D8.2 THE SCALABILITY AND REPLICABILITY ANALYSIS OF LOCAL ENERGY COMMUNITY SOLUTIONS

VERSION 1.0

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TABLE OF CONTENT

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Co-creating with partners that help to understand the needs of relevant stakeholders, we team up with intermediaries to provide an innovation eco-system supporting consortia for research, innovation, technical development, piloting and demonstration activities. These co-operations pave the way towards implementation in real-life environments and market introduction.

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1 INTRODUCTION

1.1 Aim of the report

The aim of this deliverable is to assess the scalability and replicability potential of proposed Local Energy Community (LEC) solutions on the national level and demonstrate the potential for future LECs. Specifically, this report answers the following questions:

- What are the decisive factors for assessing the scalability and replicability potential of LEC solutions?
- How can scalability and replicability potential be assessed qualitatively and quantitatively?
- What are the scalability and replicability potential for the LEC solutions developed and demonstrated in CLUE?

The assessment has been carried out according to the BRIDGE guideline for scalability and replicability analysis. Demo managers were asked to complete a questionnaire reflecting their perceptions of both technical and non-technical aspects related to the scalability and replicability of the LEC solutions. The answers were coded and calculated to indexes. In this way, the results from all demo sites were quantified, visualized, and compared.

1.2 Structure of the report

This report firstly clarifies the purpose of study which is to assess the potential of scalability and replicability of LEC solutions. Section 2 clarifies the concept of "scalability and replicability analysis", and describes the CLUE use cases and demo sites which will be evaluated in terms of the scalability and replicability potential. Section 3 presents the methodologies that the evaluation employed including factor identification, questionnaire analysis and workshop method. Section 4 shows the qualitative and quantitative results based on the data analysis for each demo for four countries- Sweden, Austria, Germany, and Scotland. Section 5 analyzes the barriers for future upscaling and replicating of current LEC solutions. And finally, Section 6 gives the conclusions.

2 DEFINITION OF SCALABILITY & REPLICABILITY AND DEMO SITES

According to the literature studies, the scalability may be defined as the ability of a system, network or process to change its scale, such as size, scope or range, to meet different volumes of demand. The replicability refers to the ability to be duplicated in another location or time [1] [2] . In this report, "scalability" only denotes the layer of increasing in the scale and excludes the layer of decreasing the scale, considering that the LEC solutions are expected to grow in the number of users and the scale of hardware and software systems. Consequently, the scalability and replicability analysis (SRA) of a LEC solution aims to determine the capability that a solution could be implemented at a larger scale (size, scope or range), at a different time and location. A schematic description of SRA is presented in Figure 1.

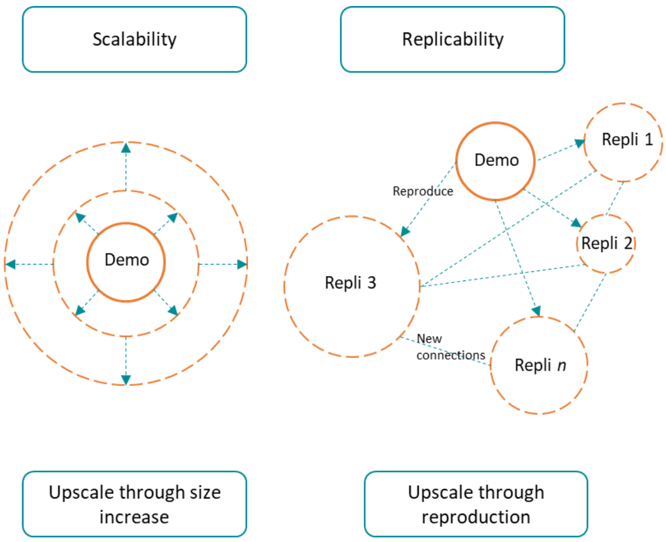


Figure 1. The schematic description of scalability and replicability analysis for LEC solutions.

The 8 CLUE demo sites and their use cases are shown in Table 1. The SRA have been carried out for 7 demo sites, while demo site Suedburgenland (one of the Austrian demo sites) was skipped due to the delay of implementation.

Table 1. The demo sites with their use cases [3].

Parent use cases	Country	Use cases	Demo sites
1. Energy trading 2. Control-based demand response 3. Customer-based demand response 4. Incentive-based demand response 5. Capacity sharing 6. Emergency supply 7. Network security	Sweden	1. Controlled E-mobility charging 2. Flexibility on city building site 3. Flexibility in a facility with heat pumps & district heating 4. Increasing utilization with local balancing	Malmö: 1. Test of flexibility using smart charging and V2G. Car park Anna and Hyllie. 2. Test of user flexibility on active city building site. Construction Site Kosterbåten.

8. Energy account/community currency			3. Test of flexibility using heat pumps in combination with district heating. The building complex "Triangeln". 4. Stationary battery in a residential building. MKB Residential building.
	Austria	1. Local self-optimization with control-based DR 2. Grid support and energy trading with control-based DR 3. Charging payment with community currency 4. Community currency payment at 3rd parties	1. Suedburgenland 2. Almenland, municipality Gasen
	Germany	1. Thermal energy trading	Shamrockpark
	Scotland	1. Sharing of community capacity 2. Customer-based demand response 3. Energy trading	Levenmouth

3 THE BRIDGE APPROACH FOR SCALABILITY AND REPLICABILITY ANALYSIS

To date, there is still no consistent and tightly defined approach to SRA performed for LEC projects. Several H2020 projects have employed a similar approach to conduct SRA, such as REUSEHEAT, WiseGRID, InterFLEX, GrowSmarter, Integrid, and so on (Table 2). Based on this, the Reproducibility and Scalability Working Group under the BRIDGE initiative has recently provided a set of generic guidelines for SRA [4] [5]. It aims to develop a common framework for implementing SRA and to provide ideas on how to define the scope and implementation of a toolbox/repository of past experience, best practices, and necessary data. The CLUE SRA methodology in this report follows its guidelines and recommendations.

Table 2. Several projects have employed BRIDGE guideline for SRA.

Projects	Deliverables
REUSEHEAT (H2020)	"D2.9 Scalability, replicability and modularity", 2020. [6]
WiseGRID (H2020)	"D18.1 Scaling up and Replication Roadmap", 2020. [7]
InterFLEX (H2020)	"D3.8 Scalability and replicability analysis (SRA) for all use cases", 2019. [8]
GrowSmarter (H2020)	"D7.4 Road to Replication - Guiding Cities on Smart Urban Development", 2019. [9]
Integrid (H2020)	"WP8 Replicability, Scalability and Exploitation", 2018. [10]

The SRA structure derived from the BRIDGE initiative is an approach that projects can follow to ensure that they execute the SRA of their projects in a high-quality manner, i.e. fulfil the quality standards that a good SRA needs to meet. The methodology is flexible to take into account the specificities of different projects while incorporate common criteria and procedures in the analysis. This makes the SRA results of different projects comparable.

Four steps were taken to conduct SRA in this report: identifying factors affecting scalability and replicability (Section 3.1); establishing questions under each factor (Section 3.2); sending questionnaires to collect data and analyzing the data (Section 3.3); and drawing conclusions (Section 4).

3.1 Identification of scalability and replicability factors

The scalability and replicability potential of a solution depends on project-specific technical factors and non-technical factors in economic, regulatory, social, and environmental aspects.

More specifically, technical factors evaluate whether the LEC technical solutions for their respective demos and tools developed in WP3 are scalable or replicable. Focusing on these factors will not automatically guarantee scalability or replicability, but not doing so will preclude many relevant opportunities to scale up or replicate the LEC solutions. Economic factors evaluate if the LEC solutions are economically viable to be scaled up or replicated. The crucial factors are if the LEC solutions are cost effective (profitability), if the business models are sustainable, how mature the market is or if the market size would grow, and if there are other external economic constraints. Regulatory factor evaluates the extent to which the current regulatory environment is ready to embrace a scaled-up or replicated version of a LEC solution. Social factor here denotes the stakeholders' acceptance, which is the extent to which the stakeholders are ready to embrace a scaled-up or replicated version of a LEC solution. The stakeholders involved in LEC are policymakers, grid operators, energy providers, end-users, investors, and so on. Finally, environmental factor evaluates if the developed LEC solutions consider environmental impact for future upscaling and replication.

The assumption, which was validated through stakeholder interview, is that there is no single factor that makes the scalability or replicability of LEC feasible or infeasible, but rather the result is a combination of a set of factors.

Under each category, a set of factors were developed based on BRIDGE approach (Table 3) [5] [7] [6].

Table 3. The developed factors for scalability and replicability analysis.

Category	Factor for scalability	Factor for replicability
Technical	Modularity	Standardization
	Software integration	Adaptation
	Hardware integration	Infrastructure
	Easiness to use/ user experience	Easiness to use/ user experience
	Technology evolution	Technology evolution
	External constraints	External constraints
Economic	Profitability	Profitability
	Business model	Business model
	Market	Market
	Constraints	Constraints
Regulatory	Regulatory issues	Regulatory issues
Social	Stakeholders' acceptance	Stakeholders' acceptance
Environmental	Environmental impact	Environmental impact

In this study, thirteen factors are defined for the evaluation. Most of them are same for both scalability and replicability analysis except the first three technical factors, i.e. "standardization" "adaptation" and "infrastructure", which are unique for evaluating replicability potential.

3.1.1 Technical factors

The technical factors are explained below.

- Modularity: This factor examines how well the LEC solution is modularized and how easy it is to add new components in upscaling. The new components could be either hardware (e.g. more energy assets like charging stations, batteries, heat pumps, grids, etc.) or software modules (e.g. new control algorithms, simulation models, databases, etc.).
- Software integration: This factor examines if the software solution can accommodate larger information volume and higher complexity during upscaling, and how easy it is to integrate new functionalities.
- Hardware integration: This factor identifies if the LEC solution can permit the integration of more hardware components when upscaling, and how easy it is.
- Easiness to use/ user experience: The factor indicates to which degree the user interface has been designed to meet the needs for upscaling or replication e.g. considering the growing number of users and the increasing complexity in functionalities.
- Technology evolution: This factor determines if and to what degree the upscaling or replication of the LEC solution can adapt to the technological advances. The technology evolution refers to the improvements and developments in the technology over time and the potential changes that may impact a LEC solution.
- External constraints: This factor refers to the external conditions which are special in the demo site and could potentially affect the upscaling or replication e.g. geography, climate conditions, terrain conditions, local generation mix, consumption mix and profiles, grid configuration, etc.

The three unique technical subfactors of replicability are explained below.

- Standardization: This factor examines whether and to what degree the LEC solution is standardized and can be implemented by e.g. different implementers, e.g. developers, service providers, customers, etc.
- Adaptation: This factor examines whether and to what degree the LEC solution can adapt to new system conditions. This factor also considers interchangeability i.e. the ability to exchange components whilst retaining the desired performance.
- Infrastructure: This factor examines if the demo infrastructure has affected the current LEC solution and to which degree it may affect impacts the replication in other conditions.

3.1.2 Non-technical factors

The non-technical factors of scalability are explained below.

- Profitability: This factor examines if and to what degree there is a positive return on the invested capital when the LEC solution is scaled up or replicated.
- Business model: This factor examines if and to what degree the business model of the solution could be valid during the upscaling or replication of LEC solutions.
- Market: This factor examines if the market is ready for upscaling or replication, and how the LEC solution can adapt to different market conditions in terms of e.g. demand for the products and services, rules for pricing and financial settlement, etc.
- Constraints: This factor examines other economic constraint that may affect the upscaling or replication of the LEC solution, such as a lack of financial and/or human capital.
- Regulatory issues: This factor examines if there are any regulatory barriers and policy changes that may affect the upscaling or replication of a LEC solution.
- Stakeholders' acceptance: This factor examines if the involved stakeholders accept and support the scheme, and if the LEC solution is compatible with the culture and norms of the stakeholders. It also examines to what degree the stakeholder composition and behaviour change may affect the upscaling or replication.
- Environmental impact: This factor examines the potential environmental impact of LEC solution in the upscaling or replication process.

3.2 Establishment of questions

Corresponding to the objective of the report in Section 1.1, there are two purposes for the questionnaires:

- Exploring if and to what degree the LEC solutions could be scaled up and replicated; and
- Exploring how to facilitate upscaling and replication of the LEC solutions.

After reviewing the questionnaires conducted by other projects within the BRIDGE framework and iterative discussions within this task group, two questionnaires were established aiming for the evaluation of scalability potential and replicability potential, respectively. Each questionnaire consists of a number of questions for both technical and non-technical factors, (Table 4). Each factor is started with a few

Likert survey questions and finished with a free-text question which summarizes the theme of the factor and collects comments from respondents. The respondents are the manager of the demo sites. The answers are based on joint discussions and agreements with other involved stakeholders within the demo site, such as technical developers, economic experts, legal and regulatory experts, DSOs, involved end-users, and so on. Finally, each factor was ranked by the respondents in order to determine the importance. All the questions measure the current development levels of the demonstrated LECs solutions, and their future potential for upscaling and replication.

Table 4. The SRA factors and numbers of questions.

Category	Scalability	Nr. of questions	Replicability	Nr. of questions
Technical	Modularity	4	Standardization	4
	Software integration	3	Adaptation	3
	Hardware integration	3	Infrastructure	4
	Easiness to use/ user experience	3	Easiness to use/ user experience	3
	Technology evolution	4	Technology evolution	3
	External constraints	3	External constraints	3
Economic	Profitability	5	Profitability	3
	Business model	4	Business model	4
	Market	4	Market	2
	Constraints	2	Constraints	2
Regulatory	Regulatory issues	5	Regulatory issues	3
Social	Stakeholders' acceptance	7	Stakeholders' acceptance	4
Environmental	Environmental impact	3	Environmental impact	2

An overview of the questions can be found in Table 5 and Table 6.

Table 5. Factors and questions for evaluating scalability potential.

Technical factors	Questions under each technical factor	Non-technical factors	Questions under each non-technical factor
Modularity	1) Can the solution be divided into independent components/independent functional units?	Profitability	21) Do the economic indicators of the demo show that the current solution is profitable enough to scale up?
	2) Would it be possible to (technically) easily add components to the solution to increase its size?		22) If the size of your solution increases, how does the cost per unit of your solution change (economy of scale)?
	3) Does the growth of your solution affect the performance of technical components?		23) If the size of your solution increases, how do the profit of your solution change?
	4) How do you divide your solution into independent components/independent functional units?		24) Are the increased profits observable and significant (net profit is greater than the additional cost, and rate of return is acceptable) when the solution is scaled up?
Software integration	5) Is it possible to add more components/functions to the current databases, models & optimization simulation, algorithms, and other calculations?		25) What impacts the profitability most in upscaling of your solution?
	6) How easy is that the design of software permits the integration of more components/functions?	Business model	26) Is there a business model for your solution which is ready to be implemented in the market?
	7) In your solution, what desirable databases, model, and algorithms could be added in order to scale up the solution?		27) Could the business model of your solution be easily scaled up (the business model is sustainable)?
Hardware integration	8) Is it possible to add more hardware components to the current solution?		28) Can you maintain performance, reliability, efficacy and quality of the solution when you increase your production or service delivery?
	9) How easy it is to add more hardware components to the current solution?		29) What impact the business model design most in upscaling of your solution?
	10) In your solution, what desirable hardware components could be added in order to scale up the solution?	Market	30) Is the market maturing enough to integrate the upscaling?
Easiness to use/ user experience	11) Is the current user interface design efficient?		31) How do you estimate the market size potential?
	12) Could the user interface be designed to become compliant with the new number of components (easy to understand, install, and use)?		32) How easy could your solution get financed, when it gets upscaled?
	13) What factors regarding interface design should be considered in order to upscale your solution?		33) What market development will help with the upscaling of the solution?

Technology evolution	14) Do you foresee the developments of relevant technologies in your solution?
	15) Do the technology advances in your solution allow the upscaling?
	16) How do the technology advances in the solution impact the upscaling (considering the technology complexities, system workload, end-user privacy, etc.)?
	17) What technologies/technology dimensions shall be further improved in order to scale up your solution?
External constraints	18) Is the scalability of the solution influenced by the specific location of your demo?
	19) Is the scalability of the solution influenced by technical regulations of electricity and heating, e.g. power grids, voltage levels, heating networks, etc.?
	20) For your solution, what are the potential external constraints?
Rank technical factors: The solution could be easily divided into independent components/independent functional units. (q1-q4) It is easy to add more components/functions to the current databases, models & optimization simulation, algorithms, and other calculations. (q5-q7) It is easy to add more hardware components to the current solution. (q8-q10) The user interface is easy to be understood and used. (q11-q13) The foreseeable development of the relevant technologies in the solution will benefit the upscaling. (q14-q17) The solution is to a low degree limited by the external factors of electricity and heating e.g. power grids, voltage levels, heating networks etc. (q18-q20)	

Constraints	34) Are there any economic constraints with respect to scaling up your solution?
	35) What are the potential economic constraints?
Regulatory issues	36) Do the solution in line with existing national policies and regulations?
	37) Are there any regulatory barriers when scaling up your solution?
	38) What are the potential regulatory barriers in upscaling your solution?
	39) Is additional policy support needed to enhance scalability?
	40) How do you foresee the regulatory environment change with the upscaling process?
Stakeholders' acceptance	41) Has the solution been tested in local setting and assessed by stakeholders?
	42) Are the concerns and suggestions of end-users addressed in adapting the solution?
	43) Is the solution relevant to the perceived needs of the stakeholders?
	44) How has the stakeholders' attitude been for your demo?
	45) How do you foresee the attitude change of the new stakeholders where the solution gets scaled up?
	46) Does the successful scaling up require changes in behavior of the end-users?
	47) For the solution to be successfully scaled up, what behavior do the end-users need to change?
Environmental impact	48) Are the environmental consequences addressed in the design and evaluation of your solution?

		49) Does your solution have a positive impact on environment if it gets scaled up?
		50) How does the upscaling of your solution impact the environment?
	Rank non-technical factors: The economic factors show that the solution is profitable enough to scale up. (q21-q25) The business model of the solution is easy to be scaled up. (q26-q29) There is a big market for upscaling. (q30-q35) The regulatory environment enables the upscaling process. (q36-q40) The stakeholders' attitudes are positive in terms of solutions being scaled up. (q41-q47) The solution has a positive impact on the environment if it gets scaled up. (q48-q50)	

Table 6. Factors and questions for evaluating replicability potential.

Technical factors	Questions under each technical factor	Non-technical factors	Questions under each non-technical factor
Standardization	1) Is the solution standard compliant to be replicated?	Profitability	21) Do the economic indicators of the demo show that the solution is viable enough to be replicated?
	2) Does your solution allow co-develop? E.g. provide with a description of the code-bases for the potential users/implementers; provide with a document on how to run, develop, build, and receive posts on bugs/issues?		22) Are the increased benefits observable and significant (net benefit is greater than the additional cost, and rate of return is acceptable) when the solution gets replicated?
	3) Does the replication of your solution affect the performance of technical components?		23) What impacts the profitability most in replicating the solution?
	4) How do you divide the solution into standard functional units?	Business model	24) Is there a business model for your solution which is ready to be implemented in other market?
Adaptation	5) Does the solution have the ability to adapt to a new environment, e.g. the ability to share data via software and hardware, or open source/protocol?		25) Could the business model of your solution be easily deployed in other environment without additional investment (time/money) (the business model is sustainable)?

	6) To what degree is the solution technically complex to be replicated?		26) Can you maintain performance, reliability, efficacy and quality of the solution when you increase your production or service delivery?
	7) How can your solution better adapt to or interact with new environments?		27) What impact the business model design most in replicating the solution?
Infra-structure	8) Does the replication of the solution require additional infra-structure support, e.g. ICT architecture?	Market	28) Do you think that you could make the solution easily (economically) compliant with a defined different set of standards?
	9) To what degree the grid characteristics (e.g. grid code compliance, voltage levels, operation conditions, etc.) impact the result of replication?		29) How can the replication of the solution better adapt to the market?
	10) Is there capacity building and/or other resource strengthening plans in place to support the replication?	Constraints	30) Are there any economic constraints with respect to replication that could affect the solution?
	11) For your solution, what are other infrastructure factors should be considered in replication?		31) What are the potential economic constraints?
Easiness to use/ user experience	12) Do the data and method available in order to reproduce user interface	Regulatory issues	32) Are there any regulatory barriers with respect to replicability that could affect the solution?
	13) Could the user interface be re-designed to become compliant with the new number of components (easy to understand, install, and use)?		33) What are the potential regulatory barriers in replicating your solution?
	14) What factors regarding interface design should be considered in order to replicate your solution?		34) How do you foresee the regulatory environment change with the replication process?
Technology evolution	15) Do the technology evolutions allow better data interchange and database migration for your solution?	Stakeholders' acceptance	35) How do you foresee the attitude of new stakeholders where the solution gets replicated to another location?
	16) How do the technology advances in the solution impact the replication?		36) Has the solution been tested in another local setting and assessed by the stakeholders?
	17) What technologies/technology dimensions shall be further improved in order to replicate your solution?		37) Does the successful replication require changes in behavior of the end-users?
External constrains	18) Is the replication of the solution influenced by the specific location of your demo?		38) For the solution to be successfully replicated in another location/environment, what behavior do the end-users need to change?

	19) Is the replication of the solution influenced by technical regulations of electricity and heating, e.g. power grids, voltage levels, heating networks, etc.?	Environmental impact	39) Does your solution have a positive impact on environment if it gets replicated to another location?
	20) What are the potential external constraints?		40) How does the replication of the solution impact the environment?
Rank technical factors: The solution could be easily divided into standardized and independent components/independent functional units. The solution could adapt to or interact with new networks and environments without requiring tailored interfaces. The solution requires low level of additional infrastructure support. The user interface is designed to be compliant with more numbers of components. The foreseeable development of the relevant technologies in the solution will benefit the replication. The solution is to a low degree limited by the external factors of electricity and heating, e.g. power grids, voltage levels, heating networks etc.		Rank non-technical factors: The economic factors show that the solution is profitable enough to be replicated. The business model of the solution is easy to be replicated. There are big markets for replication. The regulatory environment enables the replication process. The stakeholders' attitudes are positive in terms of solutions being replicated. The solution has a positive impact on the environment if it gets replicated.	

3.3 Evaluation of scalability and replicability potential

The evaluation of scalability/ replicability potential follows the following steps and are applied for each of the seven demo sites (Table 7).

1. Each question measures the scalability and replicability potential from different perspectives (technical, none-technical incl. economic, regulatory, social, and environmental).

2. Each respondent chose one answer to each question, which is coded as one particular score. The answer options were provided as Likert scale with scores, in order to measure the respondents' attitudes and opinions with a greater degree of nuance instead of binary answers. Allocation of the score among answers shows to what degree the specific factor has been considered in the LEC solution and to what degree it may affect the upscaling or replication potential.

3. The "maximum potential score" is the maximum score for each question. The "actual score" is the score corresponding to the respondent's answer. A higher score implies that the specific factor has been better considered and developed in the LEC solution.

4. The "effectiveness" is the actual score divided by the maximum potential score. This ratio measures the degree of contribution to scalability/replicability potential and normalize the scores.

5. The "importance" is the rank that respondents assigned to each factor or question. The higher rank indicates that the respondents consider it more important for the successful upscaling or replication The importance weights are calculated for the purpose of normalization.

Table 7. The coding process for each question.

Question	Maximum potential score	Actual score	Effectiveness	Importance	Importance weights
Question Nr. x	(a)	(b)	(c) = (b) / (a)	(d)	(e) = (d) / maximum score of importance

3.4 Individual meetings and interviews

A workshop was held in April 2022 to explain the objective, scope and methodology of the scalability and replicability analysis. The questionnaires were sent out in May

2022and all responses were collected in June. Data analysis work started since then. Due to the fact that demo sites kept developing and demo managers changed, a series of individual meetings and interviews with demo managers took place in October and November. The purposes were to validate the analysis results, update responses due to continuous development, and collect comments from new demo managers.

4 SCALABILITY AND REPLICABILITY ANALYSIS FOR LOCAL ENERGY COMMUNITIES

This section presents the results for scalability and replicability analysis for the LEC solutions of seven demo sites. The results are analysed based on the questionnaire and individual meetings/interviews. The evaluation results for scalability and replicability are consistent to a large degree. Therefore, the following subsections give results of scalability in details, and highlight some inconsistencies at the end (subsection 4.5).

4.1 Scalability analysis of demo country Sweden

Following the previous analysis of flexibility in Sweden [11], four demo sites were included in this SRA analysis for Swedish cell. They are: test of flexibility using smart charging in public parking garage (in short "smart charging"), test of flexibility using district heating and heat pumps (in short "DH + HP"), test of flexibility using large scale battery (in short "stationary battery"), and test of user flexibility on active city buildout site (in short "city building").

An overview of SRA for Swedish four demo sites is presented in Figure 2. In general, the scores of technical scalability & replicability are higher than scores of non-technical scalability & replicability, which indicates that there is a higher level of maturity and readiness level in terms of technologies, compared to economic, regulatory, social, and environmental perspectives. Moreover, the standard deviation of non-technical scalability is higher than technical scalability, which indicates more fluctuations among scores of non-technical scalability responses. The demo sites "smart charging" and "stationary battery" slightly outperform demo sites "DH+HP" and "city building", in terms of both scalability and replicability.

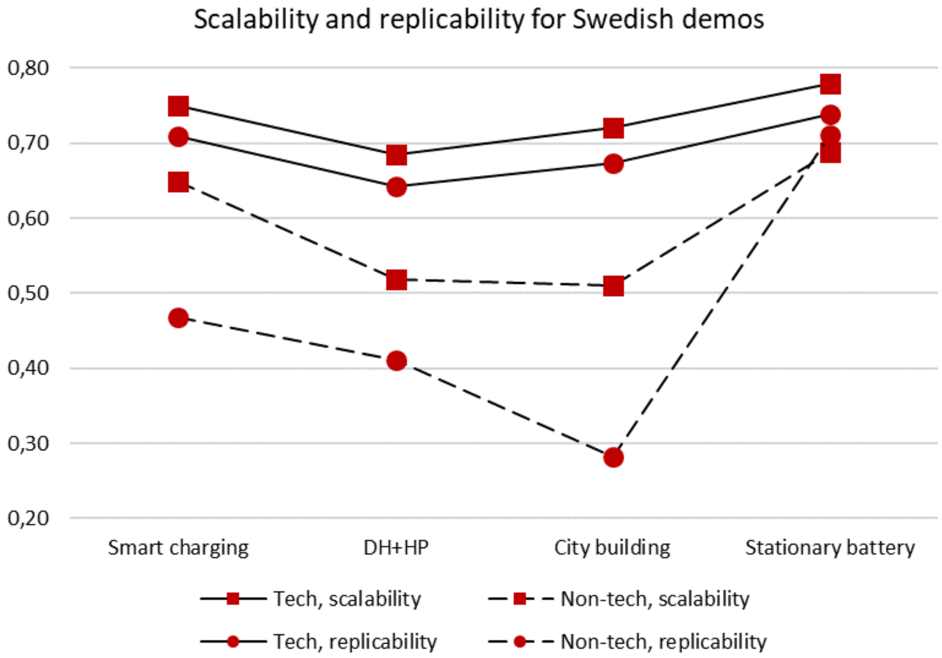


Figure 2. An overview of SRA for Swedish demo sites.

Summarizing the four demo sites in Sweden, the technical factors “modularity” and “software integration” have higher scores than the other four factors in upscaling (Figure 3). A detailed presentation of scores for each question within each factor is shown in Figure 4. For the non-technical factors, the scores of “regulatory issues”, “stakeholders’ acceptance” and “environmental impact” are higher than “profitability”, “market and economic constraints” and “business model” in upscaling (Figure 5 and Figure 6).

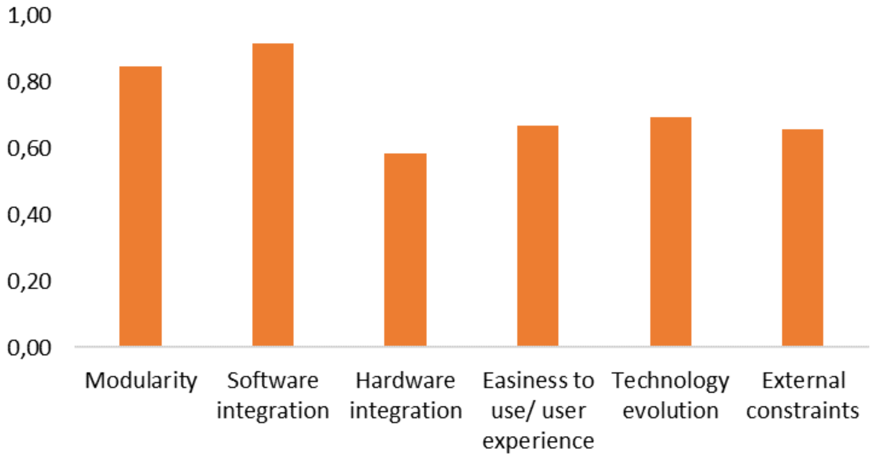


Figure 3. Technical scalability for Swedish demo sites.

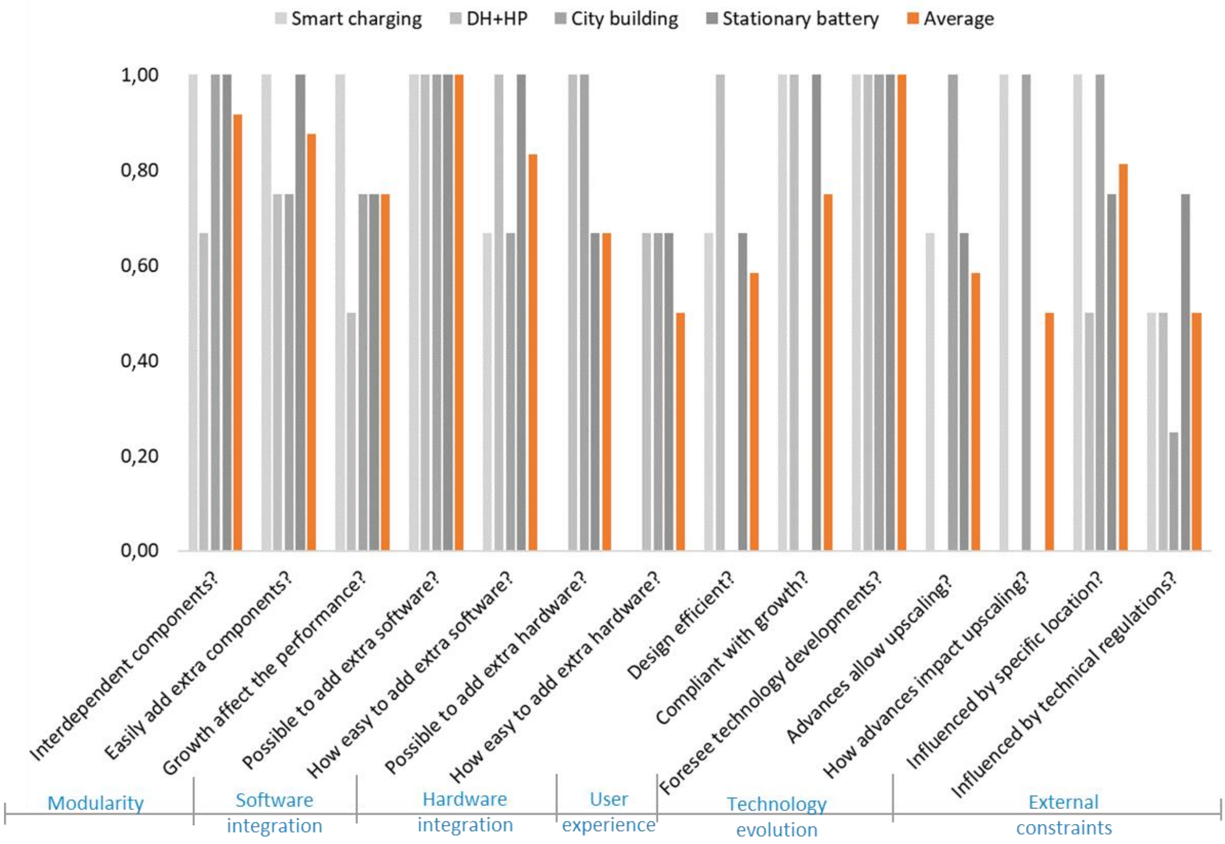


Figure 4. A detailed presentation of technical scalability scores for each question within each factor for Swedish demo sites.

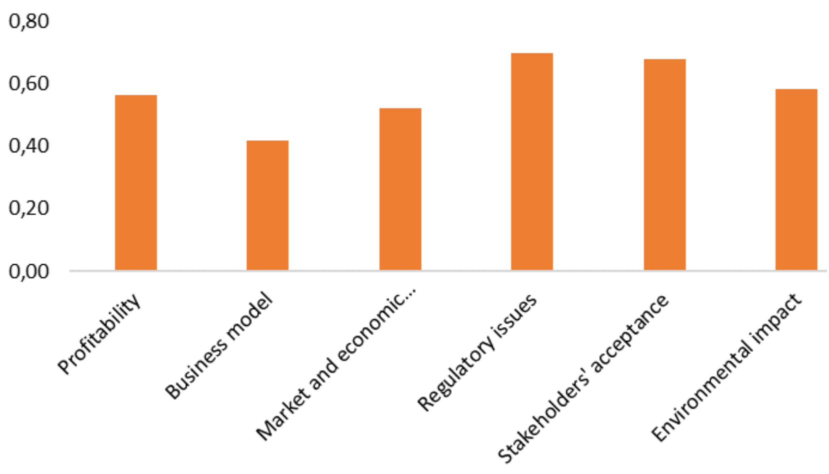


Figure 5. Non-technical scalability for Swedish demo sites.

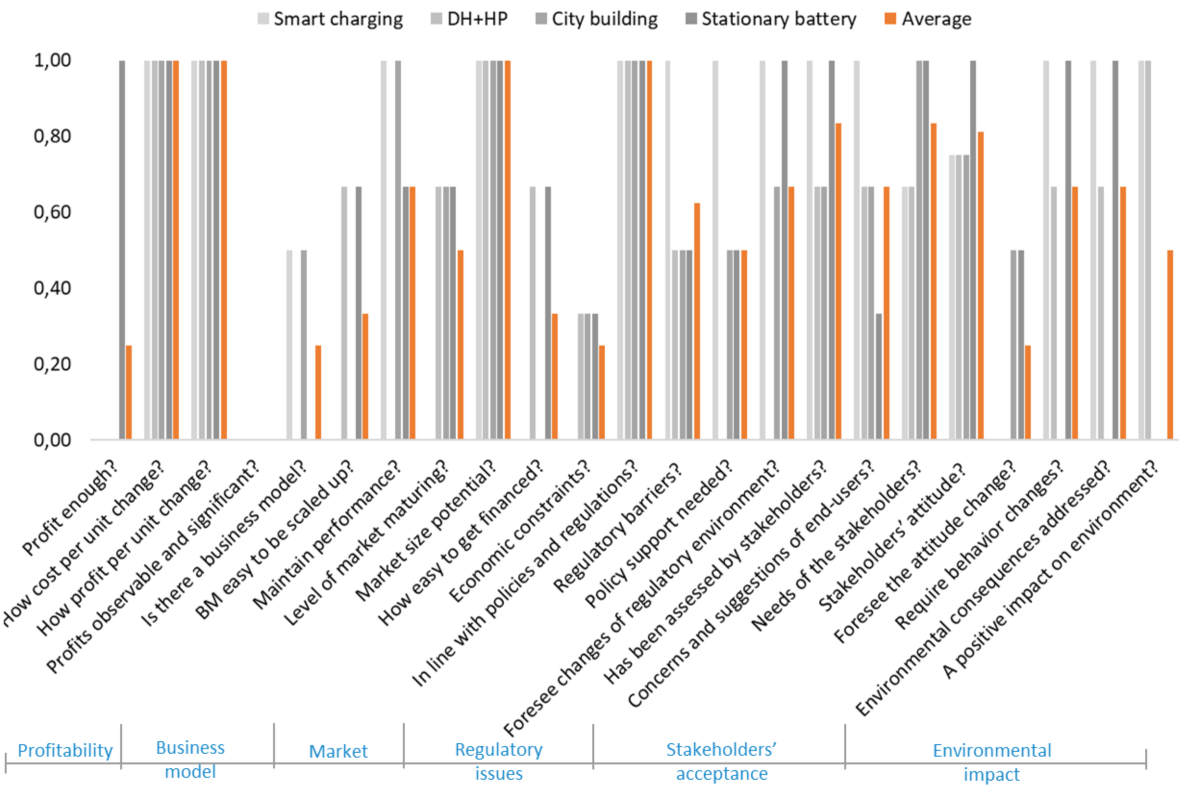


Figure 6. A detailed presentation of non-technical scalability scores for each question within each factor for Swedish demo sites.

Based on the questionnaire analysis of the technical scalability potential, some conclusions are presented in the following paragraphs (Figure 7).

The aim of "smart charging" demo site is to investigate flexibility potential in public parking with smart charging. When the solution is upscaled with hundreds of charging stations, P Malmö can make a significant contribution to providing the needed power flexibility to the local grid using smart charging. Easiness to use/ user experience is ranked as the most important factor for future upscaling, however, the design of current user interface is not efficient enough. There are more features desired for analysis and follow-up. The tests shows that the customers can hardly notice a temporary change in charging power reduction, but they can be quite worried about the consequences of such a reduction if they are told about the tests. An efficient customer interface could be of help in communicating with customers, especially when the tests get scaled up in the future. Modularity is ranked as the second most important factor for upscaling. In this demo site, the solution is evaluated to be easily divided into independent components or functional units, such as physical box, VPP platform, SWITCH marketplace, etc. The division is based on the key functionality of each component as part of the full solution. This makes adding extra components possible to increase its size without negatively affecting the performance. From the tests, it is also concluded that 78 charging points with 22 kW charging gave power reduction of up to 37,5 kW. It is possible to scale up the charging infrastructure in Malmö in order to provide bigger flexibility services to the market. The factor of hardware integration is perceived as less important and has not been considered in the current solution. However, the respondent also highlighted that, for future upscaling, it is possible to integrate stationary battery or other energy assets to the solution.

For the demo site of "DH + HP", the purpose is to evaluate the potential for electricity flexibility within a building with different types of heating solutions. Similar to "smart charging", modularity is ranked as very important for upscaling. In this demo site, the solution consists of independent components, such as heat pumps, radiator system, primary heat system, building management system, cloud IoT system, etc. It is relatively easy to add extra components for a larger system. The factor of software integration is ranked as second most important for upscaling, meanwhile the level of its development is quite high. In this case, data acquisition and exchange are based on the standardized communication protocol Modbus. The data and control rules are managed by ectocloud, which is a cloud-based solution developed by EON. The automation process for data communication and control deployment also complies with the respondent's answer that customer interface is less important. Technical evolutions are perceived important but has not been fully considered in this demo site.

For the demo site of "city building", the purpose is to investigate flexibility potential for various demands by shaving the peaks and improve energy efficiency on an active construction site. In this demo site, the external technical constraints such as power grids, voltage levels, and so on, and the easiness to use/ user experience for the construction site managers are more important than other factors in order to scale up the solution. Meanwhile, more efforts are needed to strengthen these factors.

For the demo site "stationary battery", the purpose is to investigate the flexibility provision through a large-scale battery in a residential building and the potential to commercialize such a solution. The software integration such as smart control algorithms of battery and intelligent methods to access the local balancing service, is the most important factor in terms of upscaling. This LEC solution will require further development for hourly forecast of local generation and consumption, optimal scheduling of asset control, and activation of assets to achieve the optimization setpoints. Thus, the design of software to be compatible with larger scales is critical for upscaling. Similar to the demo site of "DH + HP", technology evolution is considered less important in terms of upscaling, whereas standardization, communication and integration shall be further improved in order to scale up the solution.

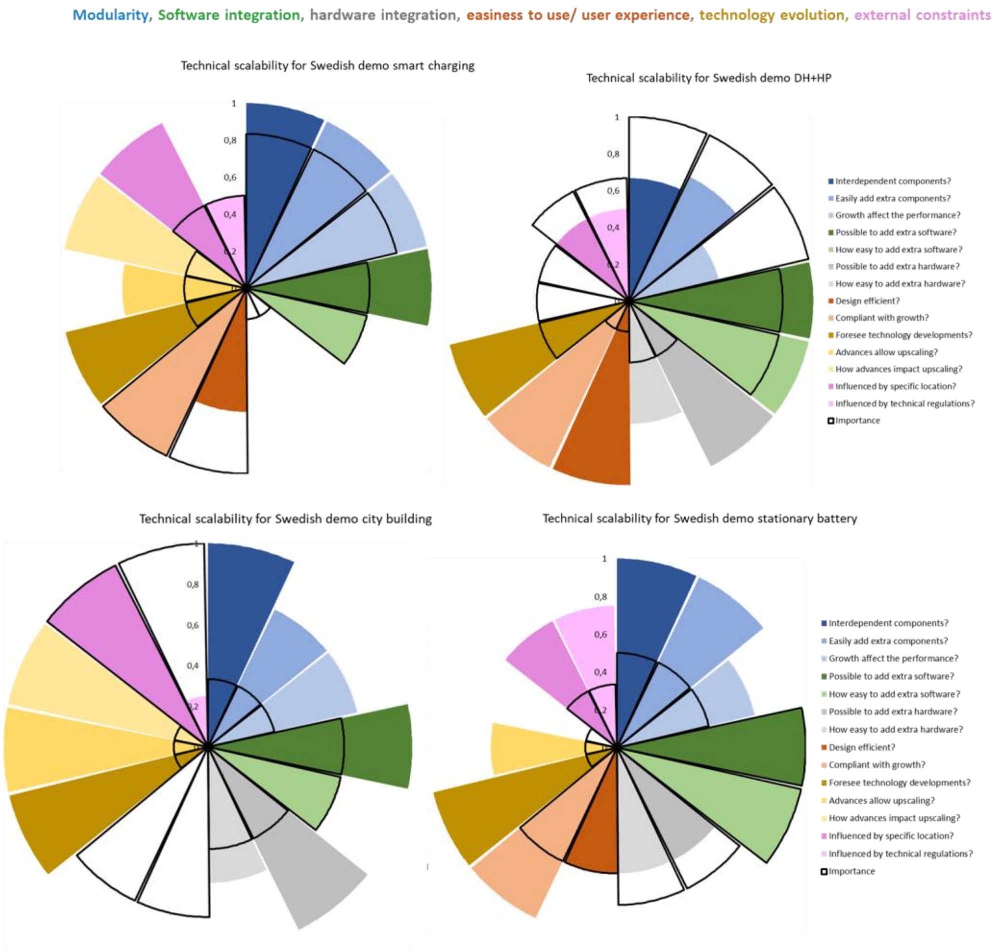


Figure 7. Technical scalability analysis for Swedish demo sites. The colours of fonts indicate different technical and non-technical factors. Different colour spectrums indicate different factors. Each sector represents one question. The sizes of sectors indicate the actual scores for scalability. The sizes of the sector outlines indicate the importance of the factor when upscaling the solution.

Based on the questionnaire analysis of the non-technical scalability potential, some conclusions are presented in the following paragraphs (Figure 8).

It is commonly recognized for the demo site “smart charging”, “DH+HP”, and “city building” that, profitability is the most critical factor for upscaling the solution. Since a comprehensive cost-benefit analysis was not conducted for most of the demo sites, it is not clear if the current technical solutions are profitable to be upscaled. But the economic potential of flexibility is expected growing in the future according to the interview with the respondent. Contrarily, a preliminary cost-benefit analysis for the demo site “city building” showed an unprofitable result which makes it not attractive for investment.

For the demo site of “stationary battery”, the most critical factor in upscaling is evaluated to be business model, similar as other demo sites. The missing of business model design in the current stage is considered as a barrier for upscaling. Therefore, it is not possible to evaluate how business models can be scaled up or if business models are sustainable and efficient for future upscaling.

It is also observed that the market outlook, such as the market potential for current solutions, is positive. This is especially due to the energy transition i.e. increased level of electrification, more distributed energy systems with a higher share of renewable and intermittent energy generation as well as the changing consumption patterns in the built environment . However, how to get financed or who should invest in the technical solutions are generally not considered.

Factors “regulatory issues”, “stakeholders’ acceptance”, and “environmental impact” are considered less important for upscaling than factors “profitability”, “market and economic constraints”, and “business model”. On the other hand, the former factors have been investigated more during the demonstration than the latter ones. The attitude of stakeholders towards the solutions has been very positive. Regulatory issues are existing but not considered as significant barriers. Environmental impacts are considered less important in current solutions in terms of upscaling.

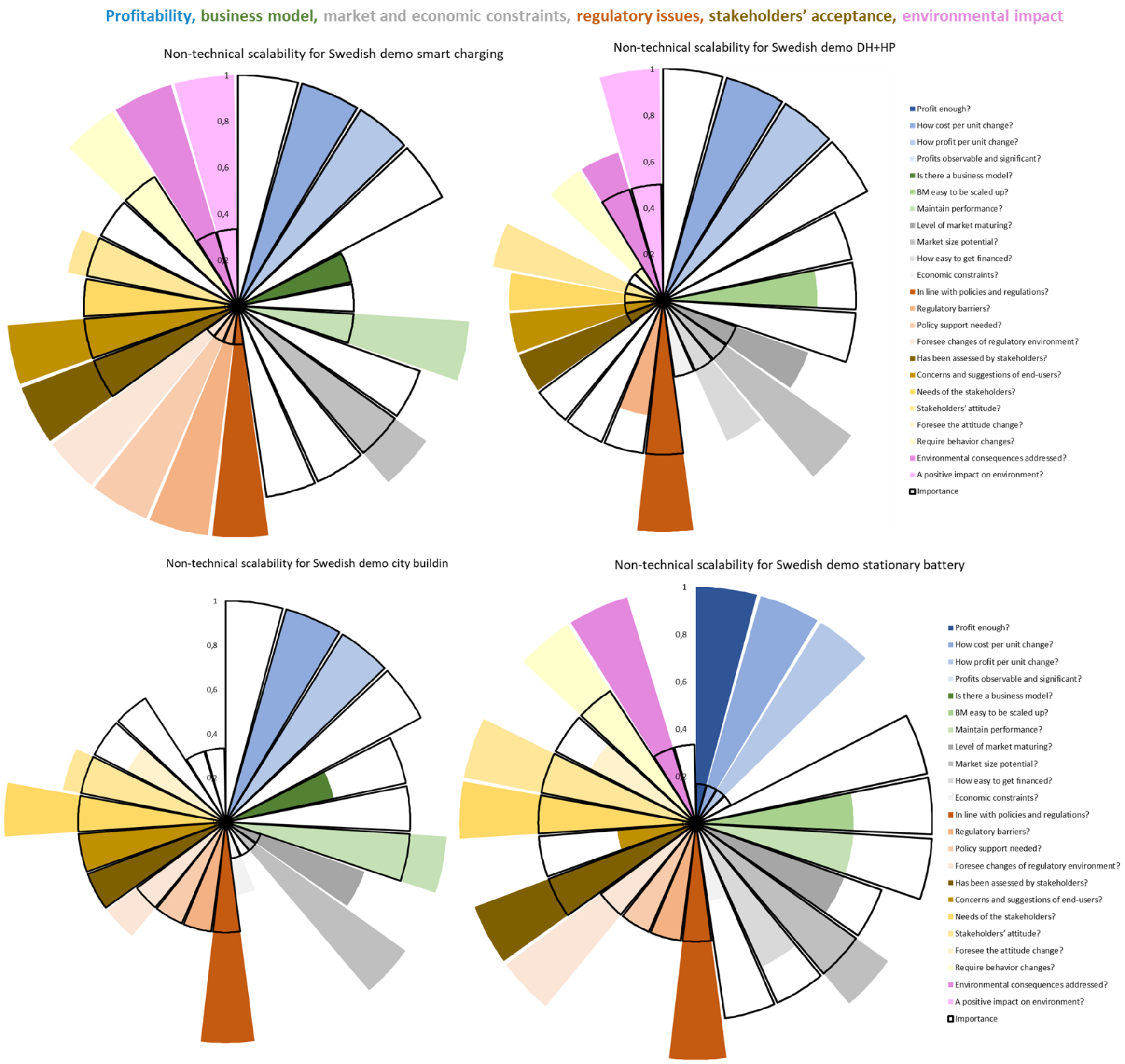


Figure 8. Non-technical scalability analysis for Swedish demo sites. The colours of fonts indicate different technical and non-technical factors. Different colour spectrums indicate different factors. Each sector

represents one question. The sizes of sectors indicate the actual scores for scalability. The sizes of the sector outlines indicate the importance of the factor when upscaling the solution.

4.2 Scalability analysis of demo country Germany

German demo site is a good example of revitalization and conversion of the existing buildings to eco-friendly new buildings. The ectogrid energy system, provided by E.ON in this project, is employed in order to structure decentralized energy system of the future. This solution is considered scalable, replicable, and energy-efficient by integrating electricity, heating, and cooling in one system. The low-temperature district heating network, the smart electric grid and 27 new & existing buildings lays the foundation of an energy community. The planning tool, which was developed in this project, optimizes the energy system and enables sector coupling within electricity, heating and e-mobility. Based on that, a significant flexibility potential via CHP, power-to-heat, a multi-faceted thermal storage, and e-mobility integration is achieved.

The use case is thermal energy trading. All members of the LEC are connected to each other via a low-temperature heat network i.e. with the inflow temperature of 20 °C and return temperature of 10 °C). The members with heat demand extract heat as an energy source for heat pumps and consequently reduce the temperature in the heat network. Members with cooling demand (supermarket all year round, offices and private buildings in summer) extract cooling energy from the return flow of the heat network for direct cooling or as an energy source for a chiller (reversible heat pump) and feedback the network with an increased temperature. Waste heat can also be provided from industrial processes. Furthermore, members of the LEC can feed in renewable heat from solar heating systems into the heat network. The possibility to feed in and take out heat and cold in a decentralized way results in a marketplace for the LEC. The particular advantage of exchanging heat is that waste heat from one member e.g., from a refrigeration unit is usable heat for another member e.g., as an energy source for a heat pump. Thus, the overall energy efficiency can be increased by using the synergy effects.

The stakeholders are aware and active within this project, including stakeholders from political, economic, social, technological, legal, and other sectors.

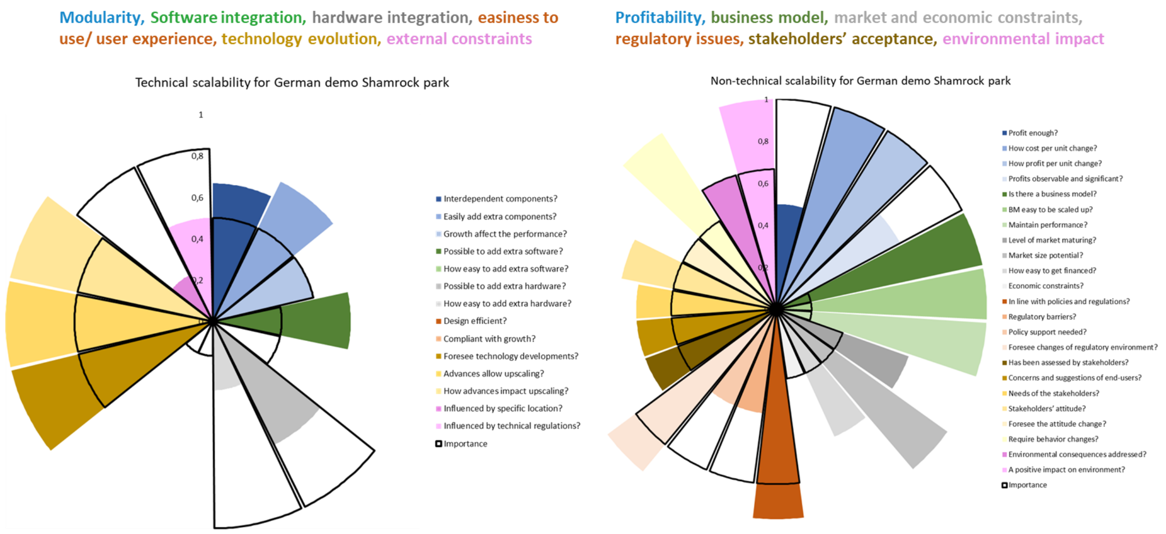


Figure 9. Scalability analysis for German demo site Shamrock Park. The colours of fonts indicate different technical and non-technical factors. Different colour spectrums indicate different factors. Each sector represents one question. The sizes of sectors indicate the actual scores for scalability. The sizes of the sector outlines indicate the importance of the factor when upscaling the solution.

Based on the questionnaire analysis, some conclusions are presented in the following paragraphs (Figure 9).

In this demo site, the non-technical scalability factors score higher than technical factors, which indicates, in general, technical aspects of the solution need to be more strengthened in order to be scaled up. In addition, the standard deviation of non-technical scalability is lower than that for technical scalability, which indicates more fluctuations among the scores of technical scalability responses.

Hardware integration is ranked as the most important factor while the factor needs to be further strengthened. Any energy source (datacenter, waste heat etc.) either as prosumer or as supplier can be a possible new component to the current solution when it is upscaled. Technical constraints is ranked as the second most important factor. External constraints such as availability of heat sources and approvability by public administration should be further considered when upscaling. Similar to Swedish demo site "DH+HP", this demo site also considers the factor " easiness to use/ user experience" as least important and thus is not considered at the current stage.

The factors "profitability" and "regulatory issues" are perceived more important than other non-technical factors. It is evaluated to be relatively profitable to upscale the current solution with foreseeable economy of scale. There are some regulatory barriers which may hinder the upscaling of the current solution, such as the unfavorable laws with respect to coupling energy sectors (heating/cooling and electricity). Current LEC regulations in Germany do not allow energy sharing between community members. In this sense, the LECs, from EU legislation's concept, are not implemented in Germany yet in regard to energy sharing. The factor "business model" was ranked as the least important factor by the by-then demo manager but was disagreed by the later manager who confirmed that developing sustainable business models is an equally important step for upscaling. Furthermore, it was stated that the end-users will not be affected by the upscaling The current solution and future upscaling will also have positive environmental impacts by replacing the less environment-friendly solutions such as gas boilers.

4.3 Scalability analysis of demo country Scotland

The Scottish demo site aims to design a multi-vector platform around a LEC setting by investigating the interactions between different energy vectors (i.e. electricity and hydrogen) through real and virtual pilot demonstrations. To do this, the concept of web-of-cells (WoC) was introduced to enable the control of energy supply and demand from cells (assets) of different energy vectors within a LEC. Three cells (assets) are investigated, i.e. Wind Power Cell, Community PV and Storage Cell, and Virtually Simulated and Future Cells, with the combination of three models of operation.

Based on the questionnaire analysis, some conclusions are presented in the following paragraphs (Figure 10).

For Scottish demo site Levenmouth, the factors of technical scalability score higher than non-technical scalability, which indicates that non-technical aspects need to be more strengthened for upscaling. The standard deviation for technical scalability is lower than for non-technical scalability, which indicates more fluctuations among scores of non-technical factors.

Modularity is considered as the most important factor and needs to be strengthened for upscaling purpose. The current solution is easily to be grouped into cells with each cell having a group of community energy assets. Each cell is interdependent on other cells based on if there is a power deficit or surplus in the cell. The cells act as functional units serving different functionalities within the architecture. Factor “hardware integration” and “software integration” are also considered more important in the upscaling process. The solution uses edge IoT devices to deploy containerized applications and connect to energy assets on site. This approach allows multiple geographically discrete sites or assets to communicate in the same ecosystem. The solution utilizes Google Firebase, a backend as a service (BaaS) platform. This is a cloud-based solution which can be scaled seamlessly. This is a key advantage of the project architecture, i.e. avoiding the need for site-based firewalls and similar security requirements. Technological advances and improvements in hardware and software (e.g. active management systems) would further enhance the scalability of the solution. The pre-existing UI was designed for utility users in an operational environment. The platform could benefit from UX improvements to enhance accessibility for non-technical users with e.g. clearer UI and reshaped dashboard to facilitate community asset management.

Many non-technical factors were not considered in the current solution compared to technical factors. Stakeholders’ attitude is perceived as the most important non-technical factor and needs to be strengthened, such as to increase uptake of smart & renewable technologies (e.g. building mounted solar PV, EV charge points, battery storage and/or smart electric heating systems) at community and private premises, increase knowledge of and confidence in engaging with 3rd party flexibility / demand control services, increase participation in informal and/or formal networks of community organizations to support each other in the engagement in above services. The market and economic constraints are considered as secondly important factors for upscaling. The existing electricity market is accessible via aggregators and virtual power purchase agreements. The future hydrogen strategy and business models are currently in consultation in the UK which might lead to introduction of a hydrogen market. Regulatory issues are considered as the least important factor, whereas further support is still needed for upscaling the solution. There are regulatory barriers that still exist in the UK on implementing LEC solutions. For example, the current legislation only allows local generation but not supply, i.e. the energy flowing through the grid can only be sold to an end user by a licensed supply company. However, the licensing process for becoming a formal supplier was designed based on a nationalized and highly centralized UK energy system which is outdated. There is no established legislation that paves the pathway for deploying LEC projects.

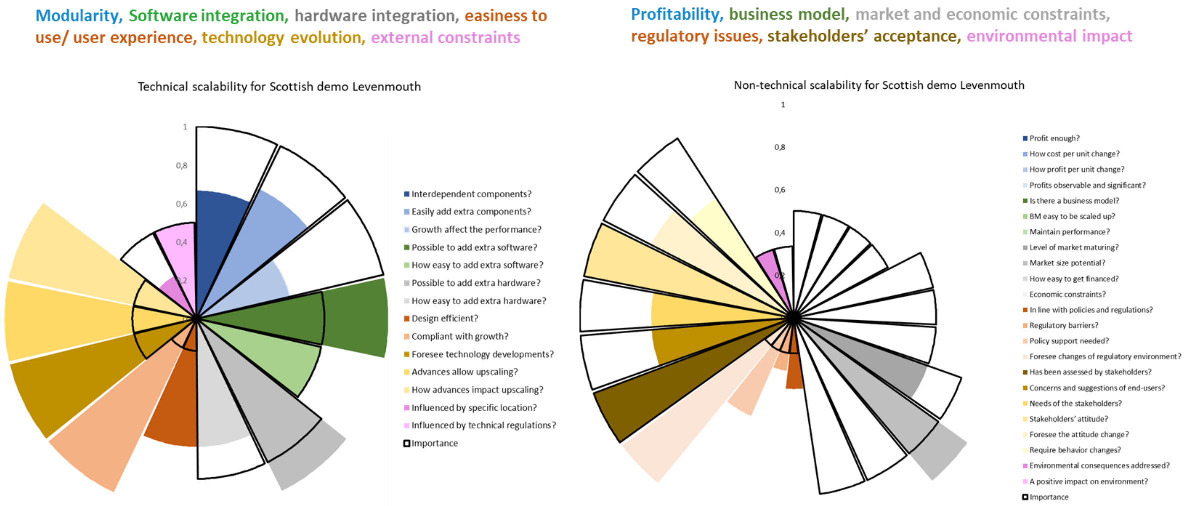


Figure 10. Scalability analysis for Scottish demo site Levenmouth. The colours of fonts indicate different technical and non-technical factors. Different colour spectrums indicate different factors. Each sector represents one question. The sizes of sectors indicate the actual scores for scalability. The sizes of the sector outlines indicate the importance of the factor when upscaling the solution.

4.4 Scalability analysis of demo country Austria

For Austrian demo site Almenland, the technical scalability scores higher than non-technical scalability which indicates that non-technical aspects need to be more strengthened for upscaling. The standard deviation for technical scalability is lower than for non-technical scalability, which indicates more fluctuations among scores of non-technical factors.

Technical constraints is considered as the most important factor in order to scale up the current solution, although it also needs further improvements. Such constraints are for example, regulatory constraints related to power grid, energy systems, energy community, technical constraints related to integrated multi-energy grids. Modularity is ranked as the second most important factor which is already of high-level development. The AIT Rapid deployment platform was developed in this project as a tool for LEC solutions. This platform uses a microarchitecture which allows modules to be reused with modifications by adding interfaces, replacing algorithms, extending algorithms, deploying in different environments, etc. Furthermore, modifications are ensured to be compatible with the platform. The factor of software and hardware integration are also considered important in upscaling. The current solution uses dockerized container approach. Each database, model, and algorithm are hosted in their own individual component. Together with the AIT Rapid deployment platform, this helps combine different parts of the implementation such as optimization and control algorithms, bookkeeping, storing historical data and so on. Some hardware components, such as controllers, measurement devices at home and grid level, communication devices, are critical for upscaling. Technological advancement in control algorithms, solvers, communication devices and infrastructure is considered having positive impact on scalability.

Stakeholders' acceptance is the most important non-technical factor and has been reflected most in the demonstration. The solution involves automation and explicit demand response. Thus, very little customer behavioral change is needed. It is perceived that the market size for the current solution will increase in the future and it is relatively easy to get financed. Extra support for energy management, local energy market and local flexibility are needed for upscaling. However, the current LEC regulation is considered as a major barrier. Regulatory issues was ranked as the least important factor in upscaling process. However, after the individual interview, the demo manager updated the rank of regulation to a higher level.

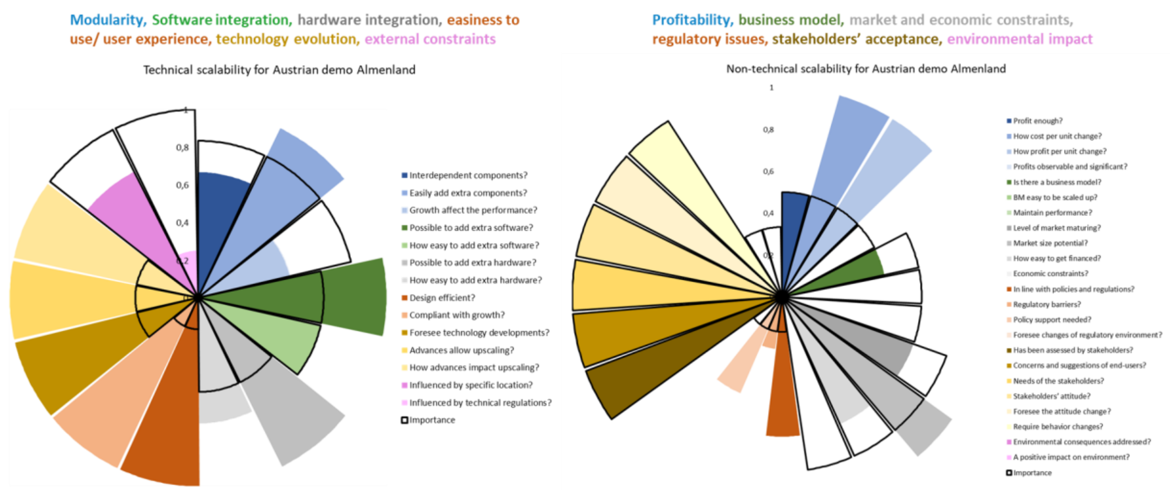


Figure 11. Scalability analysis for Austrian demo site Almenland. The colours of fonts indicate different technical and non-technical factors. Different colour spectrums indicate different factors. Each sector represents one question. The sizes of sectors indicate the actual scores for scalability. The sizes of the sector outlines indicate the importance of the factor when upscaling the solution.

4.5 Replicability analysis

While scalability and replicability are not the same things, they both involve the ability to maintain or improve performance under different conditions. In the case of scalability of LEC solutions, this involves adapting to changes in demand or workload, while in the case of replicability, it involves ensuring that results or experiments can be reproduced consistently at other locations. Both concepts are important in different contexts and can contribute to the success and reliability of LEC solutions in the CLUE project. Most of the factors are the same for both scalability and replicability. Therefore, the replicability analysis functions as a complementary to scalability analysis based on the questionnaire survey and interviews.

The results of original questionnaire responses of replicability are presented in Appendix. From the results, most of the responses go in line with scalability analysis in terms of the development level and importance of certain factor. Certain answers were further discussed and revised during the individual meeting and interview process.

5 CONCLUSIONS

This deliverable presents the results of the scalability and replicability analysis of the LEC solutions demonstrated by the CLUE Project. The SRA methodology is based on the BRIDGE method which is to ensure homogenous measurement with high quality across the demo sites. The analysis provides a clear evaluation on how the technical and non-technical factors impact scalability and replicability for the demo sites, in terms of LEC solutions. Based on the data analysis from the questionnaire survey, some common conclusions regarding scalability and replicability potential are summarized in Table 8.

A good understanding and reparation of the factor list are essential in order to design and implement future successful upscaling and replication projects. Both technical and non-technical factors should be fully considered, especially clearly articulated business model, quantified economic benefits, financially sustainable position, sufficient policy support, and stakeholder engagement can be further improved beyond this project life cycle in order to scale up and replicate the LEC solutions. It is important to keep in mind that there is no single factor that makes the scalability or replicability of a LEC solution feasible or infeasible, rather the result is a combination of a set of factors. It is also important to note that scalability and replicability can be complex and time-consuming, so it is important to approach it with a well-planned and systematic approach from the beginning.

Table 8. Some conclusions based on SRA of seven demo sites.

Percents	Factors	Factor description
100% of demo sites agree:	• technology evolution • market and economic constraints	• foresee the developments of relevant technologies in your solution. • estimate the market size potential for your solution will increase.
[70%, 100%) of demo sites agree:	• software integration • technology evolution • profitability • profitability • regulatory issues • profitability	• possible to add more components/functions to the current databases, models & optimization simulation, algorithms, and other calculations. • the technology advances in the solution will strengthen the upscaling (considering the technology complexities, system workload, end-user privacy, etc.). • if the size of your solution increases, the cost per unit of your solution change (economy of scale) will decrease. • if the size of your solution increases, the profit of your solution will increase. • the solutions are in line with existing national policies and regulations. • not clear or not consider if the increased profits observable and significant (net profit is greater than the additional cost, and rate of return is acceptable) when the solution is scaled up.
[50%, 70%) of demo sites agree:	• hardware components • technology evolution • regulatory issues • stakeholders' acceptance • stakeholders' acceptance • profitability	• possible to add more hardware components to the current solution. • the technology advances in your solution allow the upscaling. • foresee the regulatory environment get improved with the upscaling process. • the solutions have been tested in local setting and assessed by stakeholders. • the successful scaling up requires minor changes in behavior of the end-users.

• business model • business model • environmental impact	• not clear or not consider if the economic indicators of the demo show that the current solution is profitable enough to scale up. • not clear or not consider if there is a business model for your solution which is ready to be implemented in the market. • not clear or not consider if the business model of your solution could be easily scaled up (the business model is sustainable). • not clear or not consider if the solution have a positive impact on environment if it gets scaled up.
[50%, 100%) of demo sites selects:	• profitability as the most important factor among other non-technical factors to consider in upscaling. • market and economic constraints as the second most important factor among other non-technical factors to consider in upscaling. • Environmental impact as the least important factor among other non-technical factors to consider in upscaling. 1. software integration as the third important factor among other technical factors to consider in upscaling. 2. easiness to use/ user experience is the least important among other technical factors to consider in upscaling.

6 DELIMITATIONS

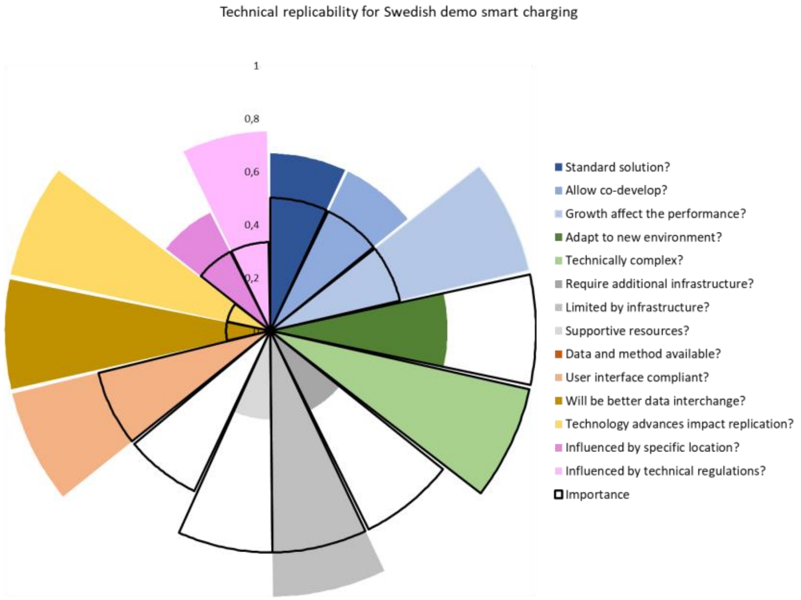
This report analyses the scalability and replicability potential for LEC solutions for seven demo sites. The delimitations of this analysis are listed below.

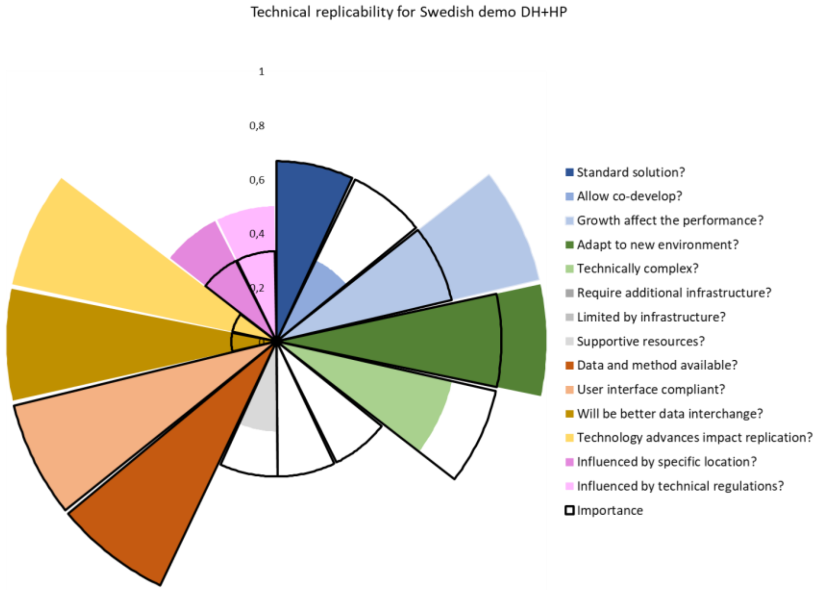
- The scores are subjective from the questionnaires and cannot be compared between demo sites.
- Overall, the implementation of the demo site has been delayed for a number of reasons. The development of the demo site was behind schedule when this Task was performed. As a result, the scalability and replicability potential were not fully considered at that stage.
- Five out of seven demo sites (Swedish and German demo sites) experienced changes of demo managers and/or colleagues after the questionnaire was answered. As a result, new managers may have different perceptions when answering certain questions. Some of these may contradict the perceptions of the previous managers. Although this was resolved by the follow-up individual meetings and interviews, the robustness of SRA results can be impacted.
- One important partner of German demo site, the owner and developer (FAKT AG) of the demo site, went bankrupt one year before the project finishes. Therefore, there had been a major delay in that demo site. Thus, the SRA is not representative of the final project development status.

Regardless, the analysis and conclusions are still valuable in understanding how to further upscale and replicate current LEC solutions.

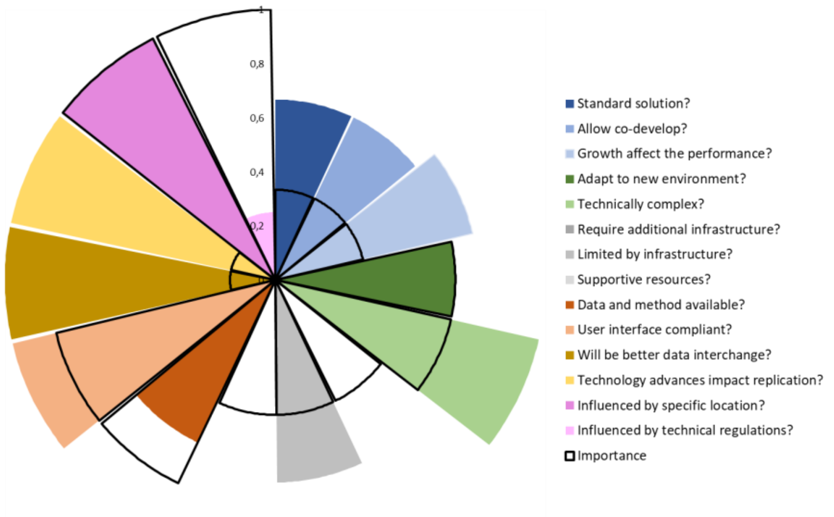
7 APPENDIX: REPLICABILITY RESULTS

7.1 Appendix A: Technical replicability results

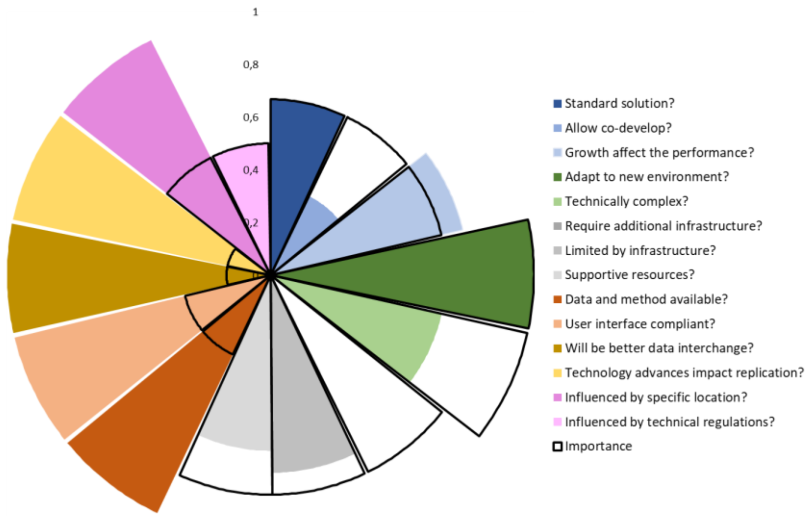




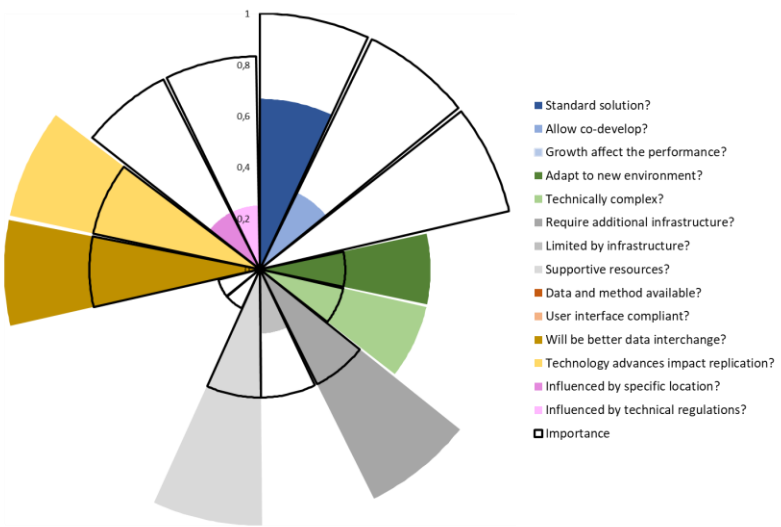
Technical replicability for Swedish demo city building



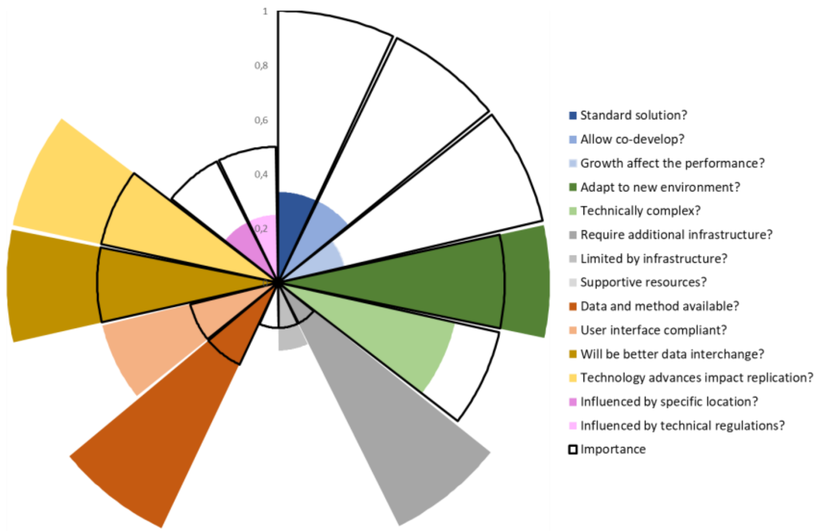
Technical replicability for Swedish demo stationary battery

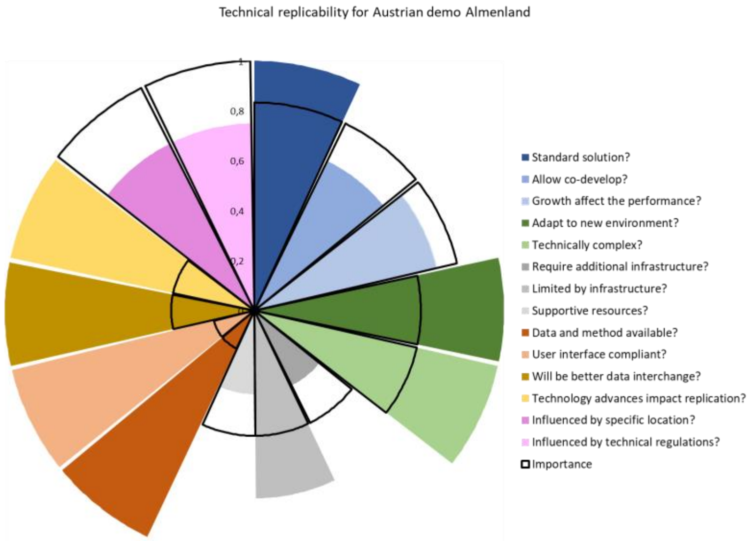


Technical replicability for German demo Shamrock park



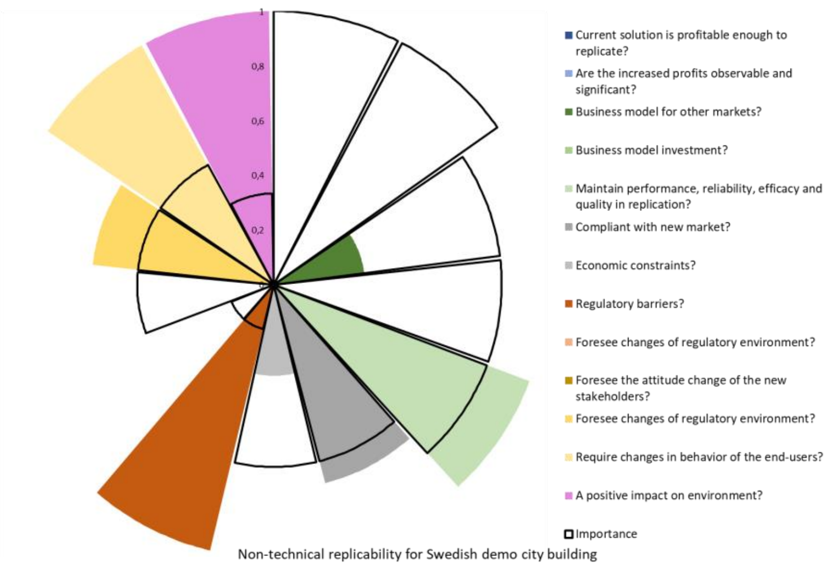
Technical replicability for Scottish demo Levenmouth



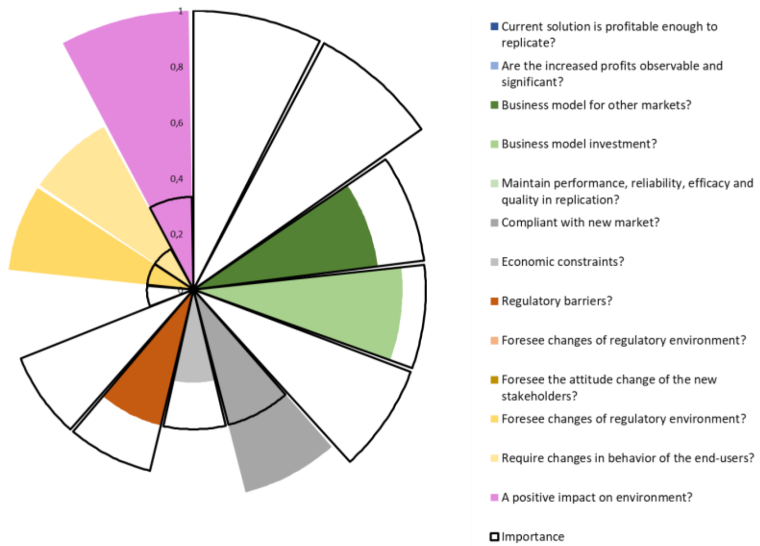

Technical replicability for Austrian demo Almenland
1
0,8
0,6
0,4
0,2
Standard solution?
Allow co-develop?
Growth affect the performance?
Adapt to new environment?
Technically complex?
Require additional infrastructure?
Limited by infrastructure?
Supportive resources?
Data and method available?
User interface compliant?
Will be better data interchange?
Technology advances impact replication?
Influenced by specific location?
Influenced by technical regulations?
Importance

7.2 Appendix B: Non-technical replicability results

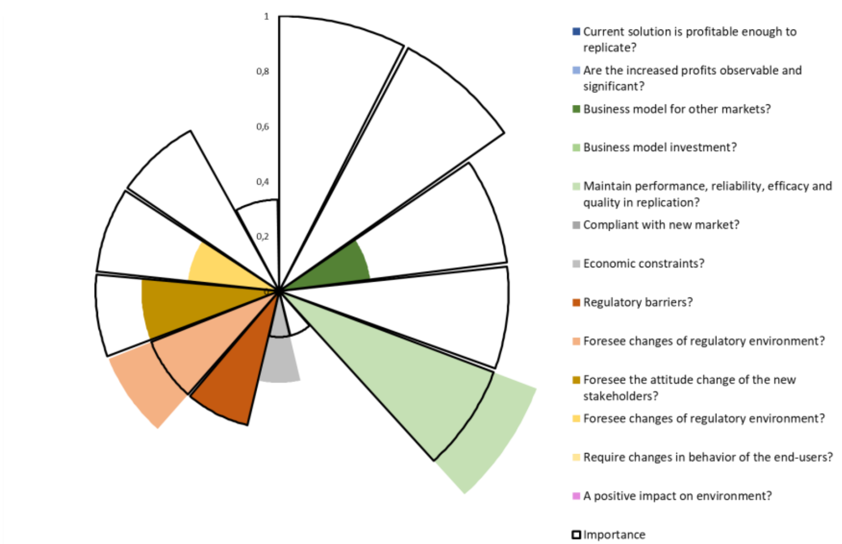
Non-technical replicability for Swedish demo smart charging



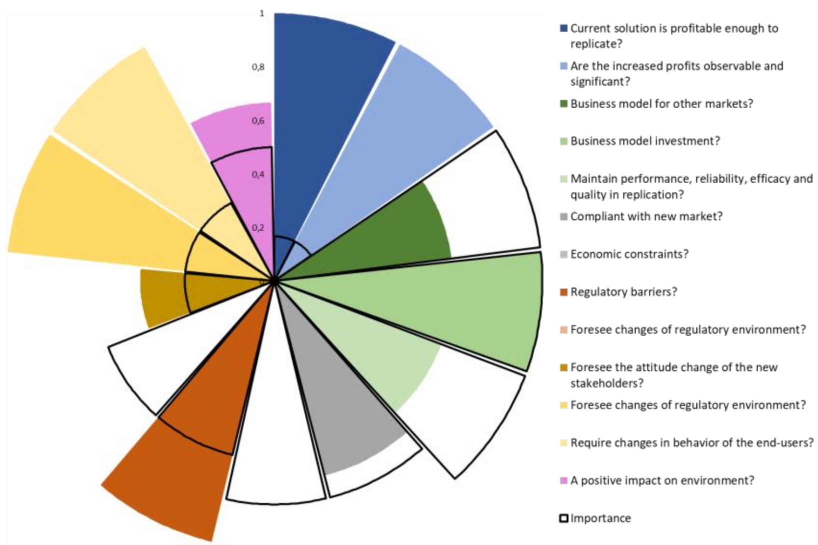
Non-technical replicability for Swedish demo DH+HP

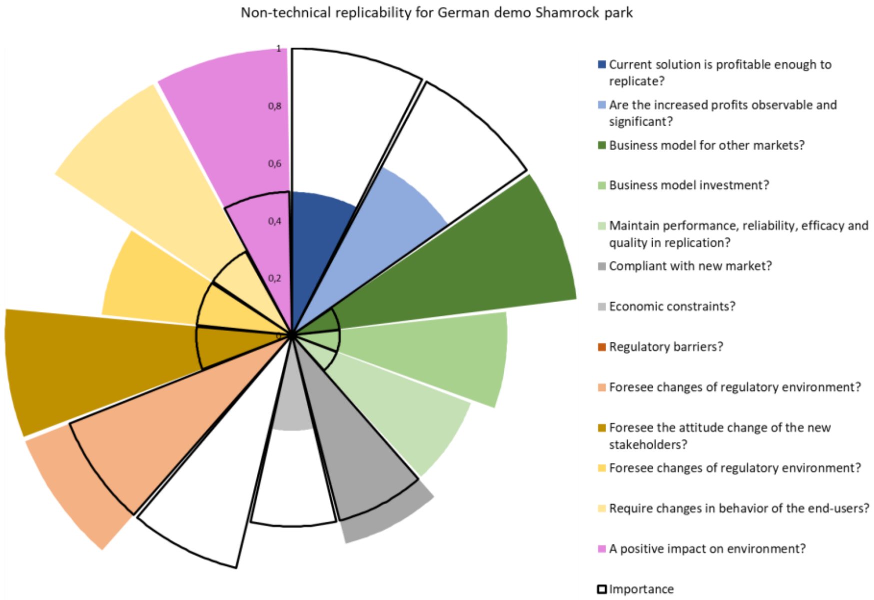


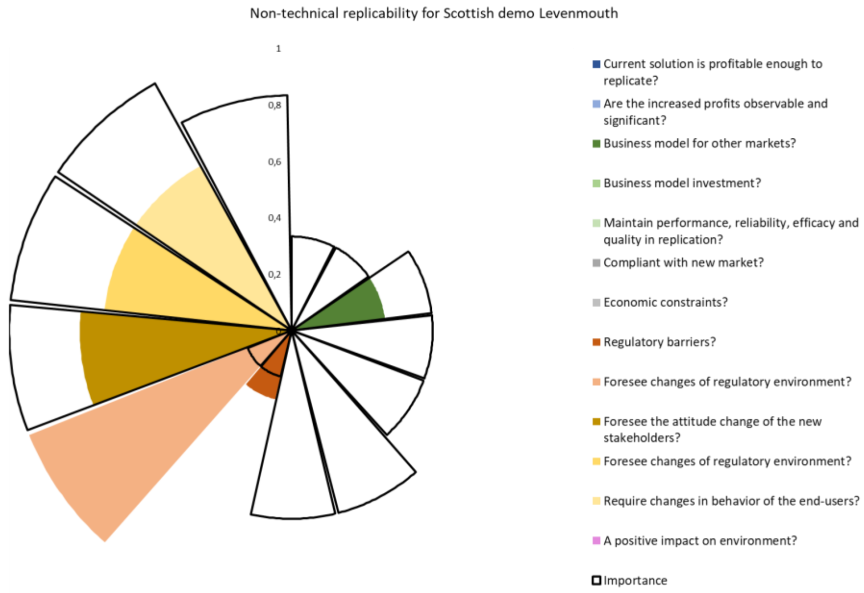
Non-technical replicability for Swedish demo city building



Non-technical replicability for Swedish demo stationary battery




Non-technical replicability for German demo Shamrock park
1
0,8
0,6
0,4
0,2
Current solution is profitable enough to replicate?
Are the increased profits observable and significant?
Business model for other markets?
Business model investment?
Maintain performance, reliability, efficacy and quality in replication?
Compliant with new market?
Economic constraints?
Regulatory barriers?
Foresee changes of regulatory environment?
Foresee the attitude change of the new stakeholders?
Foresee changes of regulatory environment?
Require changes in behavior of the end-users?
A positive impact on environment?
Importance


Non-technical replicability for Scottish demo Levenmouth
1
0,8
0,6
0,4
0,2
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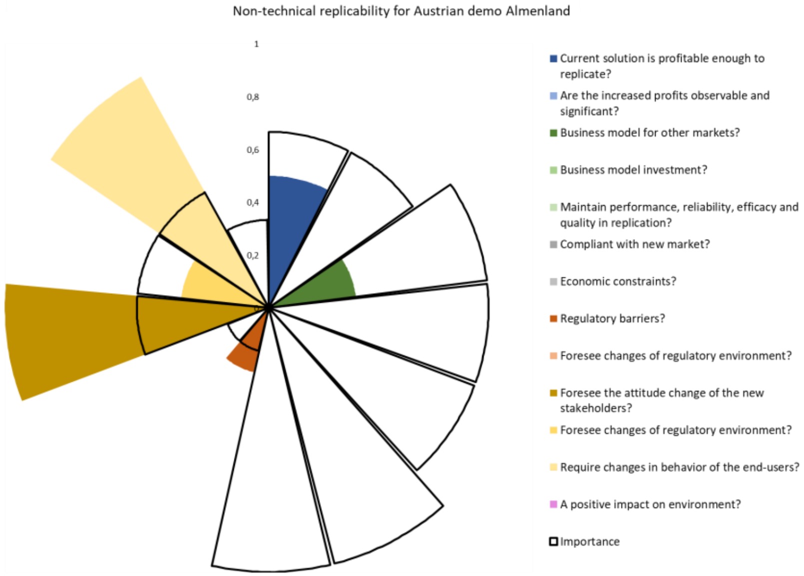
Are the increased profits observable and significant?
Business model for other markets?
Business model investment?
Maintain performance, reliability, efficacy and quality in replication?
Compliant with new market?
Economic constraints?
Regulatory barriers?
Foresee changes of regulatory environment?
Foresee the attitude change of the new stakeholders?
Foresee changes of regulatory environment?
Require changes in behavior of the end-users?
A positive impact on environment?
Importance


Non-technical replicability for Austrian demo Almenland
1
0,8
0,6
0,4
0,2
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Business model for other markets?
Business model investment?
Maintain performance, reliability, efficacy and quality in replication?
Compliant with new market?
Economic constraints?
Regulatory barriers?
Foresee changes of regulatory environment?
Foresee the attitude change of the new stakeholders?
Foresee changes of regulatory environment?
Require changes in behavior of the end-users?
A positive impact on environment?
Importance

8 REFERENCES

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