Improving Scalability and Replicability of Smart Grid Projects

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ABSTRACT

Today most smart grid projects are still in the R&D or the demonstration phases on small scale. The condition that these projects are implemented in the future on a large scale is that they have a suitable degree of scalability and replicability to avoid that project demonstrators remain local experimental exercises. The current paper tackles the question of what makes a particular smart grid project scalable and replicable. Factors that affect the scalability and replicability of smart grid projects were derived in a first step through the analysis of complex systems and smart grid projects. These factors can be categorized into technical, economic and regulatory & stakeholder-related factors. In a second step, a short case study is performed on on-going European and national smart grid projects in order to validate the factors, which allows then quantifying the status quo of the analyzed projects with respect to the scalability and replicability. This paper provides a feedback on to what extent they take into account these factors and on whether their results and solutions are actually able to be scaled-up and replicated.

Results are based on the research done within the European FP7 Coordination and Support project Grid+.

INTRODUCTION

The emerging smart Grid concept appears to be a significant change of paradigm for one of the most conservative sectors in modern society, the Power Industry. Therefore deployment of smart grids does not merely mean introduction of new ICT technologies, but also includes radical changes of the business models, working methods and approaches. The problem is that despite a number of ongoing and completed smart grid R&D and demonstration projects there are still very few successful full scale industrial implementations across Europe. The full roll-out of the tested solutions requires a suitable degree of scalability and replicability to avoid that project demonstrators remain local experimental exercises unable to transfer their knowledge and solutions to real-life industrial scale applications. This is why scalability and replicability have become equally important factors for projects within the smart grid domain.

The paper addresses the scalability and replicability of smart grid projects. Scalability can be defined as the ability of a system to change its scale in order to meet growing volumes of demand [1]. In contrast, replicability denotes the property of a system that allows it to be duplicated at another location or time. Scalability and replicability are the preliminary requisite to perform scaling-up and replication successfully.

IDENTIFICATION OF SCALABILITY AND REPLICABILITY FACTORS

As a first step, the factors that affect the scalability and replicability of smart grid projects are identified by means of a review of the state of the art of complex systems and smart grid projects [2]. Based on this analysis factors emerged that influence the scalability and replicability of smart grid Projects. These factors can be divided into three main areas of factors: technical, economic and regulatory & stakeholder related area.

- Technical factors determine whether the solution developed in a particular project is inherently scalable and/or replicable.
- Economic factors reflect whether it is economically viable to pursue scaling up or replication. This crucial step – validating whether investment analysis (e.g., internal rate of return, net present value, etc.) and business models hold at a larger scale or in a different setting than the original case – is often neglected and constitutes a major barrier in gaining a critical mass.
- Factors related to acceptance and involvement of end users, regulators, authorities, and stakeholders, reflect the extent to which the current environment is ready to embrace a scaled-up version of a project or whether a new environment is suitable for receiving a project.

Table 1 provides an overview on the identified factors listed within the 3 areas of factors. Paying attention to these factors will not automatically guarantee the scalability or replicability, but a failure to do so will rule out many chances to it.

Areas	Scalability Factors	Replicability Factors
Technical	Modularity	Standardization
	Technology evolution	Interoperability
	Interface design	Network configuration
	Software tools integration	
	Existing infrastructure	
Economic	Economy of scale	Macro-economic factors
	Profitability	Market design
		Business model
Regulatory & stakeholder-related	Regulation	Regulation
	Consent	Acceptance

Table 1: Scalability and Replicability factors with their corresponding area

Scalability Factors

Technical factors

The technical factors cover the extent to which the solution itself is inherently scalable, the compatibility with the technical environment it will be implemented in, and the interaction between the components of the solution and the outside world.

Modularity is the basic precondition for scaling-up. It refers to whether a solution can be divided into interdependent functional units. A monolithic solution will seldom be appropriate for implementation at a larger scale. Clearly defined (and separated) constituent parts, on the other hand, allow for the flexibility needed to transfer the setup to a larger scale. For example, substation automation projects usually design in order to easily add new utility system functions for monitoring, control and protection applications. It should be easy to add or substitute for instance protection devices carrying out the protection applications [3].

In the light of the long life of many of the different smart grid components, **expected technology evolution** is crucial. Previously considered unviable solutions, may turn previously impossible exploits into feasible ones through the evolving state-of-the-art in underlying technology (computing power and cost, telecom speed and capacity, advanced materials,...). For instance, progress in communication infrastructure and particularly, a transition from power line carrier to fiber optics could increase the available bandwidth. This in turn allows increasing the number of controllable elements (both loads and generators) within an area.

Interface design addresses the number of interactions among components. Limitations arise when the number of interactions increase more than linearly with the size, the scaled-up solution may at the desired scale exhaust the existing physical capacity of the given interface or/and become overly complex and redundant. For instance, within the GridWise Olympic Peninsula Project local and centralized demand-side control designs have been compared. It has been concluded that avoiding centralized top-down control flows reduces complexity by avoiding the need to centrally control individual loads via intermediate entities Further, without centralized control, new participants do not add additional cost to the system, leaving the growth of the smart grid unbounded.

Apart from the complexity of the solution itself, the **software tools** needed to deploy it (e.g.: simulation models; databases) need to be able to cope with the increased size.

Project can encounter limitation on the maximum scale to their proposed solution from the **existing infrastructure** in which they operate. The limitations can range from mild constraints to insurmountable barriers. The rating of the substation transformer of a photovoltaic plant needs have to be taken into account when adding new photovoltaic arrays such that the plant output grows beyond the nominal rating of the substation transformer. Alternatively, the number of parallel substation transformer needs to be increased.

Economic factors

An important factor question regarding the upscaling is the economically viability of the solution on the intended scale. The development of the marginal cost curve and revenue functions when the scale is increased is key in this matter. Where increase, decline or stepwise development of the marginal cost curve indicated possible **economics of scale**. Do note that this analysis assumes the original project does not necessarily need to be economically viable and the analysis only looks at the effect of increasing its size.

Additionally the **profitability** of the project must be positive on a larger scale any other situation will lead to unattractive financial situations.

Regulatory and stakeholder related factors

This area of factors analyse the willingness of the different stakeholders (e.g. regulators, policy makers and end user) to enlarged project. **Regulation** can facilitate or may limit curtain smart grid solutions. Assessing this factor may involve considerable work, as regulatory frameworks tends to be complex and doesn't have steady-state character.

Finally, an assessment is necessary of whether **consent** can be gained from stakeholders such as regulators, end users, authorities, policy makers, etc. Project might have overcome the regulatory and legal barriers (e.g., by adapting the regulatory framework), it is very important that other stakeholders accept the proposed solution. As example the LINEAR projects field tests aim at quantifying the amount of flexibility that could be exploited from the customers . An important barrier for the field tests is that the field test participants have to buy the smart appliances installed in their house [5].

Replicability factors

Technical factors

An important cornerstone on replication is that a given solution can interwork with other systems. The use of published (open) **standards** by the solution is key. Concerning the grid operator this avoids tailor made solutions that may only function in a given setting. Iberdrola's STAR project, clear technical specifications for the smart meter communication have been established and eventually a common standard for the OFDM type 1 communication technology has been developed (the PRIME specification) [6].
Given the many standards, standardization in itself will not be sufficient, the proposed solutions by the projects have to be **interoperable** with a given system/setting (that operates according to a different standard).
The external conditions imposed by the host **network configuration** need to be conducive to integrating the solution. This refers to elements, which are given and cannot be changed within the scope of a project (e.g., climate conditions such as temperature, wind, precipitation levels, terrain conditions, local generation mix, demographics, consumption mix and profiles, etc.).

Economic factors

A first step in the consideration of the economic feasibility of a replication of a project is an analysis of **macro-economic factors**. Which addresses whether the solution proposed is (still) profitable within different economic boundary conditions. This is mainly done through limited scenario analysis on a few selected target countries. Within these scenarios carbon cost, inflation, the interest rate, etc. is taken into account.
Secondly, the success of the replication highly depends on the new **market design**. The new market design may apply different tariff structure (fixed/variable, time of use, etc., additional constraints as taxes or subsidy schemes that make the application of the project difficult or even impossible. For instance note that network tariffs and feed-in tariffs considerably vary across Europe [7][8].
Finally, the viability of the project/solution under a different **business model** needs to be checked. It is highly likely that the original project's business model will not hold – at least not without modification – in a new setting. For example, the deployment of distributed generation could help reducing distribution grid losses. However, not all European countries have regulations that give incentives for loss reduction and therefore, a solution which is viable due to loss reduction might not be an attractive solution in another host area [9].

Acceptance and involvement

An obvious prerequisite to replicate a project in a hosting area is to be in line with the local **regulation**. Similar to scalability, the regulatory analysis is not a straightforward assignment. The assignment is for example hampered by a lack of single European regulatory framework.
Finally, as well stated regarding the scalability potential the **acceptance** of the solution by key stakeholders is required. This may mean a more fundamental consent than the one required for scalability. After all, stakeholders have to be willing to embrace potentially something entirely new, which may possibly can count on more reluctance.

METHODOLOGY FOR ASSESSING THE FACTORS

This section describes the methodology for the assessment of the scalability and replicability factors. The used methodology consists in collecting data of smart grid projects to assess and evaluate the identified scalability and replicability factors, this through the use of questionnaires. The evaluation of the factors allows then quantifying the status quo of on-going and new projects with respect to the scalability and replicability, i.e., they provide a feedback on to what extent projects take into account these factors and on whether the projects' results and solutions are actually able to be scaled-up and replicated. The developed methodology consecutively evaluates the technical, economic and regulatory & stakeholder related areas of factors, the overall applied methodology is shown in Figure 1.

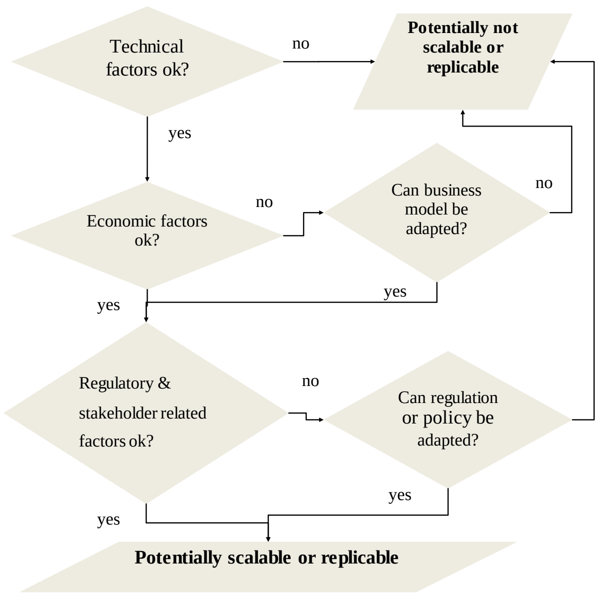

Figure 1:Overview of the methodology for assessing the factors

The stepwise analysis of the potential of the projects can indicate a certain order and a certain priority of importance given to factors. For instance, if a project is not technically scalable, it could be deemed as potentially not scalable although it is regulatorily scalable. Each factor could thus to be weighted and a weighted sum for each of the three areas (technical, economic and regulatory & stakeholder-related) as well as a total weighted sum (over all three groups) is computed. which could be translated into weights associated to each factor and/or area. Consequently a different weight, and ditto importance may be given to factors and areas of factors. Considering the lack of information, the factors are equally weighted.

Finally, a minimum score should be established for each factor in order to avoid incongruence within a group (e.g., a very modular project with very poor interface design should not be directly deemed scalable although the mean score is sufficient). The required minimum score has been set to 50% of the maximum score of a specific factor. The most positive answer among the predefined answers scores 1 (maximum score), whereas the most negative answer scores 0. The remaining questions follow a strictly linear law (questions with five, four or three predefined answers are available). The 50% criterion implies that a factor is always considered or that it is at least not neglected.

The data collection was carried out by means of questionnaires [10]. For each identified factor a specific question with predefined answers has been formulated. Whereas scalability and replicability factors already describe the requirements for scalability and replicability, the answers to the questionnaires show the achievements and barriers of the participating project. The predefined answers allow translating the actual answer into a numerical value and consequently, the corresponding factor receives a numerical value.

In addition to the factor-related questions, additional questions on the project, its nature and on the importance of a specific question have been included. The latter provides a feedback on which questions and congruently, which factors the participating project deems important.

RESULTS

Scalability and replicability potential at aggregated level			
Area	Average score on scalability	Average score on replicability	Min. Score
Technical	0,54	0,57	0,5
Economic	0,55	0,52	0,5
Regulatory & stakeholder-related	0,55	0,72	0,5
Sum	1,64	1,80	1,50

Table 2: Aggregated results scalability and replicability

Table 2 shows the scalability and replicability potential on the three scalability and replicability areas on aggregated level. The results indicate that all three scalability areas obtained nearly the same score whereas the regulatory & stakeholder-related area of replicability scores higher than the other replicability areas.

The global replicability potential is then also higher (1.80) than the global scalability potential (1.64) and both replicability and scalability potentials are higher than the minimum score.

A more detailed picture of the aggregated results can be obtained by analyzing the results on the factor level. Figure 2 shows and compares the average scores of the scalability and replicability factors and their importance as seen by the participants. The scalability factors technology evolution, economies of scale, and existing infrastructure, and the replicability factors standardization and market design obtained lowest scores.

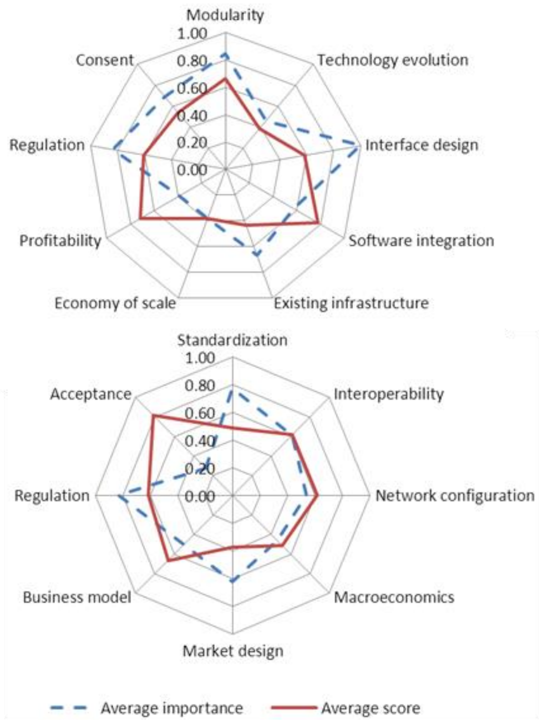

Figure 2: Average Score and Importance on factor level

The comparison shown in Figure 2 between the average scores of scalability and replicability factors and their importance as seen by the participants is of particular interest too, since diverging results point to possible barriers and limitations. As long as a factor scores are high, no problem arises. When the factor score is low and the importance is low too, the impact is minimum in case of importance-based weights (the score reflects the importance). It is interesting to point out that the scalability factor consent has an average to high importance and an average score, whereas the replicability factor acceptance has a high score and a low importance. Again, stakeholder involvement has been rather addressed for replication or it seems less problematic for replicability. However, interface design, existing infrastructure, regulation, standardization, and market design have a high importance but score comparatively low. Some barriers might arise there.

CONCLUSIONS

This paper has studied the scalability and replicability of smart grid projects. For this purpose, factors have been sought and identified that influence and condition a project's scalability and replicability. These factors are of technical, economic and regulatory nature and they have been chosen based on an in-depth literature review. Briefly, technical factors determine whether the solution developed in a particular project is inherently scalable and/or replicable; economic factors reflect whether it is economically viable to pursue scaling up or replication. Factors related to regulation and social acceptance reflect the extent to which the current environment is ready to embrace a scaled-up version of a project or whether a new environment is suitable for receiving a project.

The proposed scalability and replicability factors have been applied to a case study performed on on-going European and national smart grid projects in order to evaluate and validate these factors. It seems in general that so far technical, economic, and regulatory and stakeholder-related issues were given the same priority for scalability, whereas regulatory and stakeholder-related issues dominated in replicability. Economic replicability issues seem to have attracted less attention. In fact, the scalability factors technology evolution, economies of scale, and existing infrastructure, and the replicability factors standardization and market design obtained lowest scores. Further, the factors interface design, existing infrastructure, regulation, standardization, and market design have a high importance in comparison to the factor score, bearing some potential risks for scalability and replicability. Finally, barriers mainly arise from those factors of which the detected limitations are rather difficult to overcome since overcoming these limitations mostly depends on actors outside the project with limited influence of the project. Other factors might or might not pose an actual barrier depending on the project. In particular, limitations for scalability and replicability might arise from the absence of standards, the physical limits of the existing infrastructure, the absence of cost-benefit analyses and the neglect of varying macroeconomic factors, stakeholder involvement and from the dependency of projects on regional or national regulatory frameworks and market designs.

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