flexibility providers. Although the rules of the platform are strict, as is typical of European intraday market platforms, it does not impose any restrictions on national markets to follow other models. The matching algorithm developed for the demonstration has a significant impact on scalability. These algorithms were tested on two markets (Bulgaria and Cyprus) with varying levels of maturity, but not on several coupled markets.

In terms of scaling up the proposed approach, because the matching algorithm is solving a mathematical problem continuously, the required computational capacity grows linearly with the size of the problem. The demonstration, on the other hand, can be replicated in other countries if the necessary data are shared by the relevant market operators. Only the interfaces should be changed; the main components can remain unchanged. It should also be noted that this market is separate from the system operators. Finally, integrating the new order types necessitates a change in the matching algorithm used across Europe, but the solution fits within the overall European market structure.

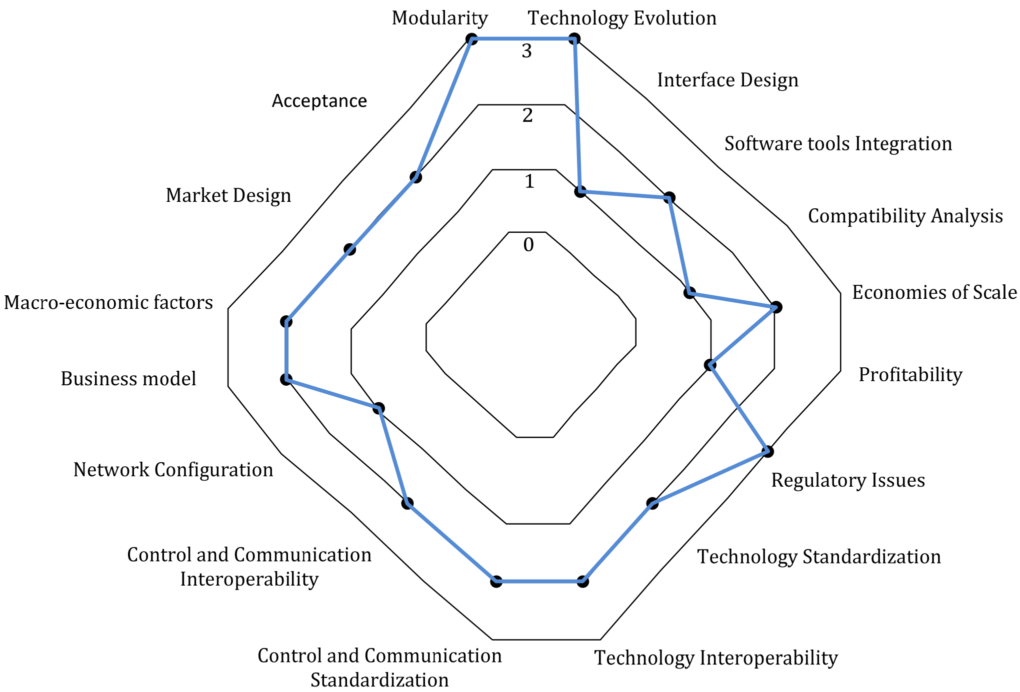

Figure 6. Scalability and replicability assessment DEMO 4: Improve transfer capacities and clean electricity flows through Power Flow Control Solutions.

Concerning the delivered solution's business aspect, the economic impact should be evaluated by taking into account number of trades, market participants, and number of participating flexibility providers.

The following Figure 7 shows the overall scalability and replicability assessment. Moreover, in Tables 11 and 12, the main remarks regarding the scalability and replicability analysis, respectively, for DEMO 5 are presented in detail.

DEMO 5 receives high marks in both scalability and replicability. However, developments on the European markets have taken a turn since the project's inception, and other solutions appear to be emerging. This severely limits the rationale for considering adapting the developed solution to other markets; however, the solution is scalable and replicable.

6.6. DEMO 6: Flexible Substations Advanced Control and Services Demonstration

Demo 6 "Flexible substations advanced control and services demonstration" includes clearly defined independent functional units. However, some modifications would be required to add components to the solution in order to increase its size. Technological conditions permit increasing the size of the solution, but system redesign may be required due to short to medium term technological advance. Finally, the design of software allows for the incorporation of more elements, and there are no physical size constraints.

On the economic side, no economic barriers to scalability and replicability have been identified, and no regulatory barriers that could affect the solution are currently in place. The solution is partially standard compliant, but more standardization is required. Finally, stakeholder acceptance is unimportant in terms of the developed solution's scalability and replicability.

The following Figure 8 shows the overall scalability and replicability assessment. Moreover, in Tables 13 and 14, the main remarks regarding the scalability and replicability analysis, respectively, for DEMO 6 are presented in detail.

Table 9. Scalability factors analysis for DEMO 4.

Area	Sub-Areas	Factors	Achievements	Issues
Technical	Technology	Modularity	The solution can be divided into interdependent components/independent functional units.	If a large impudence is required, design considerations need to be taken to substation space availability. However, as the devices are modular, there is flexibility around how they are deployed on the system.
		Technology Evolution	Technological conditions allow increasing the solution size.	Development of technology means more advanced and capable units now available based on learnings from innovation installations.
	Control and communications Interface	Interface design	Centralized and decentralized.	Modification will be needed for a new utility system to be added.
		Software tools integration	The design of software permits the integration of more elements.	Integration to different operational and market platforms to be further analyzed.
	Infrastructure	Compatibility analysis	Physical size limitations exist.	Solution design depends on the type of transmission lines and towers.
Economic	Economy of scale	Economies of Scale	Evolutions in the short to medium term will have a positive influence on the cost-benefit ratio.	If the size of the solution increases cost and benefit would increase.
		Profitability	The business model should be viable enough to scale up.	This will vary from network to network, so individual cases would need to be investigated.
Regulatory and Stakeholder	Regulation	Regulatory Issues	No regulatory barriers with respect to scalability that could affect the solution.	-
	Consent by users, local authorities, and public	Acceptance	Stakeholder acceptance is of some important regarding scalability potential for your solution.	Being a newer technology preference can sometime lean towards more established technology where concerns around issues such as noise and visual impact are better understood.

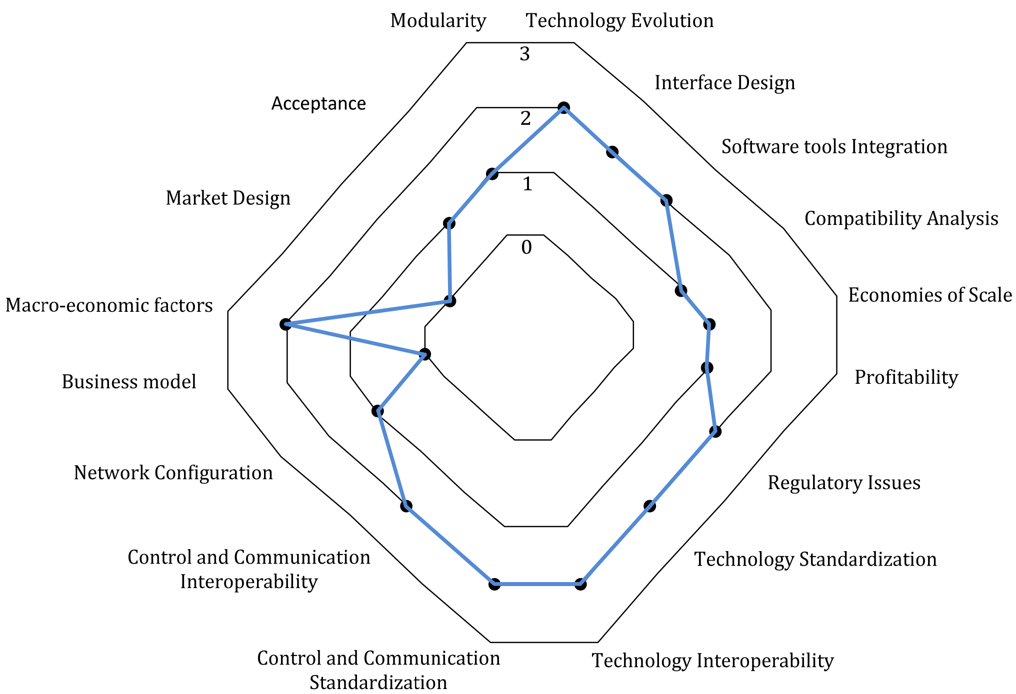

Figure 7. Scalability and replicability assessment DEMO 5: New wholesale market approach with flexibility services.

Table 10. Replicability factors analysis for DEMO 4.

Area	Sub-Areas	Factors	Achievements	Issues
Technical	Technology	Standardization	The solution is standard compliant.	Will still require studies on individual networks to ensure optimal performance
		Interoperability	There is the ability to share data via software and hardware.	-
	Control and communications Interface	Standardization	The solution is partially standard compliant.	Communication with the devices uses radio frequency to ensure ease of installation. Some sites may require the speed of fiber optic as provided by the later models of the technology.
		Interoperability	There is the ability to share data via software and hardware.	-
	Infrastructure	Network Configuration	The solution is partially standard compliant.	-
Economic	Business Model	Business model	The demo case demonstrates that it is viable enough to replicate.	Further analysis on business model exist that could be deployed in different environment.
	Profitability Analysis	Macro-economic factors	Different options (locations, network topology, etc.) have been evaluated before the implementation.	-
		Market Design	Solution can be (economically and technically) compliant with a defined different set of standards.	Further analysis on the use in market environment.
Regulatory and Stakeholder	Regulation	Regulatory Issues	No regulatory barriers with respect to replicability that could affect the solution.	-
	Acceptance	Acceptance	The stakeholder acceptance is of some important regarding replicability potential for your solution.	Being a newer technology preference can sometime lean towards more establish technology.

Table 11. Scalability factors analysis for DEMO 5.

Area	Sub-Areas	Factors	Achievements	Issues
Technical	Technology	Modularity	Independent functional units clearly defined.	Not clear if the solution could be divided.
		Technology Evolution	Technological advances in the short to medium term have positive impact.	-
	Control and communications Interface	Interface design	Centralized and decentralized.	Modification will be needed for a new utility system to be added
		Software tools integration	The design of software permits the integration of more elements.	Integration to different operational and market platforms to be further analyzed.
	Infrastructure	Combability analysis	No physical size limitations.	-
Economic	Economy of scale	Economies of Scale	No economic barriers with respect to scalability that could affect the solution.	-
		Profitability	The business model is viable enough to scale up.	-
Regulatory and Stakeholder	Regulation	Regulatory Issues	No regulatory barriers with respect to scalability that could affect the solution.	-
	Consent by users, local authorities, and public	Acceptance	Major importance	-

Table 12. Replicability factors analysis for DEMO 5.

Area	Sub-Areas	Factors	Achievements	Issues
Technical	Technology	Standardization	The solution is partially standard compliant.	Further standardization to be further developed.
		Interoperability	There is the ability to share data via software and hardware.	-
	Control and communications Interface	Standardization	The solution is partially standard compliant.	-
		Interoperability	There is the ability to share data via software and hardware.	-
	Infrastructure	Network Configuration	The solution is partially standard compliant.	-
Economic	Business Model	Business model	The demo case demonstrates that it is viable enough to replicate.	Further analysis on business model exist that could be deployed in different environment.
	Profitability Analysis	Macro-economic factors	With some effort the solution would be profitable in different countries.	-
		Market Design	Solution can be (economically and technically) compliant with a defined different set of standards.	Further analysis on the use in market environment.
Regulatory and Stakeholder	Regulation	Regulatory Issues	No regulatory barriers with respect to replicability that could affect the solution.	-
	Acceptance	Acceptance	The stakeholder acceptance is important regarding replicability potential for your solution.	-

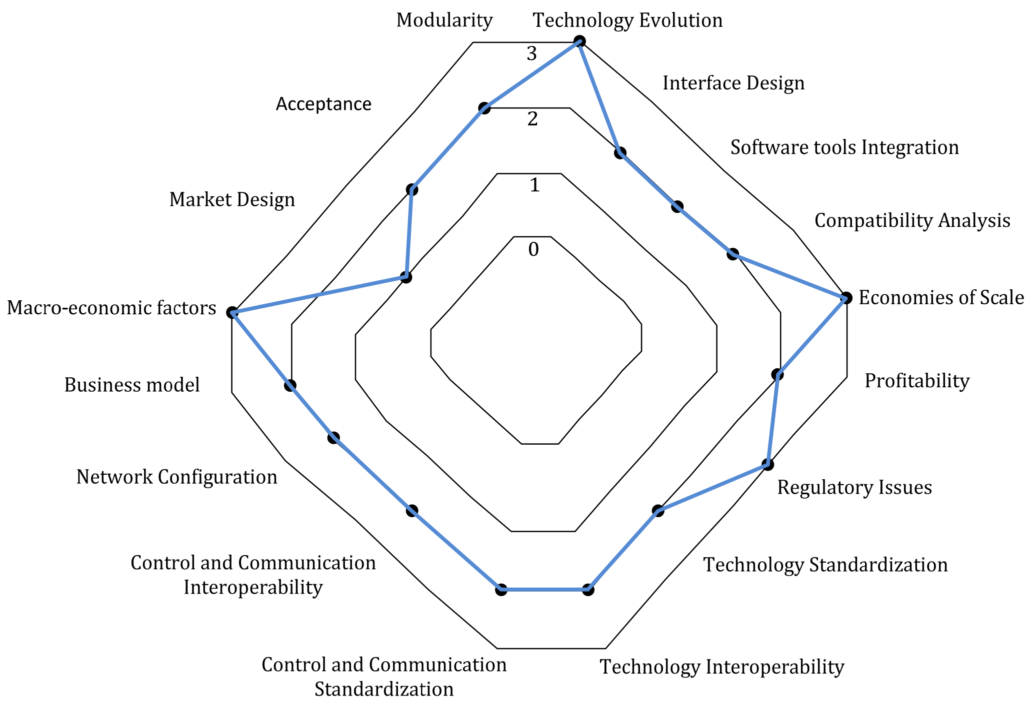

Figure 8. Scalability and replicability assessment DEMO 6: Flexible substations advanced control and services demonstration.

Table 13. Scalability factors analysis for DEMO 6.

Area	Sub-Areas	Factors	Achievements	Issues
Technical	Technology	Modularity	Independent functional units clearly defined.	Some changes would be needed to add components to the solution to increase its size.
		Technology Evolution	Technological conditions allow increasing the solution size.	Redesign in the system may be needed due to technological advances in the short to medium term.
	Control and communications Interface	Interface design	Centralized and decentralized.	Modification will be needed for a new utility system to be added.
		Software tools integration	The design of software permits the integration of more elements.	-
	Infrastructure	Combatibility analysis	No physical size limitations.	-
Economic	Economy of scale	Economies of Scale	No economic barriers with respect to scalability.	-
		Profitability	The business model is viable enough to scale up.	-
Regulatory and Stakeholder	Regulation	Regulatory Issues	No regulatory barriers with respect to scalability that could affect the solution.	-
	Consent by users, local authorities, and public	Acceptance	Not of importance.	-

Table 14. Replicability factors analysis for DEMO 6.

Area	Sub-Areas	Factors	Achievements	Issues
Technical	Technology	Standardization	The solution is partially standard compliant.	Further standardization to be further developed.
		Interoperability	There is the ability to share data via software and hardware.	-
	Control and communications Interface	Standardization	The solution is partially standard compliant.	-
		Interoperability	There is the ability to share data via software and hardware.	-
	Infrastructure	Network Configuration	The solution is partially standard compliant.	-
Economic	Business Model	Business model	The demo case demonstrates that it is viable enough to replicate.	-
	Profitability Analysis	Macro-economic factors	With some effort the solution would be profitable in different countries.	-
		Market Design	Solution can be (economically and technically) compliant with a defined different set of standards.	Further analysis in different market environment.
Regulatory and Stakeholder	Regulation	Regulatory Issues	-	Regulatory barriers with respect to replicability that could affect the solution.
	Acceptance	Acceptance	The stakeholder acceptance is of minor importance regarding replicability potential for your solution.	-

Overall, Demo 6 "Flexible substations advanced control and services demonstration" receives high marks in the various scalability and replicability factors, indicating that there is no specific barrier to scaling up and replicating the developed technology. Further standardization is recommended, as is the smooth integration of changes brought about by technological evolution.

6.7. DEMO 7: Large Scale Storage System for Combined Cycle Plant

The standard container sizes that include the batteries limit the size of the BESS. Furthermore, an increase in total BESS plant size implies an increase in external space in the power plant. This is usually not a problem because power plants are located in more isolated areas with plenty of open space. To add a new utility, modifications will be required; therefore, some architecture simplification is recommended to facilitate integration in the power plant.

In terms of the cost-benefit analysis, it has yet to be demonstrated that the benefit outweighs the additional cost. Additionally, mandatory standard compliance is recommended. Adaptation to specific standards in each country must be considered, and power plant grid services must specifically meet the requirements of the country grid code.

The following Figure 9 shows the overall scalability and replicability assessment. Moreover, in Tables 15 and 16, the main remarks regarding the scalability and replicability analysis, respectively, for DEMO 7 are presented in detail.

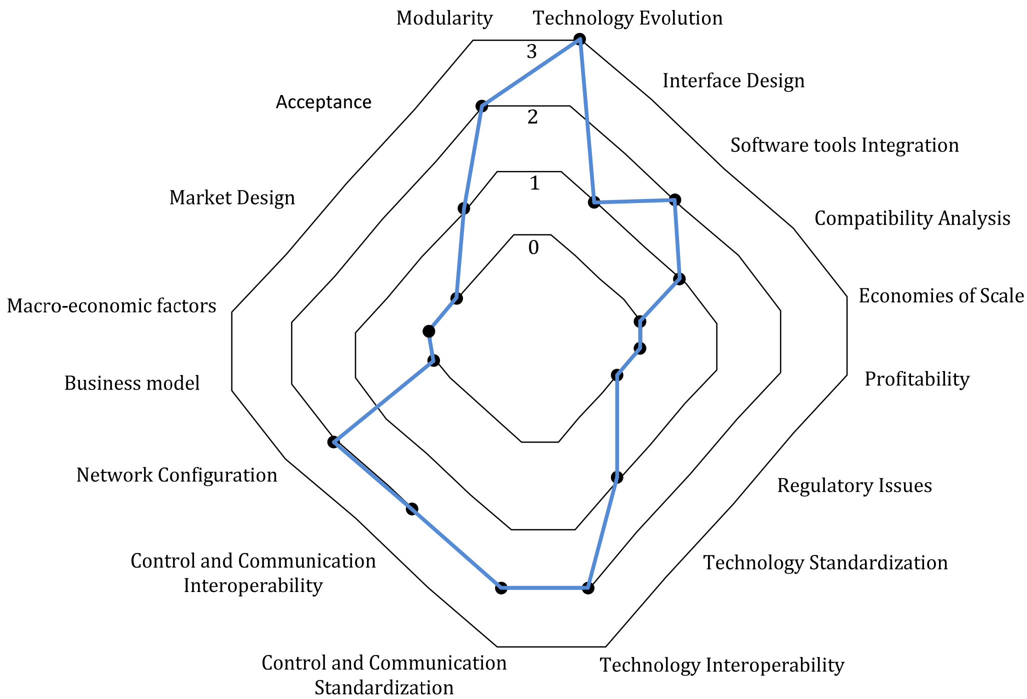

Figure 9. Scalability and replicability assessment DEMO 7: Large Scale Storage System for Combined Cycle Plant.

Even though the developed technology appears to have the potential to be scalable and replicable, GEF has received very few bids for this product/service in the last two years, none of which have been converted into reality. Furthermore, the increased benefits are not currently visible or significant. As a result, one could conclude that this technology is still in its early stages and does not have the potential to be scaled up and replicated.

6.8. DEMO 8: Advanced Control for Flexible Synchronous Generation

The developed system could be used for installations with several generators or larger generators, without increasing computational requirements. However, new computational resources would be required for large plants or when the system is deployed in new plants.

Furthermore, adding new controllers to the system and modelling new generators in the algorithms would be required to scale up the system in other plants.

It would be necessary to analyze the new system to be operated, model it, and appropriately train the control algorithms in order to replicate the demonstration activities. The controller would also have to work with the new Power System Stabilizers (PSS) and area of influence measurements.

PSS technology is well-established and has been in use for many years. The approach to installing a new PSS should be same across all TSOs (PSS is meaningless for DSOs since the plant's capacity must be high to have an influence, and such facilities are normally only found at the TSO level). Beyond what has been indicated, adding the solution to the PSS has no influence on replicability and scalability. Finally, there is currently no compensation available for providing damping.

The following Figure 10 shows the overall scalability and replicability assessment. Moreover, in Tables 17 and 18 the main remarks regarding the scalability and replicability analysis, respectively, for DEMO 8 are presented in detail.

Table 15. Scalability factors analysis for DEMO 7.

Area	Sub-Areas	Factors	Achievements	Issues
Technical	Technology	Modularity	Independent functional units clearly defined.	-
		Technology Evolution	Technological conditions allow increasing the solution size.	-
	Control and communications Interface	Interface design	Centralized and decentralized.	Modification will be needed for a new utility system to be added.
		Software tools integration	The design of software permits the integration of more elements.	Integration to different operational and market platforms to be further analyzed.
	Infrastructure	Combability analysis	Limited physical size limitations.	-
Economic	Economy of scale	Economies of Scale	Evolutions in the short to medium term will have a positive influence on the cost-benefit ratio.	If the size of the solution increases cost and benefit would increase.
		Profitability	The economic indicators of the demo case show that the business model is viable enough to scale up.	-
Regulatory and Stakeholder	Regulation	Regulatory Issues	Regulation changes under development.	Regulation barriers currently in place.
	Consent by users, local authorities, and public	Acceptance	Increasing consent.	-

Table 16. Replicability factors analysis for DEMO 7.

Area	Sub-Areas	Factors	Achievements	Issues
Technical	Technology	Standardization	The solution is partially standard compliant.	Further mandatory standard compliant should be done.
		Interoperability	There is the ability to share data via software and hardware.	-
	Control and communications Interface	Standardization	The solution is partially standard compliant.	Further mandatory standard compliant should be done.
		Interoperability	There is the ability to share data via software and hardware.	-
	Infrastructure	Network Configuration	The solution is partially standard compliant.	Further mandatory standard compliant should be done.
Economic	Business Model	Business model	Business model exist that could be deployed in different environment.	-
	Profitability Analysis	Macro-economic factors	Different options (locations, network topology, etc.) have been evaluated before the implementation.	-
		Market Design	Solution can be easily (economically and technically) compliant with a defined different set of standards.	-
Regulatory and Stakeholder	Regulation	Regulatory Issues	Regulation is expected to change that will make the solution feasible and viable.	There exist regulatory barriers with respect to replicability that could affect the solution.
	Acceptance	Acceptance	Stakeholders have shown great interest.	-

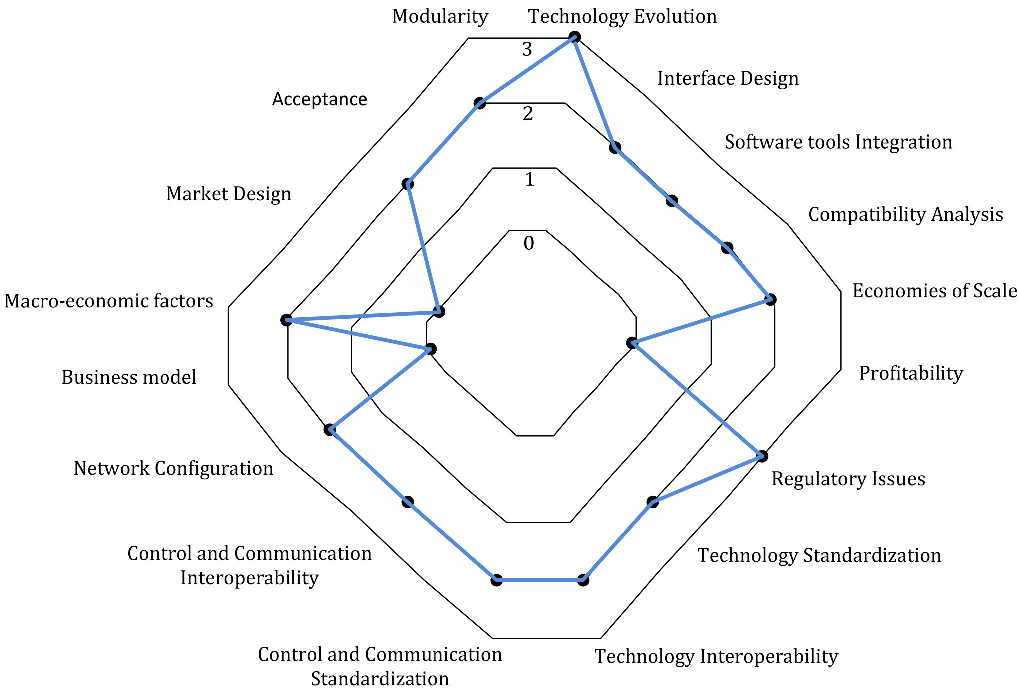

Figure 10. Scalability and replicability assessment DEMO 8: Advanced Control for flexible synchronous generation.

Table 17. Scalability factors analysis for DEMO 8.

Area	Sub-Areas	Factors	Achievements	Issues
Technical	Technology	Modularity	Independent functional units clearly defined.	Replication in a different location would require a new installation. Retraining of prediction models is needed if inputs are changed.
		Technology Evolution	Technological conditions allow increasing the solution size.	-
	Control and communications Interface	Interface design	Centralized	Modification will be needed for new systems under the same location to be added.
		Software tools integration	The design of software permits the integration of more elements.	Integration to different operational and market platforms to be further analyzed.
	Infrastructure	Combability analysis	No physical size limitations.	-
Economic	Economy of scale	Economies of Scale	No economic barriers with respect to scalability.	-
		Profitability	Yet to be determined (by increasing the damping more power can be transferred along the lines which can reduce costs).	No compensation for this kind of service (Damping Oscillations).
Regulatory and Stakeholder	Regulation	Regulatory Issues	No regulatory barriers are known with respect to scalability that could affect the solution.	
	Consent by users, local authorities, and public	Acceptance	Not of importance.	

Table 18. Replicability factors analysis for DEMO 8.

Area	Sub-Areas	Factors	Achievements	Issues
Technical	Technology	Standardization	The solution is partially standard compliant.	-
		Interoperability	There is the ability to share data via software and hardware.	-
	Control and communications Interface	Standardization	The solution is partially standard compliant (standard communication protocols are used).	-
		Interoperability	There is the ability to share data via software and hardware (standard communication protocols are used).	-
	Infrastructure	Network Configuration	The network configuration is standard compliant, by using standard networking devices.	-
Economic	Business Model	Business model	The demo case demonstrates that it is viable enough to replicate.	
	Profitability Analysis	Macro-economic factors	Yet to be determined.	-
		Market Design	Solution can be (economically and technically) compliant with a defined different set of standards.	-
Regulatory and Stakeholder	Regulation	Regulatory Issues	No regulatory barriers are known with respect to replicability that could affect the solution.	
	Acceptance	Acceptance	Minor importance regarding replicability potential for your solution.	

Overall DEMO 8: "Advanced Control for flexible synchronous generation" in the different scalability and replicability factors achieves good score. However, there are significant barriers such as market design and profitability, since currently there is not compensation for providing damping.

7. Results Discussion

The scalability and replicability of FLEXITRANSTORE technology improvements were investigated in this study. Factors that influence the project's scalability and replicability have been researched and identified for this purpose. These criteria include characteristics of technical, economic, regulatory, and stakeholder approval.

The following are the main conclusions for each demonstration:

DEMO 1: "Active Substation Controller" receives a medium overall score, with strong points being the acceptance of stakeholders as a crucial technology for future power grids and the positive impact of technology evolution. The regulatory barriers and the market design that do not satisfactory remunerate the services provided by the Active Substation Controller appear to be the weakest points at this time.

DEMO 2: "Wind Power Plant Connected to Active Substation" receives a medium score, with strong points being the acceptance of stakeholders as a crucial technology for future power grids and the positive impact of technology evolution. Regulatory barriers and market design that do not satisfactory remunerate the services offered by the BESS connected to an active substation with wind power plant appear to be the weakest points at this moment.

DEMO 3: "Increase resilience of the cross-border lines with sensors for de-icing solutions" in most of the scalability and replicability factors achieves a good score. Positive characteristics of this technology include the lack of significant regulatory barriers and the fact that the expert system can be customized to any transmission line by knowing its technical parameters. Standardization, on the other hand, could be further improved, particularly in terms of TSO security standards.

DEMO 4: "Improve transfer capacities and clean electricity flows through Power Flow Control Solutions" in terms of modularity achieves the highest score. Smart Wires has advanced this technology further with higher capacity devices with more controllability, allowing them to push and pull power from the line by increasing or decreasing the effective impedance rather than just increasing it, as was the case with this demo. Compatibility receives a lower grade since the solution design is dependent on the type of transmission lines and towers. The business model is viable, but it will differ from network to network, necessitating further investigation in individual cases. Finally, increasing awareness of the devices and their benefits to the network could help to improve acceptability.

DEMO 5: "New wholesale market approach with flexibility services" achieves high scores in both scalability and replicability. However, since the start of the project, developments on the European markets have taken a turn, and other options appear to be emerging. This severely limits the rationale for considering adapting the developed solution to other markets, yet the approach itself is scalable and reproducible.

DEMO 6: "Flexible substations advanced control and services demonstration" gets high scores on all the scalability and replicability factors, leading to the conclusion that there is no special obstacle to scaling up and replicating the developed technology. Further standardization, as well as the smooth integration of technological developments, would be beneficial.

DEMO 7: "Large Scale Storage System for Combined Cycle Plant" appears to have the potential to be scalable and reproducible; however, GEF has received relatively few bids for this product/service in the last two years, and none have been realized. Furthermore, the increased benefits are not observable or significant now. As a result, one could conclude that this technology is immature and does not have the potential to be scaled up and replicated at this time.

DEMO 8: "Advanced Control for flexible synchronous generation" in the different scalability and replicability factors achieves a good score. However, market design and profitability seem to be significant barriers because there is not compensation for providing damping currently.

8. Conclusions

The scalability and replicability of FLEXITRANSTORE technology innovations were investigated in this study. Factors that influence the project's scalability and replicability have been explored and identified for this purpose. These parameters were chosen based on a thorough literature assessment and include technological, economic, regulatory, and stakeholder acceptance considerations. In a nutshell, technical variables assess if a project's solution is naturally scalable and/or reproducible, whereas economic factors decide whether scaling up or replication is economically viable. Regulation and stakeholder acceptability factors indicate if the current environment is ready to accept a scaled-up version of a project or whether a new environment is appropriate for receiving a project.

Author Contributions: Conceptualization, G.F., C.D., E.Z., S.P. and V.V.; methodology, G.F., C.D., S.P. and V.V.; validation, G.F., V.V. and E.Z.; formal analysis, C.D. and E.Z.; writing—original draft preparation, G.F. and C.D.; writing—review and editing, V.V. and G.F.; visualization, C.D., E.Z., S.P. and G.F.; supervision, V.V. and E.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the European Union's Horizon 2020 research and innovation program under grant agreement No. 824330. The authors acknowledge financial support for the publication of this work from the Special Account for Research of ASPETE.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Al-Ali, A.; Aburukba, R. Role of Internet of Things in the Smart Grid Technology. *J. Comput. Commun.* **2015**, *3*, 229–233. [CrossRef]
2. Pramudhita, A.N.; Asmara, R.A.; Siradjuddin, I.; Rohadi, E. Internet of Things Integration in Smart Grid. In Proceedings of the International Conference on Applied Science and Technology (iCAST), Manado, Indonesia, 26–27 October 2018; pp. 718–722. [CrossRef]
3. Saleem, Y.; Crespi, N.; Rehmani, M.H.; Copeland, R. Internet of Things-Aided Smart Grid: Technologies. *IEEE Archit. Appl. Prototypes Future Res. Dir.* **2019**, *7*, 62962–63003. [CrossRef]
4. Lazarou, S.; Vita, V.; Christodoulou, C.A.; Ekonomou, L. Calculating operational patterns for electric vehicle charging on a real distribution network based on renewables' production. *Energies* **2018**, *11*, 2400. [CrossRef]
5. Lazarou, S.; Vita, V.; Ekonomou, L. Protection schemes of meshed distribution networks for smart grids and electric vehicles. *Energies* **2018**, *11*, 3106. [CrossRef]
6. FLEXITRANSTORE. An Integrated Platform for Increased FLEXIbility in Smart TRANSmission grids with STORage Entities and Large Penetration of Renewable Energy Sources. Available online: http://flexitranstore.eu/content/home (accessed on 13 May 2022).
7. Farhangi, H. The path of the smart grid. *IEEE Power Energy Mag.* **2010**, *8*, 18–28. [CrossRef]
8. CEN-CENELEC-ETSI. Smart Grid Reference Architecture; CEN-CENELEC-ETSI Smart Grid Coordination Group; Brussels, Belgium, 2012. Available online: https://www.cencenelec.eu/areas-of-work/cen-cenelec-topics/smart-grids-and-meters/smart-grids/ (accessed on 2 May 2022).
9. Ardito, L.; Procaccianti, G.; Menga, G.; Morisio, M. Smart grid technologies in Europe: An overview. *Energies* **2013**, *6*, 251–281. [CrossRef]
10. Di Santo, K.G.; Kanashiro, E.; di Santo, S.G.; Saidel, M.A. A review on smart grids and experiences in Brazil. *Renew. Sustain. Energy Rev.* **2015**, *52*, 1072–1082. [CrossRef]
11. Yu, Y.; Yang, J.; Chen, B. The smart grids in China—A review. *Energies* **2012**, *5*, 1321–1338. [CrossRef]
12. Jiménez, M.S.; Onyeji, I.; Colta, A.; Papaioannou, I.; Mengolini, A.; Alecu, C.; Maschio, I. *Smart Grid Projects in Europe: Lessons Learned and Current Developments*; JRC: Luxembourg, 2012; Available online: https://ses.jrc.ec.europa.eu/sites/ses/files/documents/smart_grid_projects_in_europe_lessons_learned_and_current_developments.pdf (accessed on 15 May 2022).
13. Novosel, D. Experiences with deployment of smart grid projects. In Proceedings of the 2012 IEEE PES Conference on Innovative Smart Grid Technologies (ISGT), Washington, DC, USA, 16–20 January 2012.
14. Niesten, E.; Alkemade, F. How is value created and captured in smart grids? A review of the literature and an analysis of pilot projects. *Renew. Sustain. Energy Rev.* **2016**, *53*, 629–638. [CrossRef]

15. Vita, V.; Christodoulou, C.; Zafeiropoulos, I.; Gonos, I.; Asprou, M.; Kyriakides, E. Evaluating the flexibility benefits of smart grid innovations in transmission networks. *Appl. Sci.* **2021**, *11*, 10692. [CrossRef]
16. Mladenov, V.; Chobanov, V.; Seritan, G.C.; Porumb, R.F.; Enache, B.-A.; Vita, V.; Stănculescu, M.; Van, T.V.; Bargiotas, D. A flexibility market platform for electricity system operators using blockchain technology. *Energies* **2022**, *15*, 539. [CrossRef]
17. Vita, V.; Christodoulou, C.A.; Zafeiropoulos, E.; Mladenov, V.; Chobanov, V.; Asprou, M.; Kyriakides, E. Flexibility adequacy assessment in the SEE region with new technology integration. *WSEAS Trans. Power Syst.* **2022**, *17*, 76–83. [CrossRef]
18. Mladenov, V.; Chobanov, V.; Zafeiropoulos, E.; Vita, V. Characterisation and evaluation of flexibility of electrical power system. In Proceedings of the 10th Electrical Engineering Faculty Conference (BulEF), Sozopol, Bulgaria, 11–14 September 2018. [CrossRef]
19. Zafiropoulos, E.; Christodoulou, C.A.; Vita, V.; Dikaiakos, C.; Gonos, I.F.; Zubieta, E.; Santamaria, G.; Lai, N.B.; Baltas, N.G.; Rodriguez, P. Smart grid flexibility solutions for transmission networks with increased RES penetration. In Proceedings of the CIGRE Paris Seeion 2022 (CIGRE 2022), Paris, France, 28 August–2 September 2022.
20. Mazidi, P.; Baltas, G.N.; Eliassi, M.; Rodriguez, P.; Pastor, R.; Michael, M.; Tapakis, R.; Vita, V.; Zafiropoulos, E.; Dikeakos, C.; et al. Zero renewable incentive analysis for flexibility study of a grid. In Proceedings of the 21st International Symposium on High Voltage Engineering (ISH 2019), Budapest, Hungary, 26–30 August 2019. [CrossRef]
21. Vita, V.; Zafiropoulos, E.; Gonos, I.F.; Mladenov, V.; Chobanov, V. Power system studies in the clean energy era: From capacity to flexibility adequacy through research and innovation. In Proceedings of the 21st International Symposium on High Voltage Engineering (ISH 2019), Budapest, Hungary, 26–30 August 2019. [CrossRef]
22. Mladenov, V.; Chobanov, V.; Zafeiropoulos, E.; Vita, V. Flexibility assessment studies worldwide-bridging with the adequacy needs. In Proceedings of the 11th Electrical Engineering Faculty Conference (BulEF), Varna, Bulgaria, 11–14 September 2019. [CrossRef]
23. Nosair, H.; Bouffard, F. Flexibility Envelopes for Power System Operational Planning. *IEEE Trans. Sustain. Energy* **2015**, *6*, 800–809. [CrossRef]
24. Lannoye, E.; Flynn, D.; O'Malley, M. Transmission, variable generation, and power system flexibility. *IEEE Trans. Power Syst.* **2015**, *30*, 57–66. [CrossRef]
25. Yang, J.; Zhang, L.; Han, X.; Wang, M. Evaluation of operational flexibility for power system with energy storage. In Proceedings of the International Conference on Smart Grid and Clean Energy Technologies (ICSGCE), Chengdu, China, 19–22 October 2016. [CrossRef]
26. Bucher, M.A.; Chatzivasileiadis, S.; Andersson, G. Managing Flexibility in Multi-Area Power Systems. *IEEE Trans. Power Syst.* **2016**, *31*, 1218–1226. [CrossRef]
27. Lannoye, E.; Flynn, D.; O'Malley, M. Evaluation of power system flexibility. *IEEE Trans. Power Syst.* **2012**, *27*, 922–931. [CrossRef]
28. Molitor, C.; Monti, A.; Moser, A. *Residential City Districts as Flexibility Resource: Analysis, Simulation and Decentralized Coordination Algorithms*; RWTH Aachen University: Aachen, Germany, 2015.
29. Dall'Anese, E.; Mancarella, P.; Monti, A. Unlocking Flexibility: Integrated Optimization and Control of Multienergy Systems. *IEEE Power Energy Mag.* **2017**, *15*, 43–52. [CrossRef]
30. Wang, Q.; Hodge, B.M. Enhancing power system operational flexibility with flexible ramping products: A review. *IEEE Trans. Ind. Inform.* **2017**, *13*, 1652–1664. [CrossRef]
31. European Commission. Clean Energy for All Europeans: Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2016:0860:FIN (accessed on 15 May 2022).
32. Smart Grid Task Force. Regulatory Recommendations for the Deployment of Flexibility—EG3 REPORT. Available online: https://ec.europa.eu/energy/sites/ener/files/documents/EG3%20Final%20-%20January%202015.pdf (accessed on 15 May 2022).
33. Sigrist, L.; May, K.; Morch, A.; Verboven, P.; Vingerhoets, P.; Rouco, L. On Scalability and Replicability of Smart Grid Projects—A Case Study. *Energies* **2016**, *9*, 195. [CrossRef]
34. Calvo, A.R.; Cossent, R.; Frías, P. Scalability and replicability analysis of large-scale smart grid implementations: Approaches and proposals in Europe. *Renew. Sustain. Energy Rev.* **2018**, *93*, 1–15. [CrossRef]
35. May, K.; Vingerhoets, P.; Sigrist, L. Barriers regarding Scalability and Replicability of Smart Grid Projects. In Proceedings of the 12th International Conference on the European Energy Market (EEM), Lisbon, Portugal, 19–22 May 2015. [CrossRef]
36. Colak, I.; Fulli, G.; Sagiroglu, S.; Yesilbudak, M.; Covrig, C.F. Smart grid projects in Europe: Current status, maturity and future scenarios. *Appl. Energy* **2015**, *152*, 58–70. [CrossRef]
37. Bonnefoy, P.A. Scalability of the Air Transportation System and Development of Multi-Airport Systems: A Worldwide Perspective. Ph.D. Dissertation, Engineering Systems Division, Massachusetts Institute of Technology, Boston, MA, USA, 2008.
38. Menci, S.P.; Herndler, B.; Kupzog, F.; Zweistra, M.; Steegh, R.; Willems, M. Scalability and Replicability Analysis of Grid Management Services in Low Voltage Networks in Local Flexibility Markets: An InterFlex analysis. In Proceedings of the IEEE Madrid PowerTech, Madrid, Spain, 28 June–2 July 2021. [CrossRef]
39. Bridge Horizon 2020. Task Force Replicability & Scalability Analysis, Draft Methodological Guidelines to Perform a Scalability and Replicability Analysis. Available online: https://www.h2020-bridge.eu/download/ (accessed on 13 May 2022).
40. Centre for Coordination of Agricultural Research and Development for Southern Africa (CCARDESA). Scaling Up and Scalability: Concepts, Frameworks and Assessment—Research Report Commissioned by Vuna. Available online: https://www.ccardesa.org/knowledge-products/scaling-and-scalability-concepts-frameworks-and-assessment (accessed on 13 May 2022).

41. Rocabert, J.; Capo-Misut, R.; Munoz-Aguilar, R.S.; Candela, J.I.; Rodriguez, P. Control of Energy Storage System Integrating Electrochemical Batteries and SC for Grid-connected Applications. *IEEE Trans. Ind. Appl.* **2018**, *55*, 1853–1862. [CrossRef]
42. Meng, L.; Zafar, J.; Khadem, S.K.; Collinson, A.; Murchie, K.C.; Coffele, F.; Burt, G.M. Fast Frequency Response From Energy Storage Systems—A Review of Grid Standards, Projects and Technical Issues. *IEEE Trans. Smart Grid* **2020**, *11*, 1566–1581. [CrossRef]
43. European Parliament. *Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on Common Rules for the Internal Market for Electricity and Amending Directive 2012/27/EU*; OJ L 158, 14.6.2019; European Parliament: Strasbourg, France, 2019.
44. Khoo, W.C.; The, J.; Lai, C.M. Demand Response and Dynamic Line Ratings for Optimum Power Network Reliability and Ageing. *IEEE Access* **2020**, *8*, 175319–175328. [CrossRef]
45. Numan, M.; Khan, A.Z.; Asif, M.; Majeed, M.S.; Imran, K. Exploiting the Inherent Flexibility in Transmission Network for Optimal Scheduling, Wind Power Utilization, and Network Congestion Management. *IEEE Access* **2021**, *9*, 88746–88758. [CrossRef]