RUGGEDISED
Designing smart, resilient cities for all

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Executive summary

This report describes and presents the results of the impact assessment of the implemented and monitored solutions in the RUGGEDISED project across the different activities of the Monitoring Work Package (WP 5), which focused on monitoring and evaluating 30 solutions in the action areas of the smart thermal grid, smart electricity grid and e-mobility, energy management and ICT Smart Open Data Platform. It also provides insights on the impact of the solutions that were implemented in three Lighthouse cities (Glasgow, Rotterdam, Umeå).

The foundation for this monitoring process was established in early stages of the project (T5.1, T5.2, T5.3) and was structured in previous deliverables, such as D5.1 “Monitoring and Evaluation Manual”, D5.2 “Monitoring Templates”, and D.5.3. “Maintenance Plan”. Furthermore, D5.6 the “Analysis of alignment of smart solutions in the Lighthouse cities with city strategies” intensively address the qualitative assessment. This report outlines the results of all the monitoring tasks conducted during these last six years, including quantitative and qualitative monitoring, social impact assessment and business model analysis.

One of the key aspects assessed in the evaluation and monitoring is the objective impact of the tested solutions in each city in terms of advancing to more emission neutral cities. Hence, an important bulk of the monitoring exercise involved the definition of a series of Key Performance Indicators (KPIs) to assess to which extent there had been a reduction in emissions on mobility, increased efficiency on energy systems, primary energy consumption, etc. For each of the lighthouse cities and at a project, city and solution level, these KPIs have been calculated using the data provided by local partners and cities.

The KPIs calculated indicate that overall, the environmental targets, and those for energy efficiency, reducing energy consumption and providing more sustainable mobility have been reached. With the goal to achieve climate neutrality and improve the life of citizens, RUGGEDISED could manage to refurbish a total of 58,244 m² of floor area in tertiary buildings. Thanks to the energy efficiency measures and the smart solutions implemented at the building and district level in RUGGEDISED, 5,901 tonnes of CO2 have been mitigated and an annual amount of 26,833 MWh of primary energy has been saved. The achieved energy savings by waste, street lighting and building energy efficiency measures is estimated at 21,993 MWh per year. Moreover, thermal grid solutions like the deployment of heat-pumps by geothermal storage or the development of new performance buildings have generated around 325,340 kWh of thermal energy per year, which also effected an annual saving of 1,109 MWh of primary energy.

Furthermore, photovoltaic systems and battery storages reduce energy imports from the electrical grid and decrease the greenhouse gas emissions related to electric vehicle charging hubs. According to these measurements, the interventions on the smart electric grid cluster not only reduced the primary energy consumption but contributed to a reduction of 1191 tonnes of CO2. With the aim to roll-out the usage of sustainable mobility transport, 55 e-vehicles have been successfully deployed in the demonstration areas and resulted an annual energy saving of 5,210 MWh and a reduction of 2,218 tonnes of CO2.

Another important aspect considered during the monitoring and evaluation and presented in the present report, are the non-technical aspects related to the impact of new technologies on their environment. On one side, it is analysed how they can alter the business models sustaining them and the relations between the different stakeholders involved in their operation and exploitation. On the other, how they affect citizens and other groups directly interacting with the final solution. For both analyses, a selection of solutions was made across the three cities, and interviews were conducted with citizens and beneficiaries of the solutions (for the social impact assessment analysis) and with key stakeholders involved in the

implementation and operation of the solution (for the business model analysis and the qualitative monitoring).

The results of the non-technical aspects indicate that the experimentation with new technologies has led to the exploration of new collaboration mechanisms between the key stakeholders (mostly, energy companies and city authorities) and to test new approaches and business models. This phenomenon is mostly due to the requirements of the combination of different technologies, and the new roles that have had to be assumed by these actors. Although these experiments are still far from generating a shift of paradigm on the classical relations between providers and consumers, they have set the basis to build more innovative business models in the future. Regarding the social impact of these new technologies, and despite most of the solutions analysed did not have a direct impact on citizen's lives, the results of the social impact analysis highlight that the studied solutions are positively perceived by citizens, and that they are not disruptive for them, generating little opposition to their implementation in normal conditions and opening the door to further scale up and replication.

The RUGGEDISED project has been implemented during the last six years, overcoming important challenges caused by the Covid-19 pandemic and the global events that have followed. Despite these challenges, the evaluation indicates that the different solutions have effectively contributed to helping the participating lighthouse cities to adopt more sustainable practices, integrate innovative and more efficient technologies, and identify institutional and financial bottlenecks and potential solutions to ensure a smoother implementation and a successful scaling and replication in the future.

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1. Introduction

RUGGEDISED is a smart city project funded under the European Union's Horizon 2020 research and innovation programme. Over the last six years (2016-2022) RUGGEDISED has brought together **three lighthouse cities (Glasgow, Rotterdam, Umeå) and three fellow cities (Brno, Parma, Gdansk)** to design and test smart solutions in the field of energy, E-Mobility, and **ICT,** to accelerate the transformation towards smart resilient districts. **Thirty-four partners** from city administrations, utilities, start-ups and research organisations, universities and building/house owners across Europe implemented the different solutions of the RUGGEDISED project in close coollaboration with citizens.

Figure 1: The Lighthouse and Follower Cities

1.1 Lighthouse cities: Rotterdam, Umeå and Glasgow

Facts:

Lighthouse cities: Glasgow (United Kingdom) ,Rotterdam (Netherlands), Umeå (Sweden)

- **Follower Cities:** Brno (Czech Republic), Gdasnk (Poland), Parma (Italy)

Duration: 2016 - 2022

In total, **30 smart solutions** in **four main action areas** contributing to the vision of the RUGGEDISED project have contributed to transform the districts to low energy-districts with integrated infrastructure and sustainable mobility. Fifteen of these solutions have been monitored and reported in this deliverable, while five solutions have been cancelled.
The four main action areas encompass solutions in the field of 'Smart Thermal Grid', 'Smart electricity grid and e-mobility', 'Energy management and ICT' and 'Smart Open Data Platform'.

Table 1: Number of solutions per action area in RUGGEDISED

Action areas and number of monitored solutions in RUGGEDISED			
Smart Thermal Grid	Smart electricity grid and e-mobility	Energy management and ICT	Smart Open Data Platform
10	9	8	3

Six cities working in partnership with businesses and research centres have demonstrated solutions to improve the quality of life of citizens, reduce the environmental impact of activities and create a stimulating environment for sustainable economic development.

This deliverable outlines the results of a consolidated assessment of technical and non-technical outcomes of the three lighthouse cities: Glasgow, Rotterdamand Umeå. It dives deeper into the evaluation of the quantitative and qualitative impacts based on a defined set of Key Performance Indicators (KPIs) and observations at the level of the project, the cities, and the solutions. The technical performance assessment focusses on showing the technical, environmental and economical impact of the solutions, such as the achieved energy savings of buildings and mobility solutions, the use and production of local renewable energy, or the reduction of CO2 emissions, whereas the non-technical assessments address the qualitative aspects such as structural changes in behaviour or relationships. The non-technical assessment uses qualitative approaches to reflect the economic, social and institutional effects of piloting these new technologies.

To provide an overview on how the information has been gathered and processed, and what KPIs are necessary for assessing the impact of the project, section 2 of this document elaborates on the monitoring and evaluation framework. Within this section, the methods and methodology to assess the technical and non-technical outcomes are detailed. Section 3 gives an overview of the overall results of the project RUGGEDISED and reflects on KPIs across all cities and the different solution clusters. It shows the benefits of the RUGGEDISED project and gives the whole picture of what impacts the project has achieved in the last 6 years.

Finally, Sections 4 to 6 present the results of the implemented and monitored solutions for each lighthouse city. The cities of Glasgow, Rotterdam and Umeå have implemented and tested manifold solutions contributing to energy efficiency, environmental impact and ICT development etc. and these sections detail the results of each of them and additionally at the city level at technical and non-technical level.

At the end of the report, a conclusion will summarise and comment the data and information provided across the document.

2. Monitoring and Evaluation framework

2.1. Methodology

Monitoring and assessment approaches distinguish between evaluating impacts and processes. The objective of assessing impacts is to 1) understand what has been achieved and to justify funding; 2) identify strengths and weaknesses and learn from errors; 3) ascertain cost effectiveness; 4) generate knowledge and share lessons and 5) to influence policies and sectoral priorities.

The objective of assessing processes is to improve communication, information and the relationship between clients and extension organizations; to create an environment of critical self-reflection and a culture of learning; to empower clients, and to generate knowledge and share lessons and new concepts inside the system.

The monitoring procedure and methodology were essentially developed throughout Work Package 5, and mostly consisted of Tasks T5.1., T5.2. and T5.3. This work was condensed on the monitoring deliverables D5.1, D5.2, and D5.3, in which the framework for the monitoring process is described in detail, including the KPI calculations, the methodology for the different domains to monitor, the tools to collect data, and the assessment of the monitoring process itself. A brief overview of these documents is provided below. The implementation of the methods described in these documents are the foundation of the impact assessment presented in this deliverable.

- D5.1 "Monitoring and evaluation manual"

This deliverable is the main guidance for partners and regarding the methodological approach for the work package, and provides a common framework to unify the approach of the monitoring and evaluation efforts across solutions and cities. The document indicates which are the different fields of assessment of the project to get a holistic approach, including the technical and non-technical perspectives, and the information that will be considered for the evaluation.

In this manual, five assessments clusters[1] are defined to enable the comparability among the different types of solutions in the different cities. The assessment methods for each cluster are detailed in this manual, including scope, inputs, outputs, and planning.

- D5.2 "Evaluation templates"

This deliverable defined the essential datasets to evaluate the performance of smart solutions and other interventions in RUGGEDISED. The templates included in this deliverable were developed based on the definitions outlined in D5.1. and follow the clustering of smart solutions presented there. In particular, this deliverable served for the technical performance assessment and economic, environmental and social impact assessment.

The templates provided in D5.2 bring together all the datasets necessary in one single template, so that a whole assessment of the solution is possible. The templates also foresee data entries for different stages of implementation (baseline data and monitoring data). Moreover, each template was adapted to the cities' demonstration areas, taking into consideration that each of them would differ in their scope and local situation.

[1] The clusters are: i) energy efficiency interventions at district level, ii) smart thermal grid, iii) smart electricity grid, iv) mobility solutions, v) city-wide ICT infrastructures.

- D5.3. "Maintenance Plan" [2]

This report is a non-public confidential deliverable. The maintenance plan defines three monitoring data types for the different smart solutions that will be considered in the monitoring process and outlines the data flow towards the evaluation. This document can be used as an inventory for the necessary data sets and their properties, defining minimum requirements for the specification of monitoring, identifying maintenance actions to ensure the quality of data, and specifying how the data handling is going to take place.

- D5.4. "Monitoring documentation" [3]

This is a non-public deliverable considering data protection. Documenting the monitoring process is particularly important in projects like RUGGEDISED, whose implementation has been affected by different global events such as COVID-19. This deliverable describes for each city and solution how the monitoring was affected in its different stages, including delays on the implementation, changes on the monitoring devices, variations on the initially expected datasets, and details about the methodology to calculate KPIs and assess the non-technical impacts.

Figure 2: Foundation deliverables for the assessment of the lighthouse projects

Overall, the monitoring and evaluation process can be summarised in the following steps:

[2] Confidential due to data privacy

[3] Confidential due to data privacy and IPR.

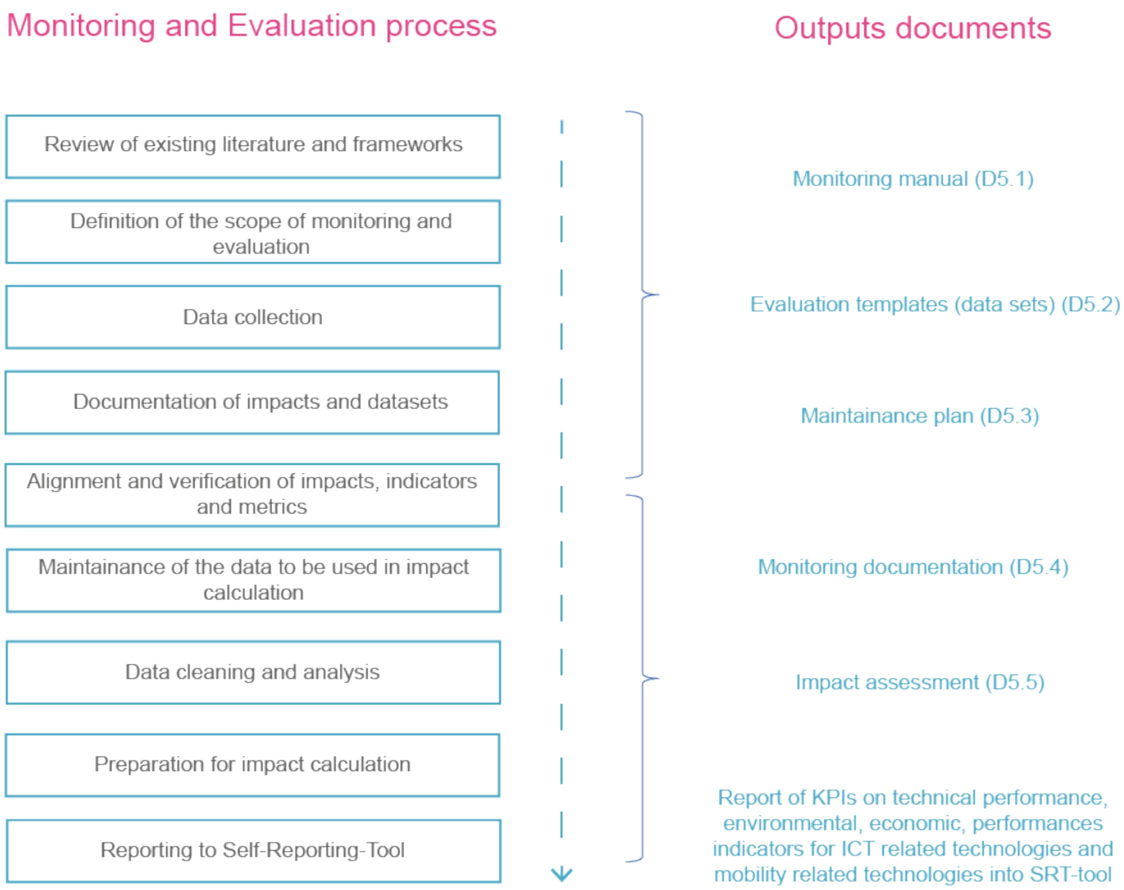

Figure 3: Monitoring and evaluation process and steps

As it is presented in Figure 3, the monitoring and evaluation process is based on nine essential steps implemented throughout the project duration. The scope of the impact assessment and a comprehensive set of KPIs were defined, based initially on a review of existing literature of monitoring and evaluation frameworks and project partners' experience. Once this framework and methodology were consolidated in D5.1. and D5.2., the data collection phase started.

The Data Collection was conducted primarily before and after the implementation and was collected from different partners and cities, based on the evaluation template defined in D5.2. In the meantime, the maintenance plan (D5.3) helped to avoid failures and faults in the implementation of the monitoring and evaluation, ensuring the alignment and verification of the impacts, indicators and metrics to adapt and adjust the impact assessment to the current situation. Once the data is collected and transferred to the monitoring team, it is stored, and cleaned for the impact calculations. All these processes (data collection, transfer, storage and analysis) are described in D5.4 "Monitoring Documentation".

These steps help to detect problems, communicate with partners regarding data quality, make a recommendation in case of problems, and generate intermediary KPIs values. The following chapters describe the methodology and key observations seeked for each dimension of the assessment (technical, and non-technical).

2.2. Monitoring and Evaluation framework for the technical outcomes (quantitative evaluation)

During the monitoring and evaluation exercise, different fields of assessment are addressed to measure the impact targets of the project and to support the replication of solutions. During the implementation and operation of the solutions, a technical assessment used monitoring data on the performance of the applied technologies. The outcomes seeked for this technical analysis will be described in this chapter.

Alongside this technical analysis, a non-technical assessment was also conducted, consisting of a qualitative monitoring, a social impact assessment and a business model analysis, which together provided a series of non-technical outputs useful to understand social and policy effects of the different solutions.The underlying approach of these assessments will be described in the following chapters.

In Table 2, the different impact dimensions and monitoring clusters of the technical analysis are listed. KPIs are calculated for the whole project and for each city, and the KPIs for each solution reflect the impacts at a small scale.

Table 2: Impact dimensions and monitoring cluster

IMPACT DIMENSIONS	MONITORING CLUSTER
Technical performance assessment	• Energy efficiency at building and district level • Thermal energy grid cluster • Smart electricity grid cluster • Mobility cluster • ICT on city level cluster
General assessment of buildings	
Performance assessment	
Environmental Impact assessment	
General Economic and Demographic Impacts on District Level	
Non-technical impact assessment	
Business-model impact assessment	
Social Assessment	

Smart solutions in RUGGEDISED cannot be seen as single interventions since these are part of an overall system. Also, not all smart solutions in Lighthouse Cities are of the same kind, which makes acomprehensive assessment difficult and does not allow for the aggregation of all impacts. Hence, the smart solutions and other activities on district level have been screened and clustered to come to a consistent methodology for performing evaluation and calculating the project impact.

The method for clustering was based on groups of smart solutions affecting different elements: smart thermal grid, smart electric grid and e-mobility, ICT on city level. Because these clusters did not cover all interventions performed within RUGGEDISED, a cluster for energy efficiency interventions on building and district level were added to cover building interventions. To ensure consistency in the assessment, also other measures to increase energy efficiency at building and district level were added – innovative street lighting and smart waste management.

2.2.1. Technical performance assessment

The technical performance assessment focuses on energy efficiency interventions on the different monitoring clusters: i) Buildings, both for new constructions and transformation of existing ones, ii) the thermal energy grid, iii) smart energy grid, iv) Mobility, and v) ICT tools. For each of them, a set of KPIs was initially developed.

On this regard, Table 3 shows the relevant KPIs for describing the performance of the smart solutions in the different clusters.

Table 3: Performance assessment of buildings and energy efficiency interventions

General assessment of buildings
KPIs
New Built Floor Area, Residential [m²]
New Built Floor Area, Tertiary Buildings [m²]
Refurbished Floor Area, Residential [m²]
Refurbished Floor Area, Tertiary Buildings [m²]
Floor Area Of Buildings With DSM [m²]
Refurbished Floor Area, Total [m²]
Cluster of solutions to increase the energy efficiency at building and district level
Energy Savings by Building Efficiency Measures [MWh/yr]
Energy Demand Reduction [%]
Final Energy Savings by street lighting interventions [MWh/yr]
Final Energy reduction by street lighting interventions [%]
Final Energy Savings by waste management interventions [MWh/yr]
Primary energy savings by building energy efficiency measures and street lighting [MWh/yr]
Smart Thermal Grid Cluster
Installed RES Capacity Heating [MW]
Floor Space to be Connected to District Heating [m²]
Share of RES (excl excess heat) in District Heating [%]
Electricity Generated by RES [kWh/yr]
Peak demand reduction [%]
Thermal Energy Generated [kWh/yr]
Thermal Storage Energy Used [kWh/yr]
Primary energy savings by cluster [MWh/yr]
Primary energy demand reduction [%]
Reduced energy curtailment of RES and DER [%],
Degree of self-supply by RES [%]

Smart Electrical Grid Cluster
Electricity Storage [MWh]
Installed RES Capacity Electricity [MW]
Primary energy savings by cluster [MWh/yr]
Primary energy demand reduction [%]
Reduced energy curtailment of RES and DER [%]
Peak demand reduction [%]
Mobility Cluster
Number of e-vehicles after the intervention [#]
Number of Vehicles with Alternative Energy Carriers (Excl. Electricity) [#]
Number of Charging Stations [#]
Number of e-Hubs [#]
Energy Savings by Mobility Measures, Total [kWh/yr]
ICT on city level cluster
Open Solutions [#]
Interoperability 3rd Party Applications [#]
Integrated ICT systems [#]

2.2.2. Environmental impact assessment

The monitoring and evaluation of RUGGEDISED included an environmental impact of the different solutions. The environmental impact assessment focuses on carbon emissions and local air quality according to the Horizon 2020 call (European Commission, 2016). The baseline to calculate CO2 energy savings is the final energy demand and the characteristics of the local electrical and gas grid as well as standard boilers. This allows to show the impact of highly innovative interventions on business as usual. Therefore, the situation before the interventions (in the case of refurbishment) is not taken into consideration but is used as a comparable case. Table 4 shows the KPIs describing the environmental impacts.

Table 4: KPIs of the environmental impact assessment

CO2 Reduction Achieved by Energy Supply Measures, Total[t/yr]
Cluster of solutions to increase the energy efficiency at building and district level
CO2 Reduction Achieved by Building Efficiency Measures[t/yr]
CO2 Reduction by Energy Measures[t/yr]
CO2 Saving street lighting[t/yr]
CO2 Reduction street lighting [t/yr]
Smart Thermal Grid Cluster

CO_2 savings [t CO_2/yr]
CO_2 reduction [%]
Smart Electrical Grid Cluster
Primary energy savings [MWh/yr]
Primary energy demand reduction [%]
CO_2 savings [t CO_2/yr]
CO_2 reduction [%]
Mobility Cluster
CO_2 savings [t CO_2/yr]
SO_2 savings [g SO_2/yr]
NO_x savings [g NO_x/yr]
PM10 savings [g CO_2/yr]

2.2.3. General Economic and Demographic Impacts on District Level

The assessment of general economic and demographic impacts can help to understand the economic effort for each solution and their sustainability, measuring the return on investment (ROI), use of public funds, savings linked to energy efficiency or self-production, etc. These indicators can be relevant for the replication of solutions and the attraction of funds. In addition to that, demographic indicators such as residents in selected areas and employees, and persons directly involved in the jobs help to measure the indirect impacts of the implemented solutions on the district level. Table 5 shows the relevant KPIs to describe the economic and demographic impacts.

Table 5: General economic and Demographic impacts on district level

General Economic and Demographic Impacts On District Level
Residents in Selected Areas [#]
Employees and Daily Visitors in Selected Areas [#]
Persons Directly Involved [#]
Average Reduction Of Energy Bill per Household in Refurbished Buildings [€/yr]
Average Reduction In Maintenance Costs per Household in Refurbished Buildings [€/yr]
Average Reduction In Total Housing Cost Per Household in Refurbished Buildings [€/m²yr]
Individual Cost for Living (Focus on Energy/Housing & Transportation) for Citizens[€/month]
New Business Models Developed and Validated [#]
Jobs Created (Directly) [#]
Jobs Created (Indirectly) [#]
Disposable Income of Citizens in Lighthouse Districts [€/month]

Discretionary Income of Citizens in Lighthouse Districts [€/month]
Investment In Construction Solutions [Million €]
Investment In Energy Solutions [Million €]
Investment In Mobility Solutions [Million €]
Investment in ICT [Million €]
Investment, total [Million €]
Leverage effect of EC funding [%]

2.2.4. Data collection and challenges

Besides the development and distribution of the Monitoring and Evaluation Manual, and the different templates prepared to collect data from all demo sites, the project team also put in place a procedure to ensure a fluid communication between the Monitoring and Evaluation team and the three lighthouse cities. This procedure involved several steps and was designed so that all relevant information would be collected during the project duration at relevant moments, giving the opportunity to both the cities and the evaluation team to exchange information, solve questions, and share updates on the collection of data. This process involved i) regular meetings with the monitoring team and the cities, ii) planning and adjusting exercises to ensure that the monitoring activities were planned despite calendar changes, iii) establishment of a data management plan at early stages of the project, and iv) defining internal mechanisms to share data once it became available.

For some solutions, the development of data analysis workflows for processing of baseline and monitoring data was done in Jupyter Notebook platform, an open-source web application, which supports many programming languages and allows creation and sharing of data analysis documents. These documents can contain live code, equations, visualisations and narrative text. One of the reasons for using Jupyter Notebook was the possibility to easily export the work as reports or share it with other stakeholders for review. Separate workflows were developed for ingestion and pre-processing of baseline and monitoring data, calculation of KPIs and exporting of results. Additional datasets necessary for performing the analyses included both time series datasets and static information and were collected from cities in cases where they had access to them, or from publicly available databases otherwise. If specific information, such as weather data, primary emission factors or primary energy factors, weren't readily available from the solution monitoring data, next best data source was sought at the increasing level of aggregation (city, region, country).

During the project implementation, the advent of the Covid-19 pandemic and the consequent lockdowns prevented partners in Glasgow and Rotterdam from conducting the necessary works to install some of their solutions, which in several cases could not be finalised until very late stages of the project. These circumstances affected the availability of monitoring data for some of the solutions, as well as the calculation of some of the KPIs. The monitoring team took care of cleaning the data and identifying any lacking datasets to calculate the KPIs for the different solutions.

In Rotterdam, some of the data were obtained through the Simaxx data portal, although in some cases the data sampling frequencies were lower than anticipated, in some there were data gaps, and some data points were discovered to be faulty and had to be repaired, which also resulted in data gaps. For those solutions that were not connected to the Simaxx portal, local partners shared the data by exchanging files via the data sharing platform. For each solution, a data analysis method was selected depending on the structure of the final dataset provided to the monitoring team, and the properties of the available data. For instance, some parts of the available data for R1 were used to calculate the contribution of the geothermal storage for heating purposes. BEST SHEETS were also used to assess the performance of the solutions with the expected forecasted values for each building.

For the solutions in Umeå, the team spotted some consistency problems with the baseline data, including some time gaps in the datasets. These problems could be solved by performing linear interpolation to fill in the gaps and by cleaning the extreme values that were out of a given range defined for each dataset. For several solutions more extensive data cleaning was necessary. Moreover, the primary energy and CO2 savings calculation of the smart thermal cluster solutions required the use of hourly marginal data for the primary energy factor and the CO2 content of the local district heating system.

In the case of Glasgow, the availability of data or its level of detail was a challenge for several solutions, also considering the late implementation of some of the solutions. In some cases, simulations were used to estimate the potential impact of the solution. One of the most complex cases was solution G4 with the EV charging hub, because of delays in the installation of some components. However, for that case, the issues were solved by converting the event-based charging data into a power load time series and by simulating the missing PV canopy using weather data from the relevant year of EV charging measurements. The impact of a battery storage system on the interactions between PV canopy and charging hub is assessed in G2, where a battery storage system was simulated in combination of data from G5 and G4.

2.3. Monitoring and Evaluation framework for the non-technical outcomes (qualitative evaluation)

In addition to technical impacts, non-technical impacts are also important and need to be assessed because they complement the outcomes of the technical solutions. As a result, the focus of the non-technical outcomes is on the development of business models and the evaluation of the social impact of the implemented solutions. For the social impact, those solutions with interactions with users are at the centre of the inquiry. Furthermore, an introduction to the main procedure of qualitative monitoring on the implementation is introduced within this section. The following sections outline the methodology for the business model analysis, social impact assessment and qualitative monitoring.

2.3.1. Business-model impact assessment

The business-related process evaluation includes the assessment of the development of new business models for Smart Cities solutions. Starting from a traditional and hierarchical form of supply and demand of energy, towards an increased emphasis on collaboration and sharing, it is essential and insightful to study how new business models for sustainable energy solutions are developed.

2.3.1.1. Theoretical framework

Business Models (BM) are essentially a set of key decisions which determine how an organization earns its revenue, incurs its costs, and manages its risks. Innovations to the model can be viewed as changes to those decisions: *what* your offerings will be, *when* decisions are being made, *who* makes them, and *why*. In this analysis, we want to conceptualise the basic BM characteristic as encompassing “objective relationships, based on contracts and organizing routines” as well as “their collective cognitive representation” (Doz and Kosonen, 2010:37). In this way we understand the BM as a type of governing collaborating function that not only affects the individual firm, but also its collaborating actors. Making the BM more relevant for the network of actors’ part of the solutions in RUGGEDISED. This allows the BM to be used beyond capturing individual firm but rather portray the collaborative function of governance and makes it more relevant for the network of actors in the solutions in RUGGEDISED:

This section takes its standpoint from a Multi-Level Perspective (MLP). The core unit of analysis in MLP is the socio-technical regime which is composed of various actor groups, institutions and infrastructures aligned around the secure and predictable delivery of a particular societal function, such as heating, shelter or mobility (Rip and Kemp, 1998). The transition from one regime type to another involves a fundamental reordering and realignment of both the social and technical components of systems. On the other hand, systems are viewed in dynamic-evolutionary terms, the causal interactions between actors, institutions and material infrastructure shape system change.

To be able to determine the possible usefulness of moving/or scaling a BM towards other cites a systems level analysis should be made towards the technology in relation to BM development. This shows how the innovation/technical solution can be understood to be embedded within the context and in which way a BM might fit within a system. A socio-technical system from a city perspective is always contextual in the details and at the same time similar, just as the way that most cites also share some commonalities (Caves, 2005). Integrating an MLP-system approach towards BM development could determine i) how the BM fits within the larger system of the city. ii) what features of the BM/system needs to be changed or altered to allow for the BM and technical innovation to be utilized, iii) If the BM is a hindrance or enabler of the technical innovation and could allow niche innovations to move into the regime or iv) if the BM itself can be seen as an innovation that could impact the system towards a more sustainable configuration.

The MLP is an analytical framework that describes transitions from a macro perspective i.e. it is a system level analysis. The main benefit of putting BM together with a system level analysis is that this approach provides an emphasis on interdependencies and interactions between different system components; MLP illuminate different aspects of the co-evolutionary relationship between BM and socio-technical transitions. It can demonstrate through a focus on these interdependencies how the BM fits within a particular empirical system context. Given the MLP framework, a BM can be understood to have different positions within a system depending on their value proposition, interdependencies and/or structure. The analysis conducted during RUGGEDISED takes inspiration from Bidmon & Knab (2018) and positions three possible examples of how a BM can be positioned within the MLP system approach:

- As representation for Industry logic

There is one position where the BM act as an “industry logic”, it is part of the established way of doing business and as such part of the current socio-technical regime and reinforces its dynamic stability. BM tend to reflect a series of ideas on how an organisation *should work*. This understanding tends to converge within an industry so that over time a typical organizations' BM logic also converges towards a common dominant industry logic (Bettis and Prahalad, 1995). They form in this way an additional barrier to societal transition but at the same time also demonstrate how a BM can function within a given industry logic.

- Devices to commercialize technology:

BM allow organizations to turn technological inventions to commercially viable innovations. The BM spans and contextualizes technology; in other words, it is a broader concept than technology (Wells, 2013). BM can function as a link between the technological niche and the socio-technical regime and facilitate the stabilization and breakthrough of novel technologies. This is linked to the industry logic above but puts greater emphasis to the technology being commercialized rather than the BM itself.

- Subject to innovation:

BM can be subject to innovation itself (Massa and Tucci, 2014; Teece, 2010; Zott et al., 2011), as they redefine the way an organization creates and captures value. The development of novel BM can be driven by new technologies, changing environments, competitions or novel market demands (Bidmon & Knab 2018). However, often times a successful BM for one product or service needs to gain traction and scale, especially when the BM depends on market creation rather than fitting into an already existing system or consumer market.

The MLP postulates that after a phase of experimentation at niche level one dominant technological design becomes the standard followed by a growing network. The standards and design specifications, which were still in flux in the phase of experimentation, gradually align in the phase of stabilization and the emergence of rules and routines around the novel technology prepare the breakthrough from niche to regime level. Transition research has identified three sub-processes that need to take place in this phase (Geels and Schot, 2010; Hoogma et al., 2002):

a) the articulation of expectations and visions to align different actors' activities and attract attention and funding,
b) learning processes to improve performance
c) the building of social networks

This theoretical framing will provide two things in the forthcoming analysis: First, it will position scalability in relation to a system understanding through the testing and tentative development of a method for BM system evaluation. And second, it will point towards what potential the analysed BM has as part of a sustainable transition in any of the two possible positions (as part of industry logic will probably not shift the system towards a sustainable transition).

2.3.1.2. Methodology

The BM analysis aims to provide understanding for the lighthouse cities on the possible scalability of the business models (BM) of some of the RUGGEDISED solutions (see Table 6). The selected solutions were specifically identified as having a focus on energy related heat/cold functions, making them somewhat comparable. Given the particularity of the technical solution and how the BM are connected to them, scalability is here referred to as the probability to transfer some or all the features of the BM *and the technical solutions* to another part of the city. The analysis made can also be useful regarding the replicability of BM, i.e. taking a BM into a completely new context. This means that the technical solution must also be taken into consideration when evaluating scalability, they are both parts of the same socio-technical system context.

Table 6: Analysed technological solutions from the RUGGEDISED project in each city

Rotterdam	Umeå	Glasgow
R1: Smart thermal grid	U1: 100% RES	G2: EV-charging hub battery storage in car parks
R2: Thermal energy from waste	U3: Geothermal storage	
R3: Surface water H/C collection		

R4: Pavement H/C collector		

The primary data for the delivery comes from semi-structured interviews based on the CCC interview guide. The interviews were based on a semi-structured approach as this enables flexibility within the interview situations at the same time as it permits a comparison of data between different contexts (Bryman 2012). Data was gathered via online interviews and compiled into themes corresponding with the MLP theoretical perspective and BM analysis. An embedded case study approach was utilized where the RUGGEDISED project formed the overarching case and boundaries, and the BM evaluated the embedded cases.

Table 7: Interviews held during the evaluation

Rotterdam	Umeå	Glasgow
Representative of Eneco	Representative of Region Västerbotten	Representative of Simens plc.
	Represenatitve of Umeå Energi	

Four interviews were held during this evaluation, the original intention was to have at a minimum of 2 interviews for each BM development/city. However, in spite of repeated attempts, only one from Rotterdam, one from Glasgow, and two from Umeå agreed to discuss the BM work that has been done in their city respectively. The work with this delivery began during the COVID-crisis and, perhaps, this can explain why it turned out to be so hard to get hold of respondents, there were more pressing matters at hand that needed attention. It has to be said that this is problematic for the validity of the conclusions that might be made from this report. The report has by necessity thus become more conceptual than was originally thought in order to still be relevant and valuable for the target group. The last interview, with a Glasgow representative, took place much later than the other two cites. This has to do with the Glasgow delivery being finished at a later stage. This does not affect the results in any large extent as each city is treated as its own embedded case study.

2.3.1.3. Context and Critical Conditions (CCC) for understanding scaling potential or implementation of BM

The MLP framework is a macro-system theory and often not very well suited to provide means for practical analysis. It is an abstract understanding of a system, and some form of translation needs to be made in order to go from an abstract idea to a useful method. This is especially important when the point is to provide insights into how a certain concept functions in one system (or context) in comparison to another system (or context). The basis for this method comes from previous work done by the EU co-funded project "ECOPOL" (2011-2014, DG ENV). The tool "Context and Critical Conditions" was developed to help actors to replicate policy measures that accelerate eco-innovation and respond to regional demands (more information on the tool can be found at https://www.ea-stmk.at/ecopol-ccc1.) In this paper the CCC has been adopted towards BM-analysis for two reasons:

- As a frame of reference for the conducted interviews and structure of the empirical material, allowing for a focus on the system context.
- To help city actors evaluate the BM in relation to scaling and sustainable transition in their specific city.

The tool is simple and intuitive enough to allow for a wide range of different stakeholders to use it while also being able to capture the essential parts of “a system”. Development of a practical way of understanding the potential of BM scale up in relation to a system could greatly improve scale up potential. An important limitation is that the CCC for BM is only conceptually developed here, real life testing needs to be done in order to validate and evaluate its usefulness. Also, as the CCC tool was developed for something very different than BM analysis some of its features were not able to accommodate a BM evaluation or was nonsensical. These were removed or changed while still preserving the CCCs main characteristics. The CCC framework, closer to its original form, was also utilized in the RUGGEDISED Urban system analysis (D6.3). The work in this delivery is thus a continuation in the development and modification of the CCC framework partly connected to D6.3.

2.3.2. Qualitative monitoring

In the RUGGEDISED project, the Monitoring and evaluation Work Package (WP5) assessed to which extent the ambitions of the project were met. The monitoring aimed to support the RUGGEDISED cities in their replication of smart solutions at the end of the project as well as other European cities who want to prepare for the implementation.

Besides the quantitative monitoring of the solutions performance and the assessment of their impact, the project also foresaw the execution of a qualitative monitoring of their implementation. This approach aimed to identify which measures were implemented, in what way they were implemented, and the main factors influencing the implementation of the different solutions. This monitoring approach is further detailed in the Deliverable 5.6. “Qualitative monitoring of the implementation of smart solutions in the Lighthouse cities” (D5.6.). Specifically, this deliverable describes the insights from the monitoring of the qualitative aspects that influenced the implementation of smart solutions in the Lighthouse cities and the alignment of these solutions with their strategies. This assessment was based on a monitoring framework developed in Task 5.1, consisting on the following:

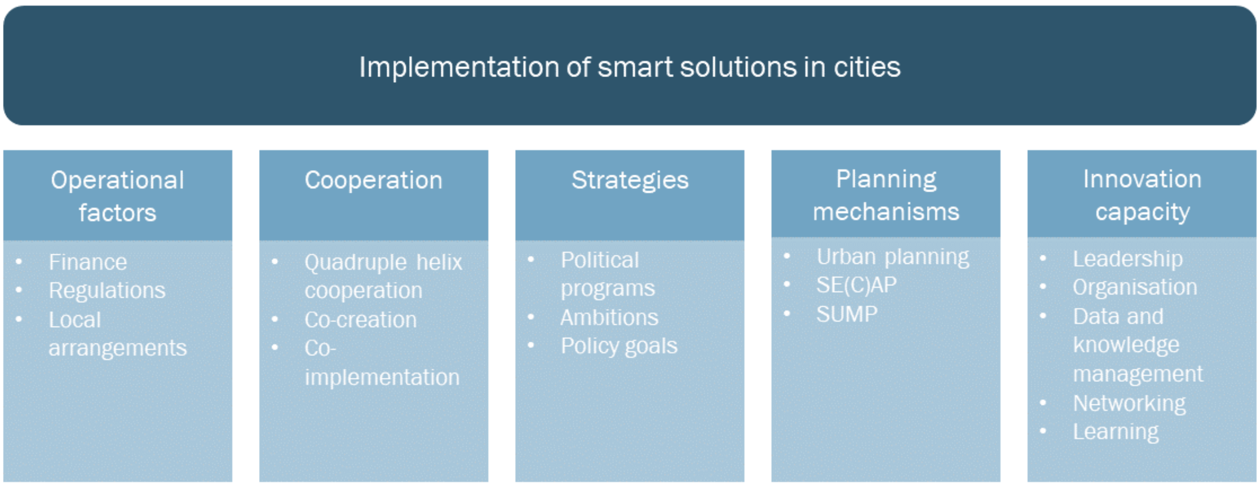

Figure 4: Monitoring Framework: factors relevant for the implementation of smart solutions in cities

Based on this framework, the implementation of smart solutions by a city can be affected by factors within five categories:

- **Operational factors** have a direct influence on implementation. The city can support the implementation of the smart solutions, for instance on financing and regulations and laws. Also, local arrangements can play a role. On the other hand, the lack of well-suited finance, regulations, or other local arrangements can hamper or even obstruct the implementation.

- **Cooperation factors** between the city and other actors as well as within the municipal organisation is necessary in the process of implementing the smart solutions (innovations). The actors of the innovation ecosystem in the city (from the Quadruple Helix: government, industries/businesses, knowledge institutes and citizens/ civil society actors) should be involved to adapt the smart solutions to the local context (co-creation), to assess obstacles for implementation and develop recommendations for removing these, and to support the implementation of the smart solutions in different ways (co-implementation).
- **Strategies of the city**, in which the project and its activities are embedded. These refer to the political program of the City Council, and the ambitions and policy goals that have been established in their strategic plans.
- On the tactical level the implementation is related to the several **planning mechanisms** of the city: the Urban Plan for a district or an area as an overarching plan, the SE(C)AP for energy measures and the SUMP for mobility measures.
- The **Innovation Capacity of the city is** an overarching factor for innovation consisting of the capabilities or capacity that a city needs to possess in order to stimulate innovation. This comprises several factors such as : i) leadership and ambitions of the city on innovation, and how these are included in policy documents or roadmaps; ii) organizational support to innovation and internal culture, iii) the capacity to deal with data and knowledge in an open way, iv) capacity to establish relevant networks with external stakeholders and cooperate with them, and v) the internal capacity of the institution to learn and adapt to new solutions and challenges.

In order to assess the importance and impact of these factors in the implementation of the different solutions in each city, the qualitative monitoring team conducted a series of semi-structured interviews with representatives of the different cities. The interviewees were all considered primary stakeholders and were part of the project teams in the respective cities. At least one interview per city focused on the implementation of each smart solution and the operational factors in each implementation process, and another put further emphasis on the planning mechanisms, strategies, and innovation capacity.

A more extensive explanation on the qualitative monitoring framework and the results of this analysis can be accessed on the D.5.6. A brief extract of the main findings is also provided in the current report in section 0.

2.3.3. Social Impact assessment

The key goal of the social impact assessment was to gather expectations from stakeholders and to follow up on experiences gained throughout the implementation of the smart solutions. The underlying framework used "quality of life" as a guiding concept. This encompassed, both from an individual and a community perspective, the awareness, acceptance, and perceived impact of the smart solutions developed throughout the course of the RUGGEDISED project. In the analysis, quality of life was analysed according to the personal, social, and work context.

2.3.3.1. Methodology

Table 8: Overview of the social impact assessment methods

Methods:
Feedback questionnaires

Objectives:
Quantify the social impact of different solutions
Assess the impact of the city's urban development projects on quality of life, awareness perceived and acceptance of smart solutions
Target groups:
Dwellers, commuters, businesses and visitors etc.

In order to investigate the perceived impact of the different interventions and smart solutions featured by the RUGGEDISED project on stakeholders' (dwellers, commuters, students, etc.), Quality of Life (QoL) and acceptance, a comprehensive feedback questionnaire was distributed in each lighthouse city. The stakeholder feedback data obtained via the questionnaire was used to quantify the social impact of different smart solutions by gauging user opinions, expectations and perceptions and comparing their statistics over time. The questionnaire was supposed to be filled out by representative samples from each relevant stakeholder group (residents, commuters, visitors, etc.) of the demonstration areas targeted in each lighthouse city. The questionnaire captured the demographic background and the perceived impact of the city's urban development projects on Quality of Life, awareness, and perceived impact of the RUGGEDISED project, as well as acceptance of smart solutions.

The investigation has been adapted for the three sites, based on the implemented solutions, and the interests, constraints, and support capabilities of the local partners. For Umeå, inhabitants of the University student campus were in the focus of interest. For Glasgow, visitors of the city and members of the University of Strathclyde expressed their expectations, and citizens' experiences with the demand side management used cases were analysed. In Rotterdam, target employees of the Ahoy Center and other businesses in the area were identified and approached, to understand the implicit impact of the novel implemented solutions

2.4. Reading guideline

This deliverable is structured by the different impact dimensions of the project at the city and solution level. At the beginning the overall impacts results of the RUGGEDISED project is outlined describing the main benefits from

- Technical performance assessment
- Environmental impact assessment
- Business-Model impacts assessment
- Qualitative monitoring
- Social impact assessment.

Followed by the benefits and a whole picture of the project, the description of the impacts for each of the cities follows the same structure. At the solution level, a description gives an overview of the interventions, expected impacts and the results of the technical and non-technical impact assessment. It should be noted, that to this stand of the deliverable, some solutions have just recently been implemented and the monitoring is not finalised, hence some data is still unavailable to be included in the report.

3. Benefits of the RUGGEDISED project

What has RUGGEDISED as a project reached in the last 6 years?

The RUGGEDISED project has set the goals to improve the citizens' quality of life, by creating a clean, safe and inclusive and affordable living environment. It aims to the reduce the environmental impacts by a reduction of CO_2 emissions and increase the leverage of renewable energy sources and deployment of electric vehicles. Within the project an environment for exploring and creating sustainable economic development is targeted by generating new jobs, involvement of citizens and cooperating with start-ups and existing companies to develop green digital economy and internet of things. All these targets have been achieved by the implementation and testing smart solutions.
At the moment of writing this report the technical performance, environmental and social impacts of 27 solutions have been captured, which are detailed in the following sections.

3.1. Technical performance assessment

The technical impact assessment of the project is structured in technical and environmental impacts that are further differentiated in solution clusters. These cluster are the building energy efficiency cluster, the smart thermal grid cluster, the smart electric grid cluster, and the mobility cluster. The following sections provide an overview on the impacts achieved by RUGGEDISED within these clusters and state the generated KPIs. Where possible, the KPIs were aggregated over the three lighthouse cities. As some solutions could not be implemented during the project, initial target values were not applicable. Beside others, the KPIs include primary energy consumption reductions and CO_2 emission reductions.

As detailed in Table 9, the project has led both primary energy savings and CO_2 emission savings. The mobility cluster solutions had the biggest impact on CO_2 emissions, as electric vehicle charging stations were implemented in Rotterdam, Umeå and Glasgow. 20,797 m² of new buildings were implemented with energy standards that reach far beyond the minimum requirements set by the relevant building code in each city. Additionally, 58,244 m² of buildings were refurbished, leading alltogether to the mitigation of 9,461 tonnes of CO_2 emissions per year.

Table 9: Impact assessment of the RUGGEDISED project

Impact Assessment of the project	
KPIs	Achieved Impact
CO_2 emission reduction of building and district cluster [t/yr]	5,919
Primary energy consumption reduction of building and district cluster [MWh/yr]	21,993
CO_2 emission reductions smart thermal grid cluster [t/yr]	133.6
Primary energy consumption reduction smart thermal grid cluster [MWh/yr]	1,109
CO_2 emission reductions smart electric grid cluster [t/yr]	1,191
Primary energy consumption reduction smart	3,731

electric grid cluster [MWh/yr]	
CO2 emission reduction of mobility cluster [t/yr]	2,218

Table 10 presents the technical performance at the project level per cluster. In addition to the primary energy and CO2 savings presented in the previous table, relevant KPIs have been calculated for the different clusters. The solutions implemented within the smart electrical grid cluster have led to 2,622 MWh of electricity generated per year, corresponding to an installed RES capacity of 3 MW. Besides, 55 buses with alternative energy carriers and 2 E-Hubs have been implemented within the mobility cluster.

Table 10: Technical performance assessment of the project

General assessment of buildings	
KPIs	Achieved values
New Built Floor Area, Residential[m²]	20,797
New Built Floor Area, Tertiary Buildings[m²]	43,854
Refurbished Floor Area, Total[m²]	58,244
Cluster of solutions to increase the energy efficiency at building and district level	
Energy Savings by Building Efficiency Measures [MWh/yr]	2,480
Final Energy Savings by street lighting interventions [MWh/yr]	5,992
Final Energy Savings by waste management interventions [MWh/yr]	776
Primary energy savings by building energy efficiency measures and street lighting [MWh/yr]	21,993
Smart Thermal Grid Cluster	
Thermal Energy Generated [kWh/yr]	325,340
Thermal Storage Energy Used [kWh/yr]	325,340
Primary energy savings by cluster[MWh/yr]	1,109
Smart Electrical Grid Cluster	
Electricity Generated by RES [kWh/yr]	2,622,695

Electricity Storage [kWh]	640
Installed RES Capacity Electricity [MWh]	3
Primary energy savings by cluster [MWh/yr]	3,732
Mobility Cluster	
Number of Vehicles with Alternative Energy Carriers (Excl. Electricity) [#]	55
Number of e-Hubs [#]	2
Energy Savings by Mobility Measures, Total [MWh/yr]	5,210

3.2. Environmental impact assessment

The environmental impacts assessed in RUGGEDISED mainly concern emissions to the air and the use of primary energy. The air emissions assessed include CO2 emissions, SO2 emissions, NOx emissions, and PM10 emissions. Table 11 summarizes the environmental impacts. The solutions implemented, contribute to a reduced climate impact and primary energy use of the lighthouse cities. Also, local air quality was improved by solutions from the mobility cluster.

Table 11: Environmental impact assessment of the project

Cluster of solutions to increase the energy efficiency at building and district level	
KPIs	**Achieved values**
CO2 Reduction Achieved by Building Efficiency Measures[t/yr]	90.5
CO2 Saving street lighting[t/yr]	5,497
CO2 Reduction street lighting [%]	52
CO2 Saving waste mangement [t/yr]	331
Smart Thermal Grid Cluster	
Primary energy savings [MWh/yr]	1,109
CO2 savings [tonnes CO2/yr]	133.6
Smart Electrical Grid Cluster	
Primary energy savings [MWh/yr]	3,732
CO2 savings [t CO2/yr]	1,191

Mobility Cluster	
CO_2 savings [t CO_2/yr]	2,218
SO_2 savings [g SO_2/yr]	23,464
NO_x savings [g NO_x/yr]	367,129
PM10 savings [g CO_2/yr]	21,128

3.3. Business-model impact assessment

In order to evaluate the prospects of BM growth and replication one needs to have an understanding of the wider interactions between infrastructure, institutions and actors that constitute a system in relation to the local context. This analysis shows the dynamic relationship between BM and the larger context it is embedded in. Understanding the synergies and alignments that come into play relative to the socio-technical systems can be a fruitful way of conceptualizing the challenge of governing sustainability transitions through BM innovation (Bolton & Hannon 2016).

The impact of each of the three solutions and their BM on the lighthouse cites cannot be summarized together. No one could point to a city-wide impact, and they also had difficulty putting a clear "quantitative value" on the work done. Instead, the three cities emphasized the learnings and new social network/connections as the most valuable from the process of implementing / working with these innovative solutions.

Following the BM impact assessments of a selection of solutions implemented during the RUGGEDISED project, it is suggested that a closer collaboration between those actors involved in the BM development in Umeå, Glasgow and Rotterdam should be established. There are lessons to be learned that can cross-fertilize future work in each city on sustainable solutions. It can also be a way to understand if the BMs discussed here should be replicated in another city. A possible way might be to do a joint CCC exercise with Umeå, Glasgow and Rotterdam for each of their BM to understand its possibility to scale and replicate.

As a final reflection over the analysis conducted during the project, three questions can be raised in order to highlight the risk management of the BM that have been outlined in this report. These questions are linked to the MLP framework and can become a central focal point for city actors that seek to implement the BM in other contexts. Focusing on these three questions can be a method for city officials and stakeholders to lower the risks at implementation:

A socio-technical system is always influenced by trends on the landscape levels, the "gradients of force". It affects the BM and might make it inflexible in another context.

a) The central question to ask is if there are dominant trends and developments that for some reason are difficult to deviate from, and which are rigid in the sense that it is difficult to change them on an individual base (e.g., globalization, climate change, ageing populations, etc.). Basically, is it the same or different forces from the landscape that will affect the BM in this new context compared to where it is situated now?

Prevailing evolutions and trends exert external pressure on the systems in place. A regime refers to the dominant culture, structure and practice embodied in physical and immaterial infrastructures (e.g., roads, power grids, routines, actor-networks, regulations, government and policy, etc.). Regimes are the backbone of the stability of societal systems and have a characteristic rigidity that very often prevents innovations from altering the standing structures.

b) Hence, a central question that needs to be answered is: How does the regime differ in this new context in comparison from where the BM was developed?

Niches are often little visible small-scale segments in society. In such protected environments, novelties are created and tested. These novelties can be (combinations of) new technologies, new rules and legislations, new concepts, new organizational arrangements, etc. Niches contain incubators for transitional experiments and proof of concepts of radical innovations. As outlined in the analysis above, a BM can fit into niches in a variety of ways depending on both the technology and the BM.

c) The question is thus split into two, what type of BM is under question and how do they influence the innovations coming from the protected niches?

In conclusion, the scaling potential of the BMs is overall positive. With a proper analysis of the context beforehand to understand how much work will be needed, all the BMs can be moved into other districts or cities. The theoretical framework from Geels and Schot, (2010); Hoogma et al., 2002) articulates some of the criteria needed for BM to be transformative:

a) align different actors' activities and attract attention and funding,
b) learning processes to improve performance
c) the building of social networks

All three BMs fulfil this, meaning that they have a potential system change and regime transition. However, the BM in all three cities represents a different way of understanding BM than what is the current norm. This creates a possible leap of knowledge and learning on how innovative solutions can be part of a cites sustainable transition, but it also means that short-term impact evaluations are difficult to perform. Thus, the benefits of the BM might be too early to evaluate in monetary value in a meaningful way at this stage. Instead, they should be seen as valuable and beneficial on their own as useful examples of BMs as a method for sustainable energy transitions in European cities.

Qualitative monitoringThe monitoring framework prepared in the RUGGEDISED project comprises both quantitative as well as qualitative monitoring. This section offers a high-level overview of the observations contained in Deliverable 5.6 (D.5.6), in which insights from the monitoring of the qualitative aspects that influenced the implementation of smart solutions in the Lighthouse cities are detailed.

For each lighthouse city (Rotterdam, Umeå, and Glasgow), D.5.6 describes which measures were implemented, in what way they were implemented and which factors affected the implementation processes. In fact, the results of the qualitative analysis conducted on the implementation of the different solutions can be seen as a set of narratives that explain why, how and when the implementation of smart solutions took place, while describing the unique context and implementation dynamics of each Lighthouse city.

This analysis was conducted following the methodology briefly presented in Section 2.3.2, which consists on the following five implementation factors:

- Operational factors in implementation of smart solutions
- Cooperation
- Planning
- Strategies

- Innovation capacity

Upon the analysis of the qualitative information obtained through extensive interviews with primary stakeholders from each city, it was found that the majority of the intended measures – 26 out of 32 smart solutions – were (partially) implemented. It was also consistently observed that many changes took place in the implementation phase, and it was clear that the implementation processes were each affected by a variety of factors in the different cities.

Indeed, the implementation processes in the Lighthouse cities were characterised by their own unique context and dynamics. While an in-depth approach for each cluster of solutions is provided in D.5.6., some prominent similarities across cities and solutions were observed:

- The most prominent **operational factors** affecting the implementation of the solutions were financial feasibility and regulations.
- **Cooperation** – both between stakeholders and within municipal organisations – is shaped by the people that are liaisons that built trust, support mutual understanding and who need to speak the same language.
- The RUGGEDISED project was positioned within the strategic context of the Lighthouses' city **strategies**. The direct impact of the RUGGEDISED project has an important demonstrational value, while its impact at strategic level is limited.
- The alignment of innovation projects like RUGGEDISED with **planning mechanisms** is crucial; misalignment can affect the entire implementation process.
- The **innovation capacities** of the cities differ, and some great examples were found of the importance of leadership, organisational support and knowledge sharing.

The RUGGEDISED project contained many valuable insights regarding the factors affecting the implementation of smart solutions, and its findings can be particularly interesting for those cities who (continue) to implement innovative measures in the context of the energy transition. Some of the following recommendations have been extracted from the analysis, to support civil servants that will (continue to) work on this transition:

Organize a continuous process of municipal internal stakeholder management for enlarging project impacts

Innovation projects like RUGGEDISED need to be embedded in the municipal organisation to ensure its impact beyond the project duration and scaling up smart solutions. This starts with sufficient support from political leaders (e.g. Mayor, Alderman) as well as the administrative leaders (directors and heads of the involved departments) to create room for innovation and flexibility in the implementation. Furthermore, it is important to align all relevant departments involved in the entire implementation process (as opposed to the predominantly sequential processes found in the Lighthouse cities). Aligning strategic and operational departments requires active and continuous stakeholder management supported by liaisons.

Invest in preparation and proactive management of smart solutions to accelerate implementation

The RUGGEDISED project has shown that the implementation processes of smart solutions often were characterised by an interplay of closely related implementation factors, being operational factors, cooperation, planning mechanisms and strategies. Implementation factors can proactively be identified and anticipated for resulting in much less implementation barriers and accompanying delays. It is highly recommended at the start of complex innovation projects like RUGGEDISED to:

- Execute (more) extensive financial feasibility studies of smart solutions;
- Assess the involved stakeholders and their organisational readiness;

- Identify the relevant regulations and potential legal barriers;
- Identify the existing knowledge base and build on lessons learned in previous projects
- Align the project goals with the relevant planning mechanisms and municipal strategies.

Furthermore, it is recommended to manage the implementation process proactively and in an integral way. As the context of innovation projects is per definition dynamic and complex, all activities listed above require continuous updates and adjustments during the project execution.

Develop and professionalise the cities' overall innovation capacity to create fertile ground for innovations

One of the key contributions of the RUGGEDISED project is the insights participants gain on how to implement smart solutions. The challenge is to embed and disseminate the insights throughout the municipal organisation and even towards the wider innovation ecosystems. Some great examples were found on the importance of leadership, organisational support and knowledge sharing. As the innovation capacity greatly differs between cities and the RUGGEDISED project first introduced this concept, it is recommended to create awareness for the importance of innovation capacity and further develop and professionalise this capacity. Cities can start by building on their strengths (such as close collaborations with knowledge institutes and universities) and exchange successful examples as inspiration.

3.4. Social impact assessment

The results from the RUGGEDISED social impact studies generally suggests acceptance of the solutions by the targeted user groups, and to match expected with actually experienced quality of life. Due to the different characteristics across the investigated use cases and their urban contexts, a number of interesting insights could be gathered. Many of the smart solutions introduced in the urban development areas were concerning infrastructure improvements or didn't directly affect citizens' daily lives. In these cases, we observed neutral to mildly positive expectations. Especially in the case of Umeå, the experience of citizens after the implementation of the solution was equally as positive as the expected impact and didn't generate complaints or rejection.

However, on the other hand, the results reported from the Glasgow demand-side management trial reconfirm that transparency, context-awareness and flexibility can be important features for citizens to make efficient use of the provided energy and to increase subjective quality of life. Moreover, it is demonstrated that socially disadvantaged population groups can highly benefit from these improvements. The evaluation at the Rotterdam site yielded notable improvements in the quality of life of the involved work force, and an impact on uninvolved businesses becoming inspired to adopt similar solutions. While not traceable, such observations are also substantial for evaluating the social impact, as they show that the project has left a legacy beyond its end-time. By influencing the decision making of external, technically uninvolved stakeholders, it proved to keep with its stated goal of accelerating the path towards a sustainable future by creating model urban areas.

4. Rotterdam

4.1. Overview of monitored solutions

Within RUGGEDISED Rotterdam has implemented and monitored 9 smart solutions in the Hart van Zuid/ Heart of South district. These solutions are distributed in three energy management and ICT, three smart and thermal grid, two smart electricity grid and e-mobility and one smart open data platform solution.

The following sections elaborate on the KPIs calculated at the city and solutions levels. The KPIs are based on the collected data from partners and the cities to assess the achieved impacts on technical (e.g. energy efficiency), environmental impact (e.g. reduction of CO2 emission) and non-technical performances such as results of business model development for a business model for Smart Thermal grid (R1), Thermal Energy from Waste (R2), Surface Water H/C collection (R3) and Pavement H/C collector (R4) and user feedback of workers and business owners of the demonstration district.

The solutions R3, R6, R10 and R12 have not been successfully implemented due to different influencing factors e.g. bankruptcy of involved companies, redundancy of solutions, economical costs. More information on these solutions can be found in the Implementation Report of Rotterdam.

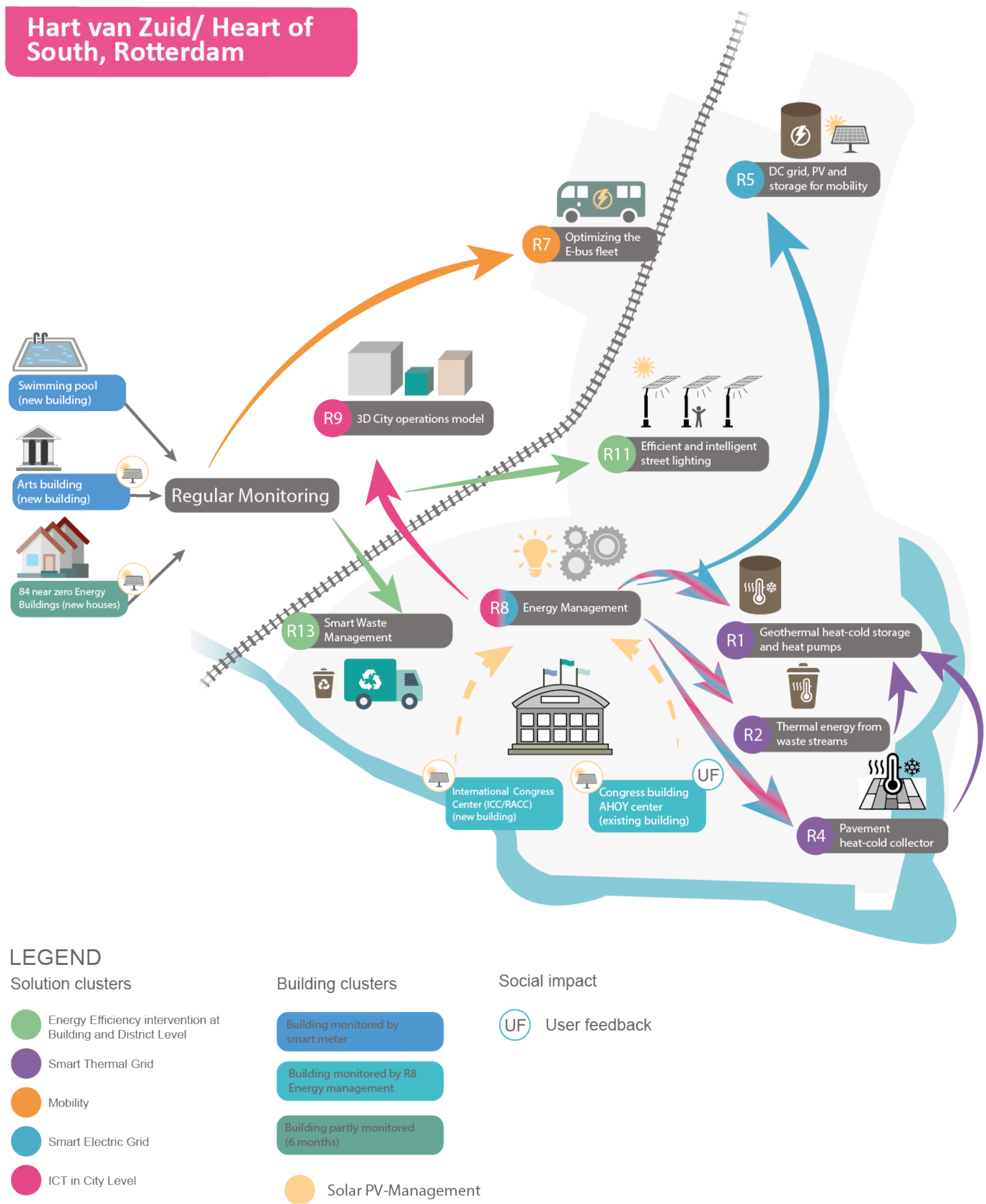
Hart van Zuid/ Heart of South, Rotterdam
R5 DC grid, PV and storage for mobility
R7 Optimizing the E-bus fleet
Swimming pool (new building)
Arts building (new building)
84 near zero Energy Buildings (new houses)
Regular Monitoring
R9 3D City operations model
R11 Efficient and intelligent street lighting
R8 Energy Management
R13 Smart Waste Management
R1 Geothermal heat-cold storage and heat pumps
R2 Thermal energy from waste streams
R4 Pavement heat-cold collector
International Congress Center (ICC/RACC) (new building)
Congress building AHOY center (existing building)
UF
LEGEND
Solution clusters
Energy Efficiency intervention at Building and District Level
Smart Thermal Grid
Mobility
Smart Electric Grid
ICT in City Level
Building clusters
Building monitored by smart meter
Building monitored by R8 Energy management
Building partly monitored (6 months)
Solar PV-Management
Social impact
UF User feedback

Figure 5: Overview of monitored solutions of Rotterdam

Action areas and number of monitored solutions in Rotterdam			
Smart Thermal Grid	Smart electricity grid and e-mobility	Energy management and ICT	Smart Open Data Platform
3	2	3	1

In the Hart van Zuid district, the following buildings are in the scope of monitoring:

- 100 zero energy residential buildings (new construction),
- Arts centre (new construction),
- Exhibition centre AHOY (new and refurbishment),
- International congress centre (new construction),
- Swimming pool (new in transformed building).

The implementation of the solutions has directly created 130 and indirectly created 300 new jobs. The investment of the whole project in the district amounts to 10 million € for energy, mobility, ICT and construction solutions.

4.2. Technical performance assessment

Table 12 and Table 13 show the calculated technical and environmental KPIs on the city level for Rotterdam. The CO2 emission reductions achieved by the solutions implemented in Rotterdam indicate that the project has effectively contributed to the advance towards the city's climate neutrality.
Within the demonstration site of Rotterdam RUGGEDISED has managed to build 56 440 m² of new floor area for residential and tertiary buildings and in total 23 364 m² of floor area have been refurbished. Cumulatively, the mobility and energy solutions implemented avoid the emission of 8715 tonnes of CO2 per year. Street lighting and mobility measures can be highlighted as the major contributors. To heat the Ahoy building, 325 MWh of thermal energy are used from the geothermal storage to avoid the use of district heating energy. The monitoring of the contribution of the geothermal storage to cooling processes in the building is ongoing but is expected to be similar.

In addition to that, the objective to roll-out sustainable transport possibilities has been reached by the deployment of 55 optimised e-buses in the demonstration area. Within the mobility cluster 2,218 tonnes of CO2 savings have been achieved.
Target values expressed in the tables are not representative in all cases because not all the solutions expected when they were calculated have been implemented, and some of them have not had the time to provide enough monitoring data before the project duration to have their contributions added to the calculations. Moreover, for certain solutions, the achieved values are higher than the targeted values, due to a change in the scope of the implementation. Indeed, most of the target values were calculated at the district scale, while their implementation and the calculation of the key performance indicators were performed at the city scale. Specific details can be found in the KPIs table of each solution.

Table 12: Technical performance assessment of Rotterdam

General assessment of buildings			
KPIs	# solutions	Target values	Achieved values
New Built Floor Area, Residential[m²]	R1 - R13	13,000	12,586
New Built Floor Area, Tertiary Buildings[m²]	R1 - R13	61,193	43,854
Refurbished Floor Area, Tertiary Buildings[m²]	R1 - R13	18,691	23,364
Refurbished Floor Area, Total[m²]	R1 - R13	18,691	23,364
Cluster of solutions to increase the energy efficiency at building and district level			
Final energy savings by street lighting interventions [MWh/yr],	R11	29	5,992
Primary energy savings by building energy efficiency measures and street lighting [MWh/yr]	R13	-	17,743
Smart Thermal Grid Cluster			
Thermal Energy Generated[kWh/yr]	R1 - R13	948,333	325,339[4]
Thermal Storage Energy Used[kWh/yr]	R1 - R13	1,632	325,339
Primary energy savings by cluster [MWh/yr]	R1-R4; R8		748
Smart Electrical Grid Cluster			
Electricity Generated by RES[kWh/yr]	R1 - R13	1,935,101	2,443,000
Mobility Cluster			
Number of e-vehicles after the intervention	R5-R7	4 (bus)	55
Number of Vehicles with Alternative Energy Carriers (Excl. Electricity)[#]	R1 - R13	2 (bus, hydrogen)	0
Energy Savings by Mobility Measures, Total [MWh/yr]	R5-R7	1,900	4,914

[4] Geothermal storage

4.3. Environmental impact assessment

Table 13 shows the environmental KPIs on the city level for Rotterdam. The CO2 emission reductions achieved by the solutions implemented in Rotterdam indicate that the project has effectively contributed to the advance towards the city's climate neutrality.

As for the technical performance KPIs calculation, the deviations between the target values and the achieved values can be explained by the fact that some solutions have not been implemented and other were implemented at a broader scale than initially planned.

Table 13: Environmental impact assessment

Cluster of solutions to increase the energy efficiency at building and district level			
KPIs	# of solutions	Target value	Achieved value
CO2 Saving street lighting[t/yr]	R11	14	5,497
CO2 Saving waste mangement [t/yr]	R13		331
Smart Thermal Grid Cluster			
CO2 savings [tonnes CO2/yr]	R1-R4; R8	1,442	26.42
Smart Electrical Grid Cluster			
Primary energy savings [MWh/yr]	R5; R6; R8		3,506
CO2 savings [t CO2/yr]	R5; R6; R8		1,173
Mobility Cluster			
CO2 savings [t CO2/yr]	R5-R7		2,031
SO2 savings [g SO2/yr]	R5-R7	435	15,100
NOx savings [g NOx/yr]	R5-R7	1,420	242,300
PM10 savings [g CO2/yr]	R5-R7	226	13,600

4.4. Economic and demographic impact

In Table 14, the general economic and demographic impacts of the demonstration area are listed. In total, it is estimated that 430 new jobs have been directly and indirectly created through the implemented solutions in RUGGEDISED. The estimated total investment of the project amounts 1.7 Million €.

Table 14: General economic and demographic impacts of Rotterdam

General Economic and Demographic Impacts On District Level		
KPIs	# of solutions	Achieved value
Jobs Created (Directly)[#]	R1 - R13	130
Jobs Created (Indirectly)[#]	R1 - R13	300
Investment In Construction Solutions [Million €]	U4, U6, U8	0.035
Investment In Energy Solutions [Million €]	R1 - R13	354
Investment In Mobility Solutions [Million €]	R1 - R13	7.5
Investment in ICT[Million €]	R1 - R13	0.9
Investment, total[Million €]	R1 - R13	1.7

4.5. Business Model Impact Analysis

In this section, we provide the outline of the empirical material gathered and analysed in relation to the Multi-Level Perspective (MLP) framework and the Context and Critical Conditions (CCC) method, described in the methodological chapter of this report.
In this use case, the focus is on the process of how the BM was developed. The BM for several solutions in Rotterdam is analysed and discussed in relation to its possibility to scale. However, the main aim of this exercise is to use the BM as illustrative case on how a BM can facilitate a system transition, while exemplifying how the CCC-tool can be used.

Business Model Case 2: Business model for Smart thermal grid (R1), Thermal energy from waste (R2), Surface Water H/C collection (R3) and Pavement H/C collector (R4)

In Rotterdam, the four technical solutions together formed an energy system that fed into the grid and which had multiple sources and multiple clients attached to it. Therefore, the BM analysed here was developed to encompass all four of the technical solutions. The development of the BM was performed by Eneco, a Dutch energy company, which designed and built the technical solution not as a joint project but as a delivery towards other actors. There was not a report specifying the BM work on this solution and hence, the analysis presented comes from interview data.

Eneco has a mission to work with the energy grid in parts of the Netherlands. Part of their tasks is to create BMs as they make many investments in the Dutch energy infrastructure. Because of this, they need to have at least an idea of costs and earnings. They have a “catch all/basic BM” which is normally adapted with inputs and outputs on a specific situation. The BM developed in RUGGEDISED turned out to be a very special situation where their BM “business as usual” didn’t fit and needed to be significantly adjusted. The major difference was that Eneco didn’t own the whole infrastructure: the municipality owned part of it: the wastewater heat and pavements. The standard BM thus had to change as the initial investments could not be made by Eneco. This fact entailed shifting parts of the BM - the investment, to the municipality. This, in turn, meant that the municipality also had to develop a BM in order to connect with Eneco and the building owner.

The respondent outlined the drive for change influencing the development of the BM. The building owner and tenant were in the process of expanding and this created three drivers for change:

- An expanded need for heating and cooling within the extended building volume.
- The building owner also wanted to outsource cooling to a third party.
- The municipality wanted the building to be more sustainable, and to use sustainable sources.

There were also some restrains that needed to be considered for the BM development. These were both project specific, making it hard to replicate in other places, or more general, making it less difficult to adjust the BM to another context. The general one was related to technical limitations related to geographical space for geothermal sources and where these can be placed. On the other side, an important project specific restrain was the economic situation that enabled the solution to happen: For the building owner it would be considerably less costly to grow the existing energy system than to connect the expanded building into a new heating/cooling system from a new vendor, as the latter would mean loss of the benefit of the tariff price regulations. However, this fact would also make the BM more complicated for Eneco, because with only one costumer, it had to incorporate multiple user and multiple sources along with unusual cost structure of heat coming into the system.

The value was outlined from each actor's perspective:

- Economic value: i) there were initial investments that needed to be made, these were mostly from Eneco who contributed with staff and technology development. A "system value" was put on this development and Eneco was paid accordingly; ii) The building owner and tenant by utilizing the tariff price regulations to its fullest; iii) Eneco charging the building owner for energy use.

- Sustainability value: generally valued high by all actors but specifically important to the municipality, the new building is connected to a sustainable geothermal source and doesn't contribute to increased CO2 emission from the city of Rotterdam.

- The building owner and tenant are able to utilize Positive PR from being perceived as sustainable from their costumer and general public. It was also a user value in increased flexibility in that the system allowing redirecting of heat or cold from one building to the next (e.g. an event in the conference centre during a 40-degree day, the heat pumps for both buildings are redirected to only cool one building.)

From a legal and regulatory standpoint, the building regulations had also an evident impact. Because the municipality of Rotterdam seeks increased sustainability, building permits need to include an independent evaluation on sustainability rating. This means that sustainable accounting and rating systems are of high relevance and a big driver for how the energy system is built and expanded within Rotterdam.

The development here had a clear socio technical part to it, the technology is interlinked with the BM and strongly influences the values listed above. The technology is both a possibility to achieve the listed value above, but it also enforces new ways of thinking of social ties involved in the technology. The logic in the technology was to expand the existing system, and this is basically one building sharing its heat and cold with another building. The consequence of this was that some stakeholders reacted with scepticism as one building is effectively transferring heat and cold away from one to the other. *'They think that I need heat/cold for my building and then if you say we are building this solution here so you will get the energy you need but we are also going to send some to your neighbours. Even though you tell them we solve this, they still think that it's strange and we have to manage that'* (Wouter IJzermans, Eneco, 2020). This meant that the project needed to find strategies to handle a changing relationship between stakeholders in the implementation of the solution. They focused not on the sustainability or economic value, rather the key that convinced the stakeholders was the possibility to use a dynamic system that could handle a higher range of heat or cold temperature.

It was mentioned that Eneco's "Business as usual BM", did not work in this project. There needed to be significant changes in how they could connect the energy solution for the building and enable innovation. But, this needed to change somewhat and a new type of BM is established in order to enable the technical solutions possibility to function within the context. It would not be prudent to call the BM developed here a BM-innovation; as it does not represent a completely new configuration. Instead, the BM is enabling the technology to get market access, and it facilitates an innovative new solution which over time might make Rotterdam a more sustainable city if this technology gains increased traction. The BM functions as intermediate between the technological niche and the socio-technical regime and facilitates the stabilization and breakthrough of this novel technology (Bidmon & Knab 2018). There are new types of relationships and alternative BM between actors and parts of the technical solutions are spread throughout the city. The BM analysed here could be a way to move towards that scenario. As the BM moves from niches into the regime it increasingly links more and more regime elements (e.g. market, policy, tech., etc.) and support its diffusion and facilitates a novel technology breakthrough (Ibid.).

The scaling potential for the BM is contingent on the above description, however in most other Rotterdam districts new buildings are developed, the drive towards sustainability is the same throughout the city and the technology is probably reasonably simple to expand. Moving the BM to another city would require a thorough analysis of that context, but from a pragmatic standpoint, the developed BM has the potential to be replicated into similar technological solutions.

4.6. Social Impact analysis

4.6.1. Focus of investigation

The investigation of the smart solutions of the Rotterdam site focused on the Heart of South (Hart von Zuid), namely Rotterdam Ahoy, the swimming centre, the arts centre and the new bars and restaurants of the Gooilandsingel. Solar panels, electric buses and heat and cold storage for Ahoy aimed to reduce CO_2 emissions and contribute to cleaner air. Furthermore, sensors in underground waste containers indicated when a container needs to be emptied, contributing to a cleaner environment. For the employees and management, "energy neutrality" was the key term for the smart solutions focused on in that area. Consequently, the awareness and expectations related to energy neutrality were placed at the center of monitoring activities.

Due to the non-residential structure of the Rotterdam Heart of South area, the main stakeholder and thus target group for the social impact inquiry were **workers and business owners**. 23 of the 33 respondents were working in Ahoy, one in the restaurant area, one in the arts center, 2 in the swimming center, and 4 worked elsewhere. In the inquiries performed in 2019, the sample was composed of 12 male and 17 female participants, with intermediate age (20 between 26 and 40, and 10 between 41 -60), as well as a vocational (10) or university education (30).

4.6.2. Expectations and Experiences

At the offset, over 80% of the respondents were aware that actions to save energy were taken at their workplace, and as shown in Figure 6, their expected benefits of energy-neutral buildings were mostly saving energy and fostering energy security.

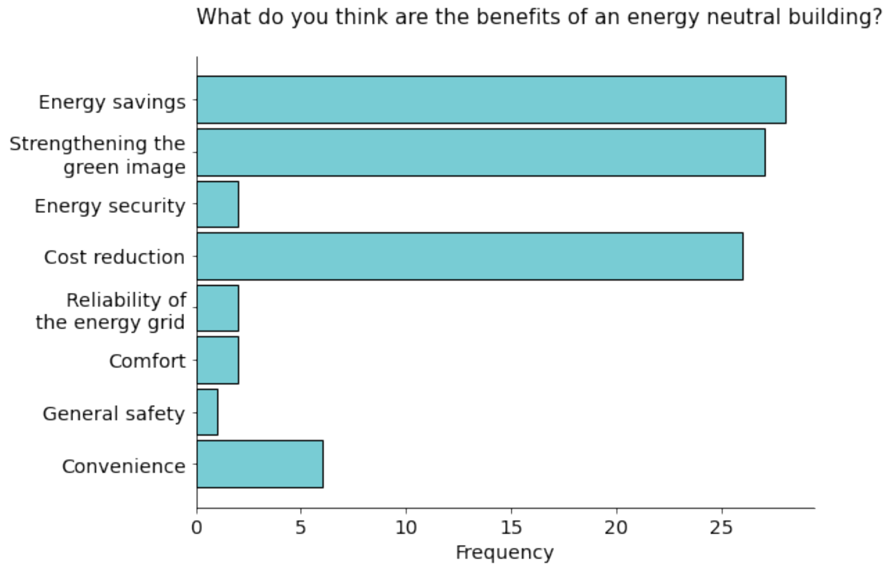

Figure 6: Perceived benefits of energy neutral buildings

In general, respondents appeared to be quite optimistic about own contributions to reduce energy consumption at the workplace (Figure 7). Respondents mostly agreed that there are multiple options to reduce energy consumption (S1) and there was also an overwhelming perception that their own contribution to energy saving is impactful (S2). When it comes to the ease of taking energy saving measures (S3), about 60% of respondents agreed that it was easy, while only 20% disagreed. The opinions were mostly split on the management's encouragement of energy saving actions (S4), where, although a slight majority agreed with the statement, a third opposed it.

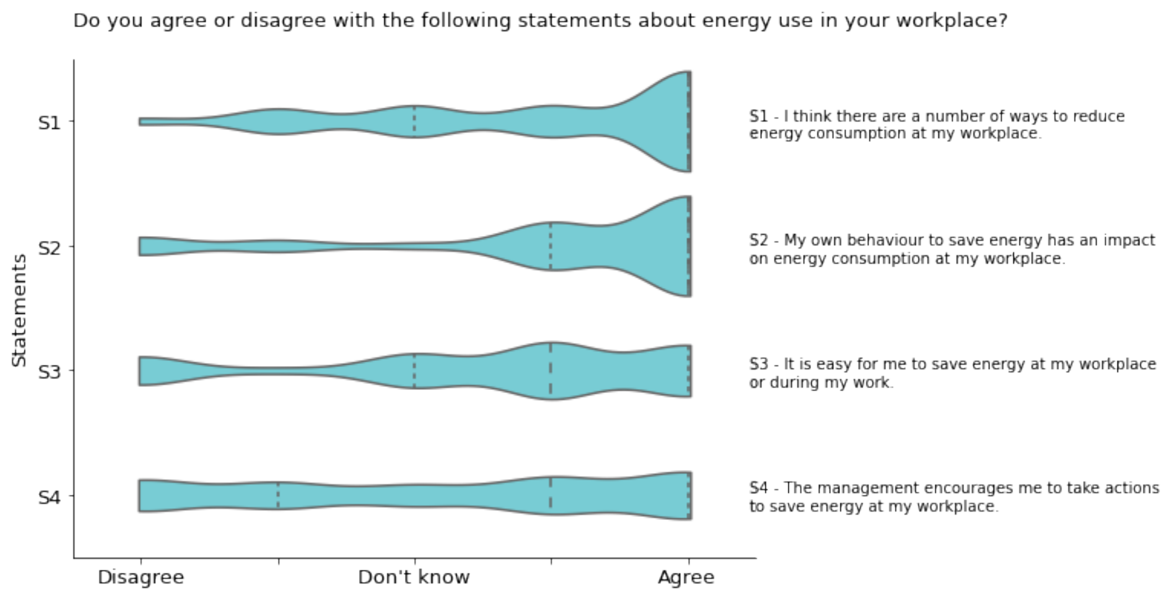

Figure 7: Agreement with statements concerning energy use at the workplace

Furthermore, when asked about potential negative effects of energy-saving measures (Figure 8) participants in most cases did not regard them as impactful towards their economic and social situations, but perceived some effect on the convenience, comfort, and reliability of their equipment at their workplace.

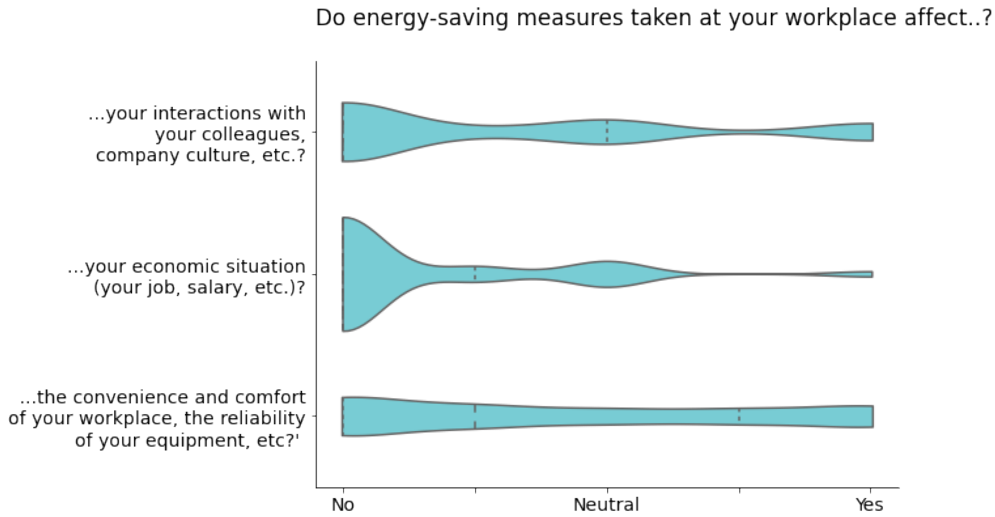

Figure 8: Agreement with statements concerning effects of energy-saving measures

4.6.3. Conclusions

The investigated demonstration site Heart of South is not a residential area, but rather a terrain for public and private events, visitor services and businesses. Thus, the experiences gained throughout the social impact assessment were focused on related needs and perceptions of stakeholders for the work and business aspects. Furthermore, like the Umeå site, many of the services implemented were not directly controlled and experienced by the users, thus responses were often rather neutral but tending to the positive side.

The assessment of the actual impact of the smart solutions on operations, work aspects and business were complicated by the small number of visitors in the two years of restrictions pandemics 2020 and 2022. Nevertheless, the activities of the RUGGEDISED project created much awareness for energy neutral building and management. Another notable outcome was that the event center's office area demanded more heating energy than its concert halls, and thus investigations on reducing energy consumption could be made even though the concert halls were not in operation during the pandemic.

As confirmed through qualitative interviews, the activities achieved notable impact by increasing awareness among the other businesses that were not directly associated with the project, such as the shopping mall. Many of these businesses were inspired to adopt and prioritize similar energy concepts in the planning of their renovation. The high visibility of the lighthouse area and its leadership in energy-neutral solutions also had an impact on the competitiveness of the event center, such as in competitions for international events.

Another consequence that should be considered is that the operation of novel energy-neutral building technologies, such as the one implemented throughout the project at the Ahoy center, require a considerable level of expertise in operation. Training concepts for engineers therefore were developed by project partners, to make the personnel aware of the necessary early preparation, estimation, and planning of events, to guarantee the optimal heating temperature for the right moment of a scheduled event.

4.7. Qualitative monitoring

The implementation of the different solutions in Rotterdam and their deployment was analysed following the qualitative monitoring framework presented in Section 3.3. of this document, which includes the following aspects: i) Operational factors in deployment of smart solutions, ii) Cooperation, iii) Strategies, iv) ; Planning mechanisms, v) Innovation capacity.

Upon analysis, it was observed that all **operational factors** had an impact on the deployment of the smart thermal grid. The most important factor was the financial feasibility, followed by regulation and a diverse set of factors resulting from local arrangements also played a role. There was a setback in the financial business case of the smart thermal grid as underground infrastructure proved much more expensive than expected. In addition, one smart solution of the smart thermal grid (R3) was not deployed because it proved financially infeasible.

Regarding regulations, the most prominent operational factor was the concession for heat that was granted to an actor who was not part of the RUGGEDISED project. Regulations therefore restricted the number of buildings that Eneco could connect to the smart thermal grid. Several local arrangements led to practical barriers to realisation (e.g. a building not being connected to the smart thermal grid due to a mismatch in planning of the construction and insufficient support of the operational department) and changes in the locations of deployment.

In terms of **cooperation**, the RUGGEDISED project team cooperated with different stakeholders: the project team responsible for the area's development of Heart of South, and private contractors in charge of deploying the solutions. This was a more challenging factor, as the dynamics of the cooperation were sometimes hampered by competing calendars and timings and changes in contractors. Part of these challenges are linked to the only incipient technical maturity of solutions, which involves more intense cooperation between actors and staff members.

Regarding the **strategic framework,** there are three major strategic developments in Rotterdam that have influenced the RUGGEDISED project, the Rotterdam Energy Approach, the Rotterdam Climate Initiative and the Rifkin method. In 2009 the Rotterdam Energy Approach (REA) was developed. It was found that the ambitions of the city council also impact the extent to which there is a fertile ground for innovation projects like RUGGEDISED. In Rotterdam, at the start of RUGGEDISED the solutions suited the city ambitions and its Smart City program. Moreover, the RUGGEDISED project proved to be a springboard for several spin-offs within the municipality. Not only in terms of scaling up measures but also at the more strategic level. The most prominent example is the fact that RUGGEDISED was at the basis of a citywide Digital Program. In terms of planning mechanisms, RUGGEDISED also had a positive influence in the city: at the start of the project, the deployment of the district heating net was the primary focus of the municipality and other energy solutions were not addressed. The RUGGEDISED project team created room to look at more sustainable solutions. The project staff gained a better position in the organization and were increasingly given a place at the table when policy plans related to sustainability are discussed. In this way, they were able to provide input in new plans such as the energy system vision.

Finally, the qualitative monitoring also analyzed the relation of the project against the city's **innovation capacity**, considering five categories (leadership, innovation support, data and knowledge, networking and learning capacity). The main observations signal that in terms of leadership, the project benefited from a political instance such as the Mayor, and also from the existence of figures such as the alderman for Sustainability and Energy Transition. Both the mayor and the alderman supported and backed the RUGGEDISED project team in their work. The city has also an extensive network and capacity to generate knowledge from data, although further internal incentives are necessary to fully profit for the internal knowledge management processes and tools. Some improvement areas identified with the project were that further support is needed at the organizational level to implement innovation projects, including adapting procurement procedures accordingly, while also supporting and sharing the learnings gained through these experiences.

Table 15 summarises the main factors that influenced the deployment of the smart solutions, based on the qualitative monitoring. More details about these factors can also be consulted in D.5.6.

Table 15: Main deployment factors Rotterdam

Deployment factors	Findings in Rotterdam
Operational factors in deployment of smart solutions	• Financial feasibility turned out to be an (unanticipated) barrier for deployment of the smart thermal grid. • Regulations, with regard to the concession and the PPP arrangements, led to deployment barriers and delays of several smart solutions. • The Smart Waste Management solution, the 3D city operation platform, smart grid solutions are considered the most successful measures and scaled up during the RUGGEDISED project.
Cooperation	• The cooperation between the RUGGEDISED project team and the area development team was hampered by incongruent timing. • Participating in RUGGEDISED has prioritised and accelerated the sustainability approach of several project partners (e.g. Ahoy Conference Centre and RET; public transport provider) and proved a springboard for several spinoffs. • The cooperation between the RUGGEDISED project team members (triple helix) was constructive.
Strategies	• RUGGEDISED was at the basis of a citywide Digital Program.
Planning mechanisms	• The area development in the Heart of South area resulted in complex spatial embedding of the deployed RUGGEDISED smart solutions.
Innovation capacity	• In general it was found challenging to find the right staff in the organizations with sufficient mandate and management support for deployment of innovative projects. • Close cooperation with knowledge institutes and universities supported knowledge exchange on innovations.

4.8. R1 – Geothermal heat-cold storage heat pumps

4.8.1. Description of the solution

Geothermal heat-cold storage heat pumps **Smart Thermal Grid**

Figure 9: Construction site/ working on the backbone
Source: City of Rotterdam

Highlights and facts of R1:

Primary energy savings:	**970 MWh/yr**
CO2 savings	**34.25 t CO2/yr**
Business Model:	**Analysed → 4.5**

Description

A central goal of this solution is to connect the **large buildings Ahoy and Rotterdam Ahoy Congress** Center (RACC) in the area to a single thermal grid. This means enabling local heat and cold exchange to lower the use of energy and the cost of ownership. To maximise the use of waste derived from heating and cooling the various buildings, seasonal storage in a geothermal layer is used for implementation (heat- cold storage). Over time, each building will be connected to a low temperature grid and provided with a heat pump to meet heat requirements. The heat generated waste will be fed back into the heat-cold storage. Cooling for the warmest days will be provided directly from the Smart Thermal Grid (STG).

The pipes are used to transport heat and cold from the Aquifer Therma Energy Storage and are connected to the two AHOY buildings (see in Figure 9). Cameras have been installed to test the existing aquifers and electrical pumps have been tested which made the improvements to bring a higher quality pumping system and thus, the storage up to the standards required for the smart solution.

Expected impacts:

- Disconnection from natural gas
- Connection to smart thermal grid in combination with connection to city heating
- Save costs on installations due to the decreasing total energy demand
- Decrease in energy consumption is 924,000 kWh/year
- Annual CO2 reduction of 70 tonnes

4.8.2. Impact assessment

This solution was among the ones undergoing the social impact analysis with a series of inquires performed during 2019 to a sample group composed of workers and business owners in the area of Heart of Zuid affected by the activities of RUGGEDISED. Although many of the services implemented were not directly controlled or experience by the users, the majority of stakeholders that were inquired knew about the RUGGEDISED project and expected that the interventions would have a positive impact by saving energy and fostering energy security. More than half of the respondents (60%) agreed that it was easy to undertake energy saving measures in their workplace.

Positively, the majority of surveyed stakeholders did not consider the solutions to have a negative impact in terms of their social and economic situations, while they did perceive some effects on the convenience, comfort and reliability of their equipment at the workplace. Moreover, additional qualitative interviews indicated that the project activities in the area had effectively increased awareness among the other businesses not directly associated with the project, and had contributed to create valuable skills to test and implement other similar solutions among the staff of the involved organisations.

Additionally, the Business Model (BM) assessment of this solution also indicates an interesting impact in terms of development of new approaches to the operation and exploitation of new energy solutions. In Rotterdam's pilot area, the solutions R1, R2, and R4 were combined to form an energy system that fed into the grid, bringing together different energy sources and consumers[5]. This combination of roles and actors required the development of a new Business Model (BM). Eneco, the Dutch energy company that designed and built the technical solution, also had to develop a new approach for the exploitation of the solution. Contrary to the usual practice in other projects, this solution required a new approach because Eneco did not own all the infrastructure: the municipality owned the wastewater heat and the pavements. In parallel, the municipality also had to develop its own BM approach to interact with the business owner and Eneco.

The main innovative feature of this solution was the combination of different technologies (the Smart Thermal Grid with the acquifer and heat pumps with a diversity of features) and that it can be connected to the grid with other energy sources. Then, although the BM created was not entirely new, it effectively enabled the market access of the technology and adapted to a new configuration, which can be a model to follow in the replication of this solution or the implementation solutions involving a similar diversity of actors in the city, especially in new buildings. In fact, the upscaling of this solution is already planned for the cinema.

Moreover, the project did explore several strategies to handle the changing relationship between the stakeholders involved in the solution, showing them the benefits of using the infrastructure in one building to operate with other buildings as a dynamic system that could handle a higher range of heat/cold temperatures, contributing to the exploration of new relationships and awareness raising among the public in the area.

Technical and environmental outcomes

Ahoy & RACC

The effect of the solutions implemented is clearly visible in the energy provided by the heat pumps – supplied by the geothermal storage. The use of geothermal energy mitigates the consumption of district heating energy and therefore decreases greenhouse gas emissions. Unfortunately, the assessment on this solution could only include storage for heating purposes, as there was not enough data available to explore more dimensions. The actual impact of the solution can therefore be regarded as higher than reflected in the KPIs that could be calculated.

[5] Initially, R3 was also part of this solution, but finally this component was cancelled due to its lack of economic feasibility.

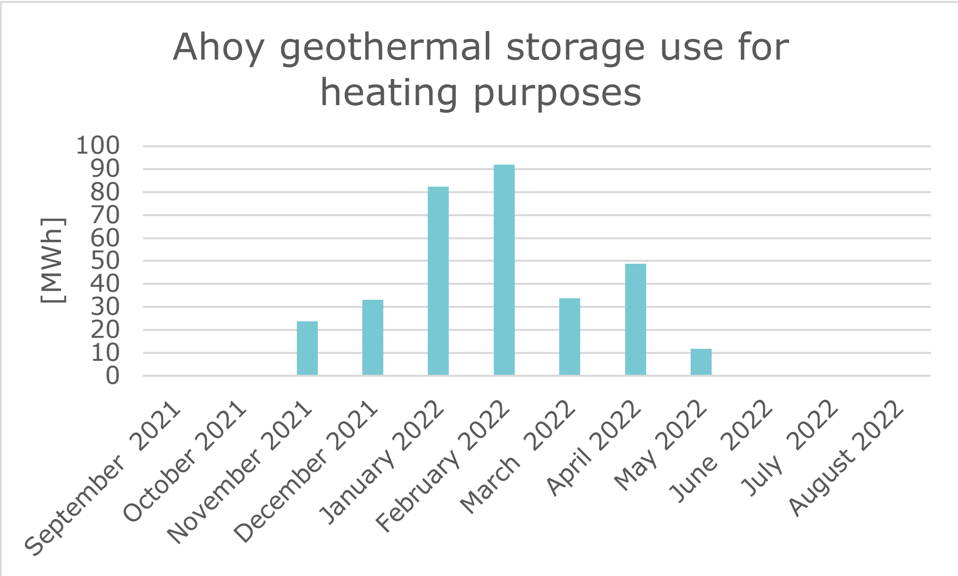

Figure 10: Partial geothermal storage use Ahoy building

Table 16: Technical performance assessment of R1

Smart Thermal Grid Cluster		
KPIs	Baseline	Achieved values
Thermal Storage Energy Used[kWh/yr]		324.735
Primary energy savings by cluster [MWh/yr]		970

Overall, the environmental impact assessment of R1 outlines the positive effect of the solution greenhouse gas emissions at the Ahoy building in Rotterdam.

Table 17: Environmental impact assessment of R1

Smart Thermal Grid Cluster		
KPIs	Baseline	Achieved values
CO_2 savings [t CO_2/yr]		34.25

The swimming pool and the arts building was planned to be connected to the STG. However, due to technical and financial issues the connection has not been implemented. Nevertheless, the energy consumption of the swimming pool and arts building have been monitored as they were solutions expected to provide a positive impact. The assessment suggests that the Arts building itself is a high efficiency building, where solar panels (PVs) were installed at the roof. This has been monitored separately.

Table 18: Energy consumption of the Swimming Pool

Swimming Pool	Best sheet estimations	Monitored values
Thermal energy consumption [kWh/m2]		198.3 (corrected with weather data 2019-2021)
Electricity consumption [kWh/m2]		103.8
Final energy consumption [Kwh/m2]	51.4	293.75 (Heating need corrected with weather data)

The yearly final energy consumption per square meter calculated based on the monitored data for the year 2021 in the swimming pool building is higher than the forecast of the best sheet. An assumption to explain this difference is that the best sheet calculation only considers the district heating and electricity consumption to cover the building heating demand, whereas the monitored consumption also includes the heating demand to heat up the pool water, generating an important difference between both values.

4.9. R2 - Thermal energy from waste streams

4.9.1. Description of the solution

Thermal energy from waste streams | **Smart Thermal Grid**

Figure 11: Panels and pipelines of the thermal energy from waste streams. Source: City of Rotterdam

Highlights and facts of R2:

Business Model: Analysed → 4.5

Description

In addition to thermal storage and heat pumps in solution R1, the use of other thermal waste streams was to be stimulated as much as possible by making further connections to the Smart Thermal Grid. On the district scale, the district sewage water from nearby households can be used to extract heat or cold for use by the grid. Depending on the need, it can be used directly or stored to refill storage and create a thermal balance.

The implementation of this solution required a close cooperation between the Municipality of Rotterdam, who is the owner of the sewer, and ENECO, the operator of the Smart Thermal Grid. In the first period of the project,a plan was developed to reuse the heat from waste streams in the Heart of South district. The sewage water from the surrounding districts was to be used to extract heat to balance the Smart Thermal Grid. The heat can be used directly or stored for several months in the Aquifer Thermal Energy Storage (ATES) in the deep underground. The heat waste can support the regeneration of the storage and create a thermal balance. In addition to that, the heat waste produced by cooling systems in buildings can be reused by other buildings in the area, or stored in the ATES.

After the consideration of different sewage streams available, it was decided to use a heat exchanger as an energy extractor which is fitted into the existing pumping station of the sewage system. The combination of the thermal heat recovery system in the sewage system and the Smart Thermal Grid has the potential to increase the impact and the solution is considered to being integrated into development of other areas in Rotterdam. The potential for upscaling this solution has been mapped for the whole city.

Expected impact:

- Use of the thermal energy waste streams to balance the ATES
- Decrease in energy consumption 39,000 kWh per year
- Annual CO2 reduction of 19 tonnes

4.9.2. Impact assessment

In Rotterdam's pilot area, the solutions R1, R2, and R4 were combined[6] to form an energy system that fed into the grid, bringing together different energy sources and consumers. As for the other solutions in this group, the Business Model (BM) assessment of this solution also indicates an interesting impact in terms of development of new approaches to the operation and exploitation of new energy solutions. This combination of roles and actors required the development of a new Business Model (BM). Eneco, the Dutch energy company that designed and built the technical solution, also had to develop a new approach for the exploitation of the solution. Contrary to the usual practice in other projects, this solution required a new approach because Eneco did not own all the infrastructure: the municipality owned the wastewater heat and the pavements. In parallel, the municipality also had to develop its own BM approach to interact with the business owner and Eneco. This is aligned with the findings of the qualitative monitoring, which indicated that due to the innovative character of the technology of this solution, combined with R1, the organizations and their staff, were not ready to collaborate on the terms required immediately and required of an exploration and adaptation periods for the different entities and teams (operational and strategic).

Although the BM created was not entirely new, it effectively enabled the market access of the technology and adapted to a new configuration, which can be a model to follow in the replication of this solution or the implementation solutions involving a similar diversity of actors in the city, especially in new buildings. Moreover, the project did explore several strategies to handle the changing relationship between the stakeholders involved in the solution, showing them the benefits of using the infrastructure in one building to operate with other buildings as a dynamic system that could handle a higher range of heat/cold temperatures.

This solution can be replicated in many cities as most of the street in Europe has a sewage system, although it is important to assess the specific context to see how the BM could be adapted, considering Rotterdam's specificities in regulations. However, it is encouraging that using the thermal energy as a source can be also found in other HORIZON 2020 cities like in Stavanger and Norway.

The implementation of this solution finished in September 2022. Due to the late start of its operation, monitoring data is still not available and hence, the technical impacts of the solution cannot be assessed at the moment of writing this report. More information on the thermal energy from waste streams solution can be found in the the **Implementation Report of Rotterdam**.

[6] Initially, R3 was also part of this solution, but finally this component was cancelled due to its lack of economic feasibility

4.10. R4 - Pavement heat-cold collector

4.10.1. Description of the solution

Pavement heat-cold collector **Smart Thermal Grid**

Figure 13: Lines on the pavement. Source: City of Rotterdam

Figure 12: Asphalt milling of the pavement. Source: City of Rotterdam

Highlights and facts of R4:

Business Model: Analysed → 4.5

Description

Testing of heat extraction included a pavement heating system, which is used to keep a stretch of 400m2 pavement frost-free in winter times and cooling down the black asphalt in summer times. Several possible locations have been considered for scaling-up the pavement heat collector in the Heart of South.
This smart solution involves balancing the Aquifer Thermal Energy Storage (ATES) by using pavement as a heat-cold collector. Heat and cold are extracted from the heat exchanger under the surface of the pavement. The pavement's heat-cold collector can keep the pavement frost-free during the winter. During summer, the pavement is cooled, increasing its lifetime, and decreasing the urban heat island effect.

Expected impacts

- Balance the ATES
- Decrease in energy consumption is 108,000 kWh per year
- Annual CO2 reduction of 52 tonnes
- Winter the roads will be slightly heated and the pavement will not freeze

4.10.2. Impact assessment

This solution has an important potential to be replicated in other areas of Rotterdam to deal with the heat stresses during the summer, and the technical impacts of the solution can help to assess which other areas in the city could benefit from it. For this, the work done in the development of an adapted Business Model (BM) can be very useful to streamline the replication and improve initial challenges.
The Business Model (BM) assessment of this solution was realized with the combination of solutions R1, R2 and R4, which were combined to form an energy system that fed into the grid, bringing together different energy sources and consumers. Although the BM created was not entirely new, it effectively

enabled the market access of the technology and adapted to a new configuration, which can be a model to follow in the replication of this solution or the implemented solutions involving a similar diversity of actors in the city, especially in new buildings. Moreover, the project did explore several strategies to handle the changing relationship between the stakeholders involved in the solution, showing them the benefits of using the infrastructure in one building to operate with other buildings as a dynamic system that could handle a higher range of heat/cold temperatures.

Additionally, the qualitative monitoring identified particular challenges in the implementation of the solution, that partly caused a vitaldelay in its implementation. These challenges were overcome later in the project, and the whole experience was useful to better understand specific risks of the PPP approach and tender procedures that could be avoided or improved in future replications of this solution. Some of these findings are quite specific for Rotterdam, but technically the solution has the potential to be replicated in other Northern European cities to avoid freezing roads in the winter time, if the areas have enough space for hot and cold storages.

This solution was implemented in September 2022. Due to the late start of the implementation the monitoring process is ongoing and relevant KPIs cannot be provided in this deliverable. More information on the Pavement heat-cold collector solution can be found in the Implementation Report of Rotterdam.

4.11. R5 - RES generation and storage for mobility

4.11.1. Description of the solution

RES generation and storage for mobility | **Smart electricity grid and e-mobility**

Figure 14: PV panels on the AHOY rooftop. Source: City of Rotterdam

Highlights and facts of R5:

Electricity generated by RES	2,443 MWh/yr
Primary energy savings	3,506 MWh/yr
CO2 Savings	1,172 t CO2/yr

Description

To provide more power to the fast charging of electric buses in Rotterdam, the public transport operator and RUGGEDISED partner RET, placed photovoltaic (PV) panels on the roof of the bus station to deliver sustainable energy directly to the grid into the charging points. The installation of solar panels was included in the design of the Rotterdam Ahoy Convention Centre, another hall of Ahoy, the bus station, the Arts building and 84 NZEB houses. The production and storage of solar energy has an impact on the capacity of the regular electrical network. For this reason, the operator of the electrical grid had reservations on how solar energy would influence the overall use of the grid - and therefore, its revenue and ability to maintain the network.

A feasibility study showed that a direct connection from the solar panels to the fast charging system of the new e-buses in combination with a small new net connection provided a better business case than the installation of batteries. In addition to that, the CO2 emission targets could be fulfilled when PV panels were installed.
In total, approximately 15,541 square meters of photovoltaic panels have been installed on the roofs of the above mentioned buildings. About a quarter of all of the electric energy used in AHOY is produced by the PV-panels.

Expected impacts:

- Decrease in energy consumption is 5.750 kWh per year
- Annual CO2 reduction of 3 tonnes

4.11.2. Impact assessment

The project has allowed the different partners to explore the technical solution, and some positive results are that the RUGGEDISED partner RET is already planning to build additional parking and electric charging stations equipped with solar panels for its e-buses. PV panels are already a common solution to use and produce sustainable local energy and this is an additional use case where these can contribute to city's sustainability and feed energy back into the electricity network.
This solution has the potential to be replicated in other European countries, although specific national regulations can have an important impact on their economic viability and interest.

Technical and environmental outcomes

The performance assessment of the PV systems installed in R5 shows energy supplied by the PV. The monthly monitoring of electricity consumption in the relevant buildings is not complete enough at this time to calculate the annual KPIs related to consumption. Figure 15 indicates the relation between the Arts building energy consumption and PV supply.

The monitoring data of the PV system on the Arts building was not available for the months July and August of 2022. However, the graph shows that PV supply could cover electricity consumption in April, May and June of 2022 in the Arts building on a monthly aggregation. Extrapolating results from previous year, it could be expected that PV production could satisfy electricity demand throughout July and August, and possibly September to a large extent. Due to the granularity of provided data (monthly totals) though, it is currently not possible to assess if all PV production for eligible months would match consumption timing.

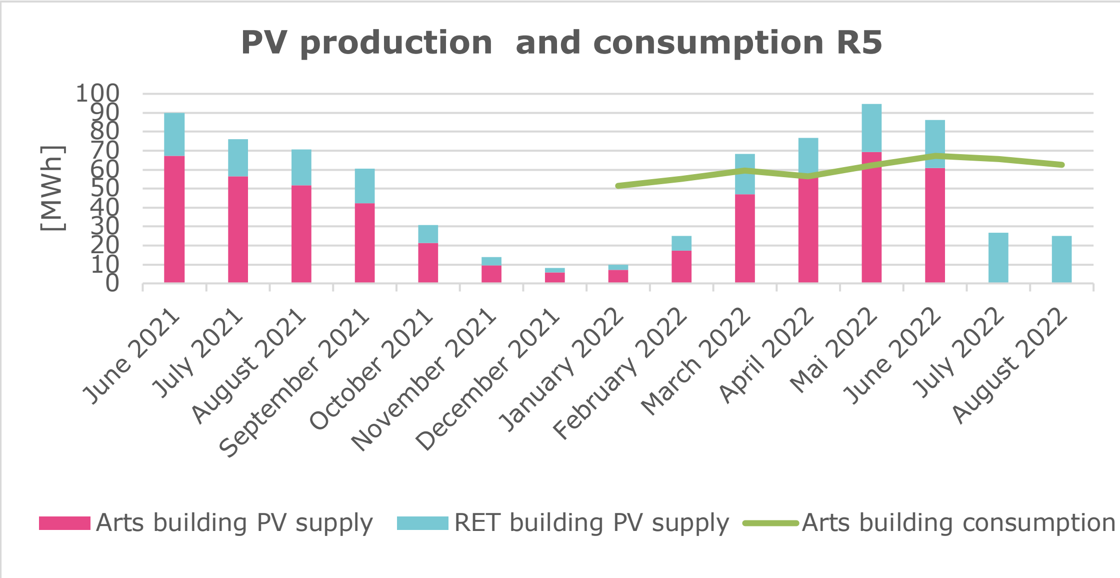

Figure 15: PV production R5

As in Rotterdam, RUGGEDISED included the implementation of further PV systems than the Arts and RET building, the technical performance assessment of R5 features the KPIs of all PV systems installed in Rotterdam related to RUGGEDISED. These include PV systems on the RACC building (685 kWp), Ahoy building (976 kWp), Arts building (505 kWp), RET station (141 kWp), Zero energy buildings (84 houses and 398 kWp), and the pumping station (4 kWp). Furthermore, due to the number and size of the installed PV systems, the assessment approach is sightly adjusted in R5. Instead of counting only PV electricity that was timely supplied to the respective consumer in a solution, all PV electricity production is counted as primary energy consumption and CO2 emission reduction.

Table 19: Technical performance assessment of R5

Smart Electric Grid Cluster		
KPI	Baseline	Achieved value
Electricity Generated by RES [MWh/yr]		2,443
Primary energy savings [MWh/yr]		3,506
CO2 savings [t CO2/yr]		1,172

According to the KPI calculations, the energy supplied by solution R5 is effectively reducing the energy consumption from the Dutch electricity grid, which otherwise would be associated with 480 g/kWh (reference year 2013) (CBS, 2022). Furthermore, the KPIs for avoided CO2 emissions and primary energy use are calculated on the basis of the offset of grid electricity use, also considering the energy fed into the grid.

4.12. R7 - RET e-bus

4.12.1. Description of the solution

Optimising the E-bus fleet | **Smart electricity grid and e-mobility**

Figure 16: RET e-bus. Source: City of Rotterdam

Highlights and facts of R7

E-vehicles	55
CO2 savings	2,031t CO2/yr
Primary energy savings	4,914 MWh/yr

Description

This solution aims to support the transition from conventional diesel buses towards battery powered electric buses (e-buses). The bus station in the Heart of South is part of a dense public transport network in which a consistent number of buses needs recharging. Therefore, the energy produced by the solar panels can be stored or used by the electric buses immediately. The introduction of electric buses and the charging infrastructure is not just a matter of implementing new technology; it is a matter of introducing a completely new transport system that is more similar to a tramway than to bus deployment.

An evaluation tool was developed to quantify potential impacts on the transition on current RET bus schedules. The tool considered different parameters such as energy consumption, number of buses and charging infrastructures. Initially, two simulation models have been tested on a fleet of 50 electric buses which are charging at the Heart of South bus terminal. The first results showed that under planned conditions the schedules are feasible but not adequate when it comes to delays. In addition to that, the introduction of chargers into the city environment is very complex and time consuming for the municipality, the grid provider and the transport company. The simulations, the calculations about the range, energy consumption, state of charge are still theoretical and need to be proven in practice.

Expected impacts:

- Decrease in energy consumption is 1,900 MWh per year
- Annual CO2 reduction of 780 tonnes

4.12.2. Impact assessment

The contract for the bus fleet will not expire before December 2034, so in total 150 buses are foreseen to be optimised for zero emission vehicles.
To scale this solution, the change of all fuel buses to zero emission buses is foreseen. For this, the infrastructure for the e-buses will need to be changed in order to have building loading stations for bus batteries.
To complete the transition, the optimisation of the schedule will also be more data driven. In this regard, it is considered that a digital twin could be combined into the solution to support the process.

Technical and environmental outcomes

The achieved energy and CO2 savings presented in Table 20 and Table 21 are higher than expected with the previous simulation conducted. Different hypothesis can be drawn to explain this difference. This difference can be explained by the higher number of e-buses implemented. Originally, RET was planning to start with six e-buses but the implementation pace was faster and 55 e-buses are already deployed in the city since 2020. Besides, the fuel consumption of electric and diesel buses is highly dependent on the driving behaviour and the topography, different assumptions for those parameters can lead to differences in energy consumption and CO2 emissions.

Table 20: Technical performance assessment of R7

Energy Efficiency Interventions at Building and District Level Cluster		
Mobility cluster		
KPIs	**Baseline**	**Achieved value**
Number of e-vehicles after the intervention	Baseline: 0	55
Primary energy Savings by Mobility Measures, Total [MWh/yr]	1,900	4,914

Table 21: Environmental impact assessment of R7

Mobility Cluster		
KPIs	**Baseline**	**Achieved value**
CO2 savings [t CO2/yr]	780	2,031
SO2 savings [kg SO2/yr]		15
NOx savings [kg NOx/yr]		242
PM10 savings [kg CO2/yr]		14

4.13. R8 - Energy management in buildings

4.13.1. Description of the solution

Energy management in buildings	Energy management and ICT

Figure 17: Technical room. Source: City of Rotterdam

Description

The energy and building management software Simaxx was implemented at Congress Center Ahoy and the Rotterdam Ahoy Convention Centre as part of RUGGEDISED. Eventually, the ambition was to have Simaxx software implemented in all buildings in the Heart of South, which would allow for the visualisation and optimisation of energy consumption, production, etc., of the buildings.
The Simaxx software at building level can visualise and optimise energy usage, comfort level and heating, ventilation and air conditioning (HVAC) operations. The system also monitors the area solution Smart Thermal Grid. This is partly based on the measured data on building scale, but also based on measured data of the Smart Thermal Grid.

Expected impacts:

- Decrease in energy consumption is 383 MWh per year
- Annual CO2 reduction of 155 tonnes

4.13.2. Impact assessment

The energy management system itself is not possible to monitor quantitatively, so its impact is estimated based on interviews with Ahoy employees”. In section 4.6. results of the interviews are described in detail. The social impact assessment of this solution was focused more on the related needs and perceptions of the stakeholders for the work and business aspects. As the implemented services were not directly used by the users, the responses were rather neutral to positive. In conclusion, the project created much awareness for energy-neutral buildings and management. The interviews confirmed that the activities have increased awareness among other businesses beyond the RUGGEDISED project. The lighthouse area gained high visibility due to the implementation of energy-neutral solutions and this had an impact on the competitiveness of the event location for international events. A final and valuable result is that training concepts are to be considered to prepare engineers for the estimation and planning of events and optimise the heating temperature during the event.
Upon the qualitative monitoring, it was observed that although there is an open data standard for sharing the data gathered from the different solutions, it was not automatically clear how each private company

and partner delivered the data to the platform and ensured access to this data to the municipality. This situation also created awareness among the staff regarding how to set up the conditions under which the city will prefer to operate with private companies in the future.
In terms of replicability and scaling, the energy management solution can technically be replicated in any other city in Europe.Nevertheless, the impact elsewhere depends on the number of data points and whether it is possible to connect it to smart grids.

More information on the Energy management in buildings solution can be found in the Implementation Report of Rotterdam.

4.14. R9 - 3-D- City operations model

4.14.1. Description of the solution

3-D- City operations model **Smart Open Data Platform**

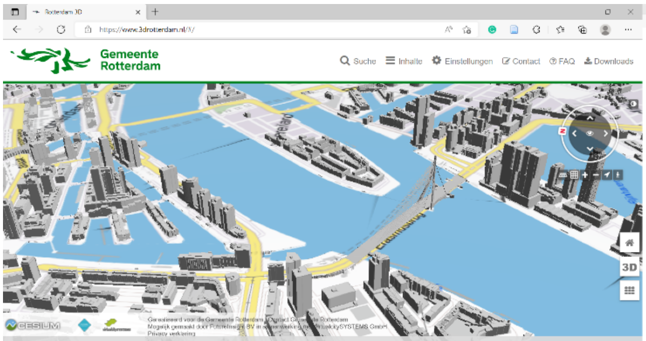

Figure 18: 3-D-Rotterdam webpage. Source: Gemeente Rotterdam

Description

The 3-D City operations model is an innovative model which was especially developed for and with the City of Rotterdam. It represents a platform where open standard data is available for initiatives which want to develop further applications on the available data in the 3-D model.

The development of the 3-D city operations platform is an iterative process of learning. Learning by understanding happens through studies and engaging with peers. The main research question is how to organise the governance of the platform and which role the municipality of Rotterdam plays in this.
The development of the platform took place through the execution of three proofs of concept, of which two are already finished as part of RUGGEDISED. The 3-D City operations model will become a digital twin of the Heart of South.

A proof of concept (PoC) has been conducted at different phases throughout the project and has led to new features onplatform. In the first proof of concept the goal was to prove that the municipal vision of the platform was technically feasible. Therefore, the parking lot data was successfully integrated in the 3D-City Model. The second PoC real-time data concerning traffic mobility, public transport and open bridges was shared in the model. Different open data standards have been tested and revealed some information on the process of disclosing real-time data which is owned by the municipality but were from (private) data sources. The lessons learnt from the testing phase contributed to the further development of the platform, but most of the features of the model will extend beyond the scope of the RUGGEDISED project.

Expected impacts:

- Decrease in energy consumption is 82 MWh per year
- Annual CO2 reduction of 41 tonnes
- Open up space for other innovations and increase the overall impact of other smart solutions

4.14.2. Impact assessment

The city of Rotterdam is still working on the city's 3D model. New features and possibilities such as the visualisation of new building plans through augmented reality and calculations on the energy savings are being explored. This solution can be technically replicated in any other city and adapted to its local situation. Upon the quantitative monitoring exercise, it has been identified that one of the cooperation challenges is to determine the conditions under which the company delivers data to the platform and to ensure the municipality has access to this data. Hence, a successful implementation will require that the city is able to define the conditions under which it prefers to cooperate with the involved private companies.

More information on the Smart Open Data Platform solution can be found in the Implementation Report of Rotterdam.

4.15. R11 - Efficient and intelligent street lighting

4.15.1. Description of the solution

Efficient and intelligent street lighting **Energy management and ICT**

Highlights and facts of R11

Energy reduction	26%
CO2 savings	5,497 t CO2/ yr
Primary energy savings	17,743 MWh/yr

Description

The lamp posts being used within the Heart of South retain, serve and enhance the principal obligations of street lighting (navigation, public safety). By using LED lighting, the lamp posts have lower emissions. They are connected as a network, enabling system wide control (i.e. a central management system) and the integration of sensors that have power 24/7 to enable continuous smart services.

The smart street lighting poles were installed in October 2019. Six poles were used as a test case, located between the swimming pool and the bus station. The rest of the poles could only be placed when the public area design was to be executed. The six installed street lighting poles used for monitoring are equipped with a telemanagement system and LED lights which can be controlled and monitored from a distance. It shows their energy consumption. The objective was to feed the energy use data into the 3D model of the digital twin.

Expected impacts:

- Decrease in energy consumption is 29,000 kWh per year
- Annual CO2 reduction of 14 tonnes

4.15.2. Impact assessment

The city of Rotterdam wants to increase the share of all light poles and this solution can be replicated in any other European city. The only requirement is a tele-management system connected to e.g. WiFi or long range LoRa network. The impact of this solution was mostly monitored using quantitative data.

Technical and environmental outcomes

The final energy and CO2 savings presented in Table 22 and Table 23 are higher than the expected impact targeted at the beginning of RUGGEDISED. The final monitored energy savings are equal to 5 992 MWh per year. An explanation for this difference is the change in the project scope between the target and the calculated data. The calculated data include the city-wide impact, whereas the target data was only calculated at district level.

Table 22: Technical performance assessment of R11

Energy Efficiency Interventions at Building and District Level Cluster		
KPIs	Target	Achieved value
Final Energy Savings by street lighting interventions[MWh/yr]	29	5,992

Final Energy reduction by street lighting interventions[%]	-	26%
Primary energy savings by building energy efficiency measures and street lighting [MWh/yr]	-	17,743

Table 23: Environmental impact assessment of R11

Energy Efficiency Interventions at Building and District Level Cluster		
KPIs	Target value	Achieved value
CO2 Saving street lighting [t/yr]	14	5497
CO2 Reduction street lighting [%]	-	52%

4.16. R13 - Smart waste management

4.16.1. Description of the solution

Smart waste management	Energy management and ICT

Highlights and facts of R13

Energy savings 2020-2021	1,442 MWh
CO_2 savings 2020-2021	565 t CO_2 t

Description

In Rotterdam, there are approximately 6,500 underground waste containers. RUGGEDISED partners equipped all the textile, paper and glass waste containers in the Heart of South with a smart sensor. The so-called ‘filling degree metre’ in the waste container measures how full the container is every hour. Based on this information, the system determines when the container can best be emptied. The routes for the drivers are automatically generated, based on the collected data to allow for ‘dynamic route planning’ All drivers are equipped with a tablet/navigation system, which shows them the ideal route to collect the waste. The moment the waste is collected, the containers are approximately 75 percent filled.

Expected impacts:

- Decrease in energy consumption is 315 MWh per year
- Annual CO_2 reduction of 72 tonnes

4.16.2. Impact assessment

The solution has been successfully implemented in the demonstration area Heart of South district and also in the rest of the city. The results have shown that the sensors in the waste containers contributed to a more efficient management and better service for the people of Rotterdam. As with other solutions involving the use of data, the qualitative monitoring exercise identified that one of the key factors for a successful implementation of the solution is the clear establishment of conditions for collaboration between the city and private operators, inculding the definition of the data standards to share information and the conditions on how this data will be delivered. This can involve important savings in terms of investment and human resources.

Technical and environmental outcomes

The data collected helped to understand the savings in driven kilometres and thus CO_2 savings. According to the different calculations, the solution R13 and the different interventions done in the domain of waste management during RUGGEDISED project effectively contributed to save more than 1 441 MWh between 2020 and 2021, and contributed to a CO_2 savings of more than 560 tCO_2 for the city. An explanation for the difference of these numbers respect target ones is the change in the project scope between the target and the calculated data. The calculated data include the city-wide impact, whereas the target data was only calculated at district level.

Table 24: Technical performance assessment of R13

Energy Efficiency Interventions at Building and District Level Cluster

KPIs	Target	Achieved value
Final Energy Savings by waste management interventions[MWh/yr]	315	2020: 666MWh 2021: 776 MWh

Table 25: Environmental impact assessment of R13

Energy Efficiency Interventions at Building and District Level Cluster		
KPIs	Target	Achieved value
CO2 savings by waste management interventions [t/yr]	72 tCO2	2020: 234 tCO2 2021: 331 tCO2

4.17. Conclusions of Rotterdam

The city of Rotterdam intended to implement 13 smart solutions. Out of these, nine solutions have been successfully implemented and monitored, and four solutions (R3, R6, R10, R12) have been cancelled. The business model assessment was conducted for four interlinked solutions, and workers and businesses oweners in the area have been interviewed for the social impact assessment.

Within the district, Hart of Zuid, 56 440 m² new floor area has been built for residential and tertiary buildings and 23 364 m² floor area has been refurbished within the RUGGEDISED project during the last six years. Through the implementation of street lighting interventions by installing smart LED luminaires yearly final energy savings of 26% could be achieved.

The city of Rotterdam has used and tested a variety of solutions to produce more energy locally. Thanks to the implementation of the smart solutions in the project, an overall 2,443 MWh of electricity has been produced within the district. With the implementation of thermal grid solutions such as the installation of the geothermal heat-cold storage heat-pumps 325 MWh of thermal energy per year were generated and 748 MWh of primary energy were saved.

With the implementation of energy efficiency interventions, energy management, mobility solutions, the installation of efficient and intelligent street lighting (R11) and the smart waste management (R13), a total reduction of 9058 tCO2 has been achieved in Rotterdam. Within the project RUGGEDISED in total 55 of e-buses have been optimised and leveraged in the district of Hart van Zuid. The smart waste management solution is considered to be successfully implemented and scaled up in the rest of the city as it has achieved more reduction in the energy consumption and CO2 reduction than expected.

One Business Model for the combination of four solutions - the Smart thermal grid (R1), Thermal energy from waste (R2), Surface Water H/C collection (R3) and Pavement H/C collector (R4) has been analysed, identifying how new collaborations can enable the local generation and selling of electricity and/or heating and cooling energy. The Business Model enabled the technology to access to the market and explore new relationships between actors. The upscaling and replication potential of the BM is possible in the context of similar technological solutions although depending on local regulations.

Regarding the social impacts, an estimated of 130 jobs could be created directly and 300 indirectly through the project. A result of interviews with 33 workers and business owners who were working in the AHOY building, in the restaurant area, the arts and swimming center have shown that the RUGGEDISED project created awareness for energy neutral building and management. Also, the implementation of energy-neutral building technologies revealed the need of training concepts for the personnel.

Approximately, a total investment of 10,1 Million € has been leveraged to implement the different solutions. Of these, 1,71 Million € were dedicated to deploy ICT-infrastructure, 7,5 Million € into energy, 0.9 Million € into mobility and 354 Million € into construction solutions.

Reflecting on the implementation factors of the solutions, the financial feasibility appeared as an important implementation barrier for the smart thermal grid solutions. In addition to that, regulations, with regard to the concession and Private-Public-Partnerships (PPP) arrangement have led to implementation barriers and delays of several solutions. Considering the combination of knowledge and expertise, the knowledge exchange and close cooperation with knowledge institutes and universities are seen as essential factors for the implementation of the solutions.

Other impacts and lessons learnt

Beyond the RUGGEDISED project the City of Rotterdam continued and extended their work on engineering, policy making and investments on energy, mobility and digitalisation.

The realisation of the Smart Thermal Grid gave Rotterdam a lot of insights in both technical challenges and policy making. On a local scale, the grid can be extended to other (new) buildings in the Heart of South area. On a city scale the city could mostly profit from all lessons learned, which are now projected on different large scale city developments where 5th generation smart thermal grids are planned.

The RUGGEDISED project in Heart of South is a valuable test case for integrated solutions on clean energy transition, ensuring efficiency, stability and security. Not only energy consumption was reduced on building level, but also the thermal energy system lowers the overall energy use by reuse, sharing and seasonal storage. This is perfectly replicable elsewhere in the city and provides a roadmap for new sustainable area (re)development in Rotterdam. Already the lessons learned are used in area development Rijnhaven (3,000 new apartments) and Merwe-Vierhaven (7,000 apartments and 850,000 m2 utility buildings). Key in this is the large amount of locally used (seasonal thermal storage) and generated (photovoltaic panels) energy. This directly lowers the energy bills of building users. Therefore, this more efficient and almost carbon free energy system ensures lower energy costs for citizens. The solution also entails an improvement of the quality of life by preventing heat emissions caused by the energy system in summer and therefore lowering the heat-island effect.

In terms of mobility, the study done within RUGGEDISED by Erasmus University indicates that the interventions implemented have a city wide effect, and the developed software for scheduling the bus routes for e-buses also impact at city level. The lessons learned will fasten the rollout of electrification of the remaining diesel buses towards 250 zero emission buses. This will have a huge effect on air quality next to the carbon savings and therefore improving the quality of life for all citizens of Rotterdam.

Rotterdam uses the knowledge from RUGGEDISED also for the city-wide Rotterdam Heat and Cooling Strategy. The energy concepts developed within RUGGEDISED are valuable input for this, alongside the vision on the energy-system city wide. Especially, the focus on cooling is new and gives opportunities to stimulate the rollout of collective sustainable cooling systems. Due to climate change, this will become inevitable and ensures on the long run lower energy costs for the citizens. Next to this, this will stimulate local economy and create jobs on this new segment. In fact it's the replication of the 4th/5th generation Smart Thermal Grid of RUGGEDISED which includes sustainable cooling and seasonal storage.
Furthermore, the team working on sustainable urban development grows every year. Started four years ago with five people on a couple of projects, to advise about climate adaptation, circular economy and energy transition. Nowadays more than 20 people are working within the city on more than 100 projects city wide, from small scale to large scale developments in which smart thermal grids will be implemented.

The three concepts developed within RUGGEDISED gave valuable input for further concretising the plans for a city-wide urban data platform. This is now decided to be built on this scale. Goal is to open up city data to the market, so new start-ups can create new business models and applications on this. Not only creating more jobs, but also improving the quality of life. A direct RUGGEDISED spin-off is also the growth of an ICT start-up, which is now also internationally reusing the knowledge. Moreover, the implementation of the Energy management system within RUGGEDISED, caused more awareness for the city owned buildings that this topic can have large value for improving energy efficiency and will therefore lower the costs for these buildings, resulting in lower taxes for citizens.

In Rotterdam now 60% of the public lamp posts are labelled as smart, in the sense that they are connected to a central ICT system. RUGGEDISED formed a test case for smart and efficient lighting and the lessons learned are used for the further rollout towards 100,000 lamp posts being smart and connected in Rotterdam. Recently an automatic failure management system was implemented, so the failures will be automatically reported and fixed. The energy consumption and dimming regime per lamp post are also possible, including registration of failures. This makes preventative maintenance possible and reduces failure, in that sense improving safety in the public space, which increases the quality of life.

Finally, RUGGEDISED also had an important impact on the waste management sector. The start during the project of the combination of filling degree sensors for household-waste containers and route planning optimization has now grown to a city-wide implementation. This reduces the amount of unnecessary driven routes and reduces the amount of waste left on the street when the container was full. In this way the city has become cleaner and uses their waste collection trucks more efficient, which improves quality of life and reduces costs for the citizens.

5. Umeå

Within RUGGEDISED Umeå has implemented and monitored a total of nine smart solutions in the university district. These solutions are distributed in two energy management and ICT, six smart and thermal grid and two smart electricity grid solutions.

The following sections elaborate on the KPIs calculated at the city and solutions levels. The KPIs are based on the collected data from partners and the cities to assess the achieved impacts on technical (e.g. energy efficiency), environmental impact (e.g. reduction of CO2 emission) and non-technical performances such as results of business model development for a business model for Smart City connection to 100% renewable energy (U1) and Geothermal heating/cooling storage and exchange (U3) and user feedback of students and workers at the Umeå university campus and University Hospital.

5.1. Overview of monitored solutions

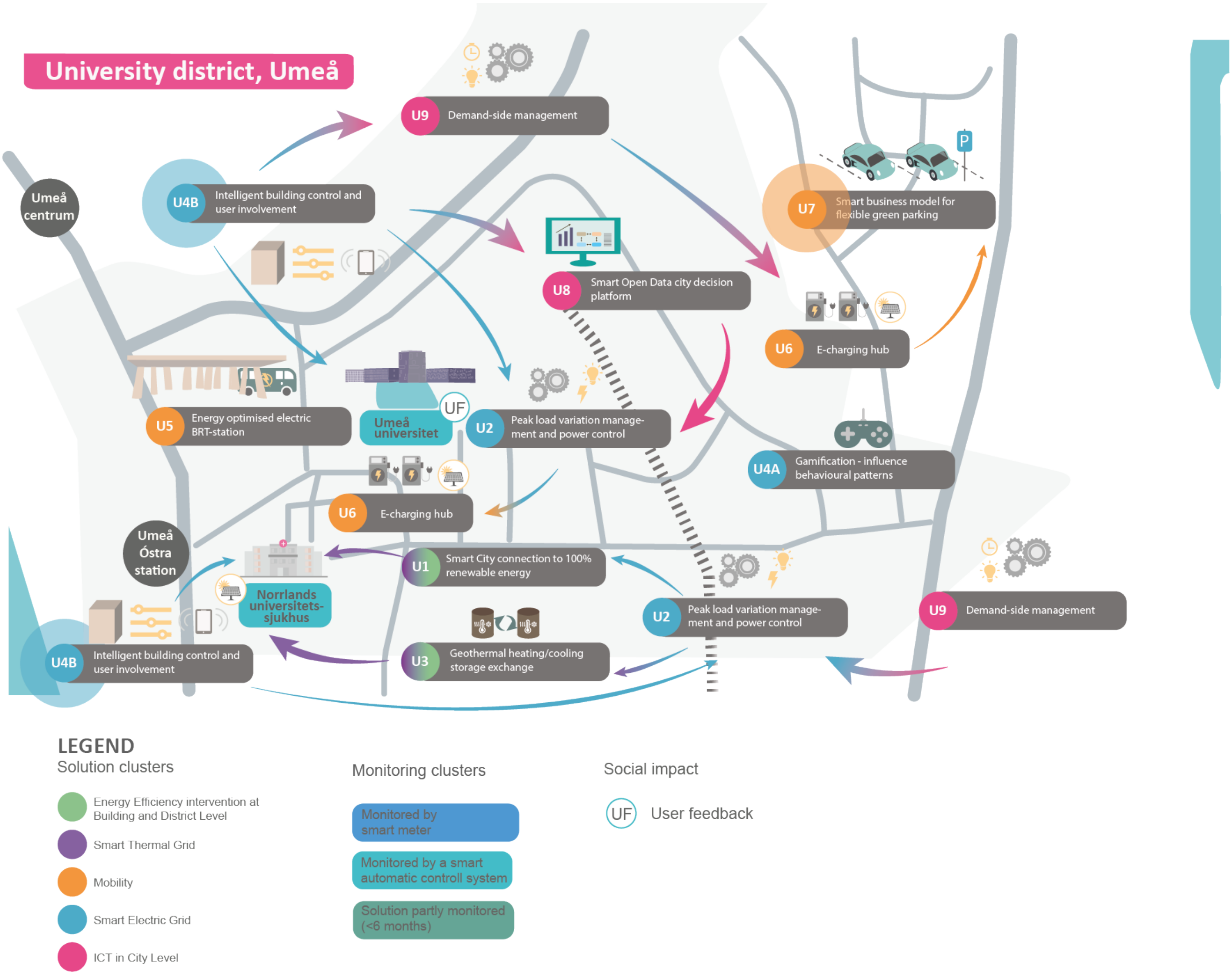

Figure 19: Overview of monitored solutions of Umeå

Action areas and number of monitored solutions in Umeå			
Smart Thermal Grid	Smart electricity grid and e-mobility	Energy management and ICT	Smart Open Data Platform
5	3	3	1

In the university district of Umeå the following buildings are in the scope of monitoring:

- Hospital (refurbishment)
- Student homes (new)
- University building with laboratory (refurbishment)

5.2. Technical performance assessment

In Umeå, the implementation of the 7 smart solutions and the construction of 45 155 square meters of new buildings and the refurbishment of 34 880 square meters has led to technical and environmental improvements. Overall, the energy efficiency interventions resulted in final energy savings of 2480.8 MWh per year. The smart solutions included in the smart electric grid cluster have led to primary energy savings of 53 331 MWh per year and enabled the generation of 17 488 kWh per year of electricity. Table 26 and Table 27 details the performance KPIs at city level for Umeå.

Table 26: Technical performance assessment of Umeå

General assessment of buildings			
KPIs	# of solutions	Target values	Achieved values
New Built Floor Area, Residential [m²]	U4	0	8,211
Refurbished Floor Area, Tertiary Buildings [m²]	U4B	36,033	34,880
Floor Area Of Buildings With DSM [m²]	U2, U9	265,000	No data
Refurbished Floor Area, Total [m²]	U2, U9		34,880
Cluster of solutions to increase the energy efficiency at building and district level			
Final energy reduction by building energy efficiency interventions [Mwh],	All buildings	2,316	2,480.8
Primary energy savings by building energy efficiency measures and street lighting [MWh/yr]	n/a	0	4,250
Smart Thermal Grid Cluster			
Installed RES Capacity Heating [MW]	-	4	No data
Floor Space to be Connected to District Heating [m²]	Possibly U4	0	No data
Share of RES (excl excess heat) in District Heating [%]	U1	90	No data
Thermal Storage Energy Used [kWh/yr]	U3	5,000	No data

Primary energy savings by cluster [MWh/yr]	U1-U3		360
Smart Electrical Grid Cluster			
Electricity Storage [MWh]	-	0	0
Electricity Generated by RES [kWh/yr]	U5, U6	88,000	17,488
Installed RES Capacity Electricity [MW]	U5, U6	0,09	
Mobility Cluster			
Number of e-vehicles after the intervention	U5, U6	20 (bus), 20 (taxi)	No data
Number of Charging Stations [#]	U6	21	No data
Number of e-Hubs [#]	U6	1	1
Energy Savings by Mobility Measures, Total [MWh/yr]		1,631	230

5.3. Environmental impact assessment

The environmental impacts of the solutions implemented in Umeå are summarized in Table 27, and are disaggregated by the solution clusters. The solutions have contributed to reduce CO2 emissions in Umeå. Additionally, the implementation of mobility solutions has led to a reduction in local air pollution.

Table 27: Environmental impact assessment of Umeå

Cluster of solutions to increase the energy efficiency at building and district level			
KPIs	# of solutions	Target value	Achieved value
CO2 Reduction Achieved by Energy Supply Measures, Total [tonnes/yr]	U5, U6	210	
CO2 Reduction Achieved by Building Efficiency Measures[tonnes/yr]	Physiology + Hospital buildings	377	90.5
Smart Thermal Grid Cluster			
CO2 savings [tonnes CO2/yr]	U1-U3	210	107.2
Smart Electrical Grid Cluster			
Primary energy savings [MWh/yr]	U6	-	34.6

Mobility Cluster			
CO_2 savings [tonnes CO_2/yr]	U5-U7	-	159.2
SO_2 savings [g SO_2/yr]	U5-U7	375	6,267
NO_x savings [g NO_x/yr]	U5-U7	1223	100,278
PM10 savings [g CO_2/yr]	U5-U7	195	5,641

5.4. General economic and demographic impacts of Umeå

Within RUGGEDISED the total investment of the implemented solutions in the demonstration area of Umeå amounts to an estimated 542,000 €, of which more than half were allocated to the deployment of Energy solutions.

Table 28: General economic and demographic impacts on district level

General Economic and Demographic Impacts On District Level		
KPIs	# of solutions	Achieved value
Persons Directly Involved[#]	U5, U6	8
Investment In Energy Solutions [Million €]	U1, U2, U3, U9	0.321
Investment in ICT[Million €]	U4, U6, U8	0.035
Investment, total[Million €]	U1-U9	0.542

5.5. Business Model Impact Analysis

In this section, we provide the outline of the empirical material gathered and analysed in relation to the Multi-Level Perspective (MLP) framework and the Context and Critical Conditions (CCC) method, described in the methodological chapter of this report.
In this use case, the focus is on the process of how the BM was developed. The BM for several solutions in Umeå is analysed and discussed in relation to its possibility to scale.

Business Models: Case 1: Business model for Smart City connection to 100% renewable energy (U1) and Geothermal heating/cooling storage and exchange (U3).

The description of the selected BM is based on the D3.2 and D3.3 along with two interviews, one respondent from Umeå Energi and one respondent from Region Västerbotten. The smart solutions “Smart City connection to 100% renewable energy (U1)” and “Geothermal heating/cooling storage and exchange (U3)” are both focused on developing the Umeå University City area towards energy efficiency and fossil free energy supply and have been treated under the same umbrella of BM development. There were predominantly two organizations that were affected by the BM development within this project: Umeå Energi AB and Region Västerbotten. Both organizations were also part of all the technical solutions and BM development.

During the analysis, three types of BM with three different business logics evaluated. **Business as Usual**:

A customer-supplier relation with an individual perspective to maximize revenues. The actors have individual ownership and complete control of their own assets. **Joint Venture (JV):** A partnership relation with shared equity. The partners agree on a method for financial redistributions, liability distribution and risk-reward. **Cooperative (COOP):** A cooperative business logic is determined between actors in control of energy production, storage and end-use based on individual drivers for a common framework and cooperation.

The aim of the analysis conducted during the project was to evaluate which type of business logic could support mitigation investments the best. The respondents clearly pointed out that the COOP BM had been the most valuable result, possibly both in short and long term. The COOP BM will therefore be the focus of the analysis in this section. However, it is important to note that the COOP BM analysed has not yet been implemented: the delivery “RUGGEDISED D3.2 and D3.3” is a conceptual report that uses simulations and calculation to draw conclusions. This means that many of the barriers and enablers of the COOP BM in real life can only be speculated on.

A basic premise for the development of BM in Umeå, specified in the report D.3.2 and D.3.3. is that linear BM for energy can’t harness peer-production despite, but that it has been difficult to put in other market mechanisms for decentralizing the grid, as one of the key barriers is to define how energy providers can become energy consumers. The “gap” that the BM is meant to fill is to allow for a 100 % fossil free heat/cold supply and hence, the business case came as a secondary need rather than a goal on its own. The COOP BM would allow for heat and cold to be shared during times of excess production from two separate energy systems.

Another BM that could have worked in a positive way was a Joint Venture Partnerhip with shared equity. However, it had three main shortcomings: i) the available technical data was not sufficient to ensure degree of profitability of a new venture; ii) a JV would tie actors for a long time and allow for low flexibility, and iii) was not aligned with public administration role of the Region Västebotten.

The technical solutions put different requirement on both Umeå Energi and Region Västerbotten. Umeå Energi has always been, and seen themselves as, a seller of heat (or energy) but, in this BM, they became both seller and buyer of heat/cold. The same thing happened to Region Västerbotten, they went from a traditional buyer to buyer and seller. The development of the COOP BM thus also had to take this into consideration and establish how a revenue stream that allowed both organisations to buy and sell and could be coupled with the technology. If this BM is implemented, the two entities will have a different and closer relationship, so they had to establish additional ways of connecting their structures together. This has meant that they now focus on any energy related questions together rather than separately, and what was preciously “mine-mine” has become more “us” as expressed by one of the respondents. Moreover, the two organisations needed to sort out which type of contractual agreement, which can be used for future collaborations with other stakeholders. Finally, if this BM is to be successful it needs to packed within the context of relationship building and trust.

One essential aspect that made the foundation for the BM development and the technical solution was what counted as sustainable or unsustainable energy by regulatory or public/policy organisations. In the geographical region Umeå city, almost all energy production is environmentally friendly. The possible environmental value that could be gained through the technical solution and the COOP BM was contingent on the Swedish electricity mix being seen as environmentally friendly. If this changed, or if the development of the solution and BM took place somewhere else then one of the main drivers for change might be missing. Thus, a possible conflict in these types of cooperation where sustainability is at the core could be a disagreement on what counts as an environmental value or not.

The COOP BM seems to be able to, in the best possible way given the present situation, facilitate the technical possibilities and business values. However, it would seem like another major system change in this context and value that the COOP BM brings to the actors over a longer time frame (and thus might provide an energy system transition) lies with how the BM repositions previous relationships to a new configuration. The previous supplier-buyer relationship is becoming more complex, moving into a configuration that can be understood to have potential to help transition the energy system. The BM is on a higher structural level than novel technology and is facilitating a system shift. The COOP BM is a novel BM that emerge at a higher level of structuration than novel technology and allows for not only commercialization of new innovations but the utilizations of sustainable technology in new ways. Moreover, both respondents think that COOP BM as a framework has great potential for scalability. If the basic feature of the technology is present (see the solutions U1 and U3), and if the situation is similar as the one in the specific context, in which there is a need for heat and cold exchange it would seem possible to replicate.

A BM innovation that is able to facilitate change and the move of an innovation to change the regime is then by definition more disruptive, both in terms of relation to institutions and infrastructure, but maybe more difficult to standardize and replicate as it requires significant activity and risk taking. The COOP BM is without certainty a BM that delivers both a business case along with reduction of Co2. However, it is a collaborate model that requires significant commitment, new ways of managing funding and types of interdependence of activities new to the involved organisations.

From a financial, or revenue, point there has not been any problems, but the BM is not yet implemented, and it is quite possible that there are a lot of unknown knots on price per kWh that haven’t been solved.

In D.3.2 and D.3.3. delivery there are speculations on the possible scalability and replicability of the technical solution and BM. In that context, the method used is modelling rather than qualitative interviews. A method for making calculations and estimations from energy analysis and BM is provided, which has shown a way in which to evaluate mitigation measures and analyse BM which have the potential to support effective measures. This calculation method can be applied basically anywhere. Along with the contribution in this analysis it could provide a strong method towards understanding how the technical solution and COOP BM could be moved (or scaled) to other cities in Europe.

The analysis made here shows that the COOP BM can play a role in transitioning Umeå towards a more sustainable city heat/cold system. This is a similar conclusion from the one shared in D.6.2., which outlines a possible future for Umeå with energy use in a smart way, where linear (Business as Usual BM) is a thing of the past and heating, cooling and electricity are increasingly being 100 % renewable. The local energy supplier is a buyer, seller and producer of energy. Investments and risks are shared among many actors but also revenues and profits. The COOP BM is probably a good start towards that goal, when implemented, tested and revaluated.

5.6. Social Impact assessment

5.6.1. Focus of investigation

The evaluation of the RUGGEDISED project in Umeå included various solutions that were developed in the university district. *Solutions for sustainable mobility* were developed in collaboration with the Umeå municipality and UPAB parking company, which worked on solution to facilitate sustainable transport in the university district. These included a climate-friendly and inviting bus stop and a business model for green parking payoff for housing. Secondly, solutions for *demand-side energy management and*

intelligent control of buildings were developed by Akademiska hus, Umeå energi and Umeå University to provide improved energy efficiency of university area buildings. This included the creation of a system that learns occupant routines and patterns to customize the energy usage and facility services. Finally, the *renewable energy supply* solutions included new business models that enable exchange of energy between organizations, and a solar cell- and battery facility was installed together with a charging hub.
The pre- and post- assessments of RUGGEDISED in Umeå were carried out in two surveys (in 2018/2019 and 2022), receiving 195 and 180 full responses, respectively. The respondents were students or workers at the Umeå university campus and University hospital, predominantly at the former.

5.6.2. Expectations and Experiences

At the offset, half of the respondents were familiar with the RUGGEDISED project, which raised to about 60% by the post-assessment, despite a lower share of respondents being involved in the project. This suggests that the project gained some general recognition as it progressed. As can be seen from Figure 20 the respondents mostly rated the impact of the project's effects on their quality of life as neutral to somewhat positive.

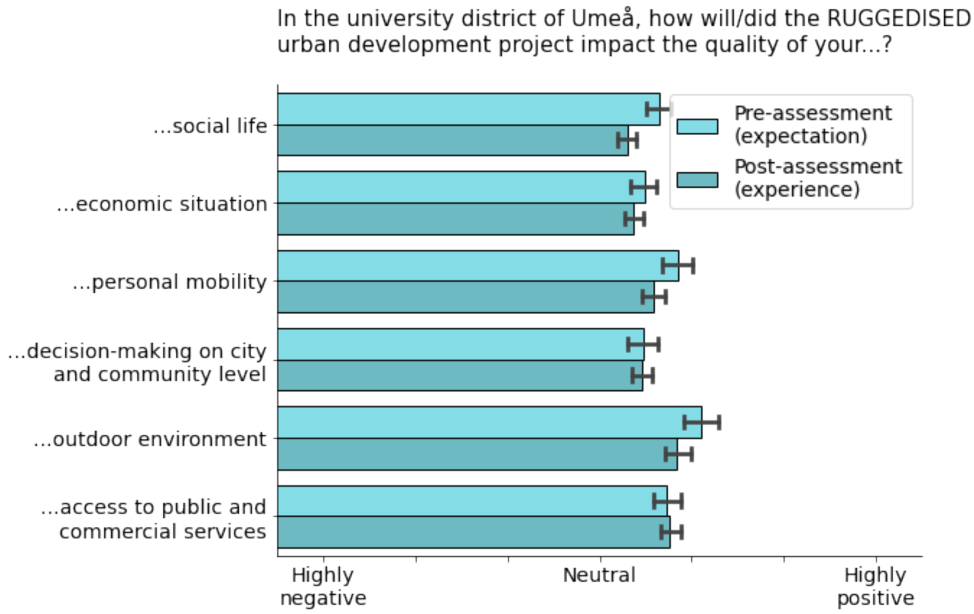

Figure 20: Expected and experienced awareness and impact of the project

Furthermore, regarding expectations and experiences with the three different services focused on in the project, Figure 20 und Figure 21 provide examples of responses to questions addressing the different installed services.

Solutions for sustainable mobility (smart bus stop): Here, the evaluation predominantly focused on the smart bus stop, as it was the one that the residents had the option to interact with**.** Most of the respondents rated the sustainable mobility solution as yielding neutral to positive advantages to themselves and the wider community with minimal differences between the pre- and post-assessment. Similar ratings were observed with the bus stop's "ease of use", pointing that it does not show significant signs of difficult or incomprehensible use, and potential interactions throughout the project did not change the initial sentiment. Further analysis showed that users most often estimated to use the solution on a weekly basis, and that it mostly affected people living within moderate distance (3-11km) of the campus.

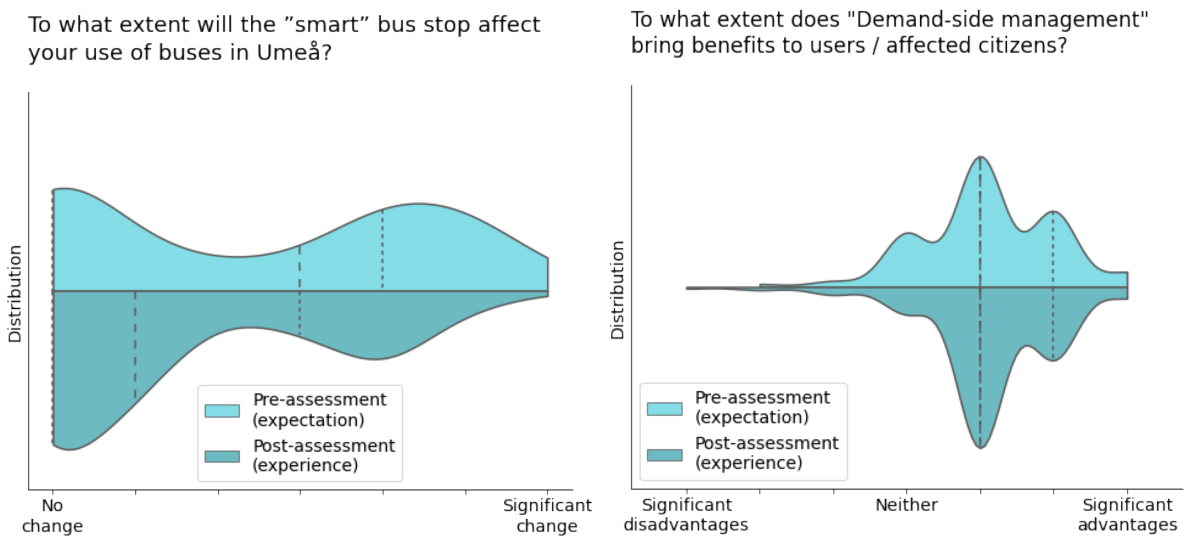

Figure 21: perceived effects of the "smart bus stop" (left and) "demand-side energy management" (right)

Demand-side energy management and intelligent control of buildings: Most respondents were familiar with the solutions' concept, and it was, in general, positively perceived (see Figure 21, right). In contrast, less than half were familiar with its implementation in the building, although the general sentiment towards energy efficiency of the buildings was overwhelmingly positive. There were no notable differences between the pre- and post- assessments, however, a more detailed analysis revealed that the sentiments towards the solution and its effects were somewhat higher with the younger, student population (for example, see Figure 22). While this is only a proxy measure, it might point towards a difference in perceptions of passive beneficiaries (students) and active users (workers) who interact with the system.

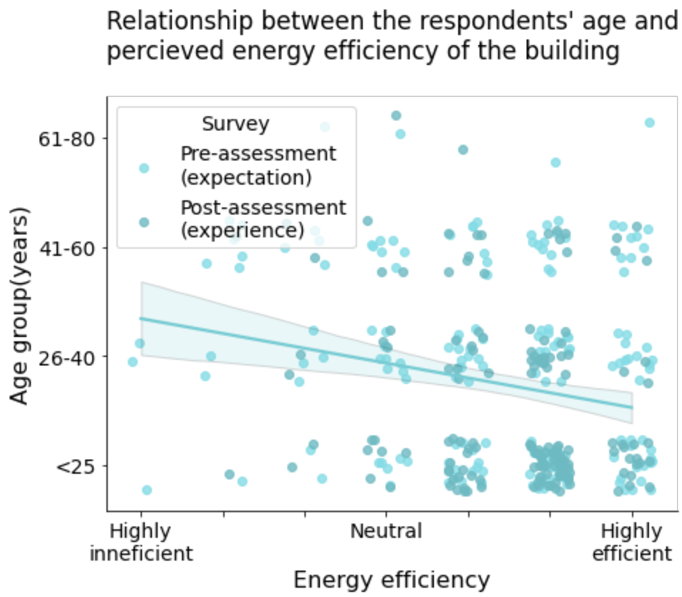

Figure 22: Relationship between the respondents' age and perceived energy efficiency of the building.

Renewable energy supply: The respondents were also asked about their attitudes towards renewable energy supply, which they generally rated as bringing some advantages towards themselves and others (Figure 23, left). When further asked about the domains of their impact, most respondents chose energy saving, followed by visibility of sustainability, reduced energy cost and reduced climate impact (Figure 23, right). The least frequent selection was "reliability of power supply". This is important information, as it may indirectly point towards the usefulness of demand-side energy management, which offers a way to increase power supply reliability.

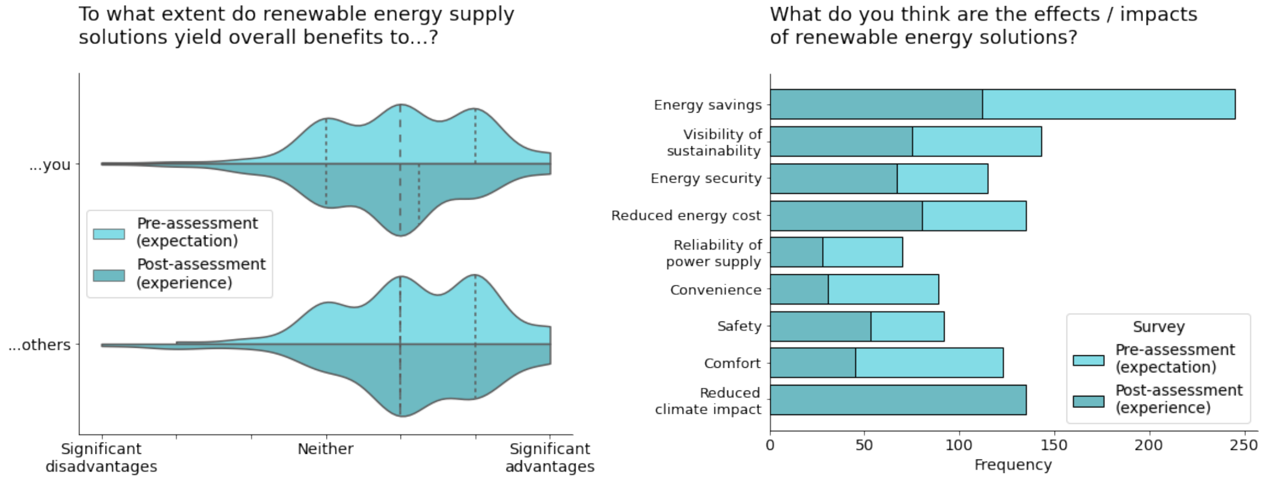

Figure 23: Perceived advantages of the "renewable energy supply" (left) and its significance regarding various areas of impact (right)

5.6.3. Conclusions

The social impact investigations in Umeå were based on a considerably large sample of persons affected by the implemented smart solutions. A notable observation is that assessments after the implementation quite consistently match with the expectations before the implementation, which were for the most part moderately positive. One of the likely reasons for this is that the demand-side management and renewable energy supply solutions are not directly visible to the citizens and were thus harder to assess regarding their impact.

This is different from the smart bus stop, which was a more tangible solution presenting a visible change. There, we observed two-faceted responses, presumably stemming from the fact that the change mainly affected a subgroup of respondents, namely those that lived within moderate distance of the campus. Others, which are more likely to use other means of transport, were more ambivalent towards the change. Taken together, the results of the pre- and post- assessments do not show remarkable changes in perception of the solutions or their effects during the project. However, even a lack of observable social impact may be a telling fact, as it points towards an absence of disruption. This too is an important finding, as it implies for low potential for pushback, should such solutions, whose benefits mostly show in other metrics, be adopted more widely.

5.7. Qualitative monitoring

The implementation of the different solutions in Umea and their deployment was analysed following the qualitative monitoring framework presented in Section 3.3. of this document, which includes the following aspects: i) Operational factors in deployment of smart solutions, ii) Cooperation, iii) Strategies, iv) Planning mechanisms, v) Innovation capacity.

The qualitative analysis has indicated that in terms of **Operational Factors**, regulations have not been influential in the deployment of the smart solutions in Umeå. According to the project staff, potential problems with regards to regulations were already covered before the start of the project by proactively identifying and handling potential feasibility challenges. However, financial constraints played a role in the deployment of the smart thermal grid, specifically geothermal heating/cooling storage and exchange (U3). The boreholes are in operation, yet the hardware connection and software need further investment which is pending. For the energy efficiency interventions, mobility solutions and ICT on city level (U4-U9) several local arrangements and practicalities caused minor delays in deployment and monitoring (e.g.

delays of (re)construction of buildings, late delivery of materials and COVID).

Cooperation between the stakeholders involved in the RUGGEDISED project in Umeå went well. A possible explanation is that the stakeholder that primarily cooperated are all public actors and hence, share similar goals, governance, ways of working and culture. Examples are Umeå Energi, the sewerage company, the parking company and the housing company, all fully owned by the city government. These companies are steered by a political committee that includes the mayor, politicians and delegates of the municipal companies. These parties are the main actors to reach climate neutrality in Umeå and are working closely together towards this goal.

In terms of **Strategy**, RUGGEDISED both benefited from the existing strategic framework and political commitment and gave much more visibility to the city. In Sweden there is a national innovation program called Viable Cities which normally only involved major cities. However, due to Umeå's Smart City Lighthouse status in the RUGGEDISED project, Umeå (despite being a smaller town) was able to participate in this Viable Cities network. Innovation projects like RUGGEDISED have the advantage that they bring in subsidies that create more room for experimentation. Specifically, companies like Umeå Energi and Akademiska Hus have realised smart solutions in RUGGEDISED that they would normally would not have.

Regarding the **Planning Mechanisms** factor, the analysis highligts the Umeå the Comprehensive Plan 2018, as the most influential policy document. The innovation projects that are deployed by Umeå are, by default, aligned with the Comprehensive Plan. This was also the case for RUGGEDISED. However, the project also contributed to enrich the existing mechanisms. RUGGEDISED instigated Umeå to submit a SEAP, which they are currently updating, focussed on the ambition for climate neutrality. In addition, the municipality has developed a SUMP. The SUMP details the 'five-kilometre' city strategy, which aims to provide all important services for all citizens in Umeå within a maximum distance of five kilometres

The **innovation capacity** of the city was an important factor to support and learn from the project. In terms of leadership, the team reported to have enjoyed of high-level support from the political and administrative leaders, and there was a strong mutual trust that supported the right implementation of the project. Moreover, the city administration is building capacity among staff to deal with new data, knowledge and innovation projects, and there is a growing learning culture in the administration. A positive aspect observed was that the city is comfortable working with local networks, including knowledge partners and private actors, which could reflect on the success of the project. An element for future improvement of the innovation support that was identified was the necessity to work less in silos and find mechanisms to share and co-create among different departments.

Table 29 summarises the main factors that influenced the deployment of the smart solutions, based on the qualitative monitoring. More details about the analysis can be consulted in D.5.6.

Table 29: Main deployment factors Umeå

Deployment factors	Findings in Umeå
Operational factors in deployment of smart solutions	• Due to the proactive identification and handling of potential feasibility challenges, operational factors were hardly hampering deployment.
Cooperation	• Cooperation between the stakeholders – all public actors– involved in the RUGGEDISED project went well.
Strategies	• The RUGGEDISED Smart City Lighthouse status allowed Umeå

	to become part of influential national networks.
Planning mechanisms	• Umeå has an overarching policy plan, called the Comprehensive Plan, which steers all city developments from urban planning to energy and mobility.
Innovation capacity	• The most prominent innovation capacity is networking; demonstrated through influential and institutionalised networks. • Close cooperation with knowledge institutes and universities supports knowledge exchange for innovation.

5.8. U1 - smart city connection to 100% renewable energy and U3 - geothermal heating/cooling storage exchange

5.8.1. Description of the solution

Smart city connection to 100% renewable energy and geothermal heating/cooling storage exchange	Smart Thermal Grid

Highlights and facts of U1 and U3

Business Model: Analysed → 5.5

Description

The purpose of the U1 and U3 solutions is to develop a new business model to make it possible to share excess renewable energy between stakeholders in a value chain and ensure better usage of geothermal storage. The overarching goal is to help the stakeholders reduce their climate impact and lower the costs of energy. Three different business models were tested and applied to nine ways of optimising energy use in the Innovation Area and evaluated to show how value creation might occur in the different scenarios.

Expected impacts:

- Extensive energy analysis and exploration
- Help to set up the baseline for optimal steps towards realising a 100% renewable energy supply between stakeholders
- New value proposition to current business model

5.8.2. Impact assessment

This solution was one of the solutions selected to undergo a social impact assessment during the project. This was realized in two batches of surveys distributed to stakeholders (students and workers) of Umeå university campus and University hospital. These surveys were distributed between 2018 and 2019 and received 195 and 180 full responses, respectively. During the social impact assessment, most of the individuals surveyed indicated that they perceived a positive impact on the use of renewable energy both on their lives and the wider community. The main perceived impacts of using renewable energy solutions were the capacity to save energy, sustainability visibility, cost reduction and decreasing climate impact, without major changes between the the pre- and post- assessments.

The Business Model (BM) assessment for this solution was done in combination with U1/U3, as both solutions aimed at the development of the University as an energy efficient and fossil free area. The two main actors that were engaged in the implementation of the solutions and participated and were affected by the BM development were Umeå Energi AB and Region Västerbotten. Altough the assessment was done before the effective operation of the solution, it was possible to assess the potential of different collaboration frameworks between the two entities.

The technical solution provoked a disruption in the usual BM of customer-supplier relation, as the actors became both suppliers, producers and sellers of energy, and investment risks were shared between them, independently of their nature. Through analysis of the solution and qualitative interviews, the cooperative BM was explored as the most fitting solution to enable the solution to reach the market, in which individual actors establish a common framework of cooperation for the energy production, storage and end-use. The assessment also indicated that a joint-venture approach with equity distribution and financial redistribution and risk-reward was not very suitable given the public nature of Region Västerbotten.

The solution then contributed to explore BMs to market the solution and descentralize the grid, and could be the basis to implement similar solutions in other areas of the city and with multiple types of stakeholders. The contractual agreements and collaboration frameworks to be developed could also provide a starting point for future projects.

5.9. U2 - Peak load variation management and power control

5.9.1. Description of the solution

Peak load variation management and power control — **Smart Thermal Grid**

Highlights and facts of U2

Peak demand reduction	**23%**
Primary energy savings	**145.22 MWh/yr**
CO2 savings	**22.05 t CO2/yr**

Description

The solution is based on an automated peak load management system which uses buildings and their storage mass as thermal energy storage hubs, so that stored energy can be used at peak periods when the need for energy is at its highest. Through this approach, it becomes possible to even out peak loads and reduce the use of fossil fuels, to secure a consistent heat supply throughout the city.

All buildings have a thermal mass that can be used to store energy. Heavy buildings (e.g. built with concrete) work better than light buildings (wood) for this purpose. A smart control unit assesses both outdoor and indoor temperatures in most existing systems. The system analyses weather data to predict the coming heat load. With this information, the system can constantly optimise the buildings' energy demand, while maintaining stable indoor temperatures. The benefits of this system are twofold – it saves energy for the property owners and reduces the peak loads of the district heating grids.

Installation of the peak load management system is expected to save up to 10% of energy and to shave peaks with around 15-50% in peak heat power usage. To make an impact, it would be preferable to scale the technology up and install units on a larger number of buildings. The aggregated benefit would be the possibility to mitigate peak loads on a city level. This could lead to less use of peak load boilers and hence reduced climate impact of the production. The challenge is to find a sustainable business model of value sharing.

This solution has been implemented for several different buildings and building clusters:

- the university campus area
- health center and
- student campus apartments.

The solution U2 "Peak load variation management and power control" is differentiated in U2A "Peak load shaving district heating in Samverkanshuset, Matematikgränd and Ålidhems HC (health center)" and U2B "University campus area".

Expected impacts:

- Save 10% and shave peaks with 15-50%
- Upscaling of the technology and installation of units in a large number of buildings
- Mitigation of peak loads on a city level
- Less use of peak load boilers
- Reduction of the negative climate impact of the production of district heating

5.9.2. Impact Assessment

U2A Peak load shaving district heating in Samverkanshuset, Matematikgränd and Ålidhems HC (health center)

Technical and environmental outcomes

The effect of U2a on the maximum heat consumption is outlined in Figure 24. Heat consumption peaks are reduced compared to the forecasted heat demand according to weather conditions, building characteristics and the initial operation strategy of the heating systems. The effect was most significant in the January and February 2022. Table 30 and Table 31 indicate the calculated technical and environmental KPIs for U2a. The implementation of U2a not only reduced peak heat demands, but also decreased energy consumption compared to the forecasted values. A wider roll out of the solution could further reduce the demands on the district heating system in Umeå and potentially mitigate the use of peak boilers, leading to reduced specific CO2 emissions. The implementation worked smoothly, and the system can easily be replicated or scaled up. Discussions with project partners are running to decide potential upscaling.

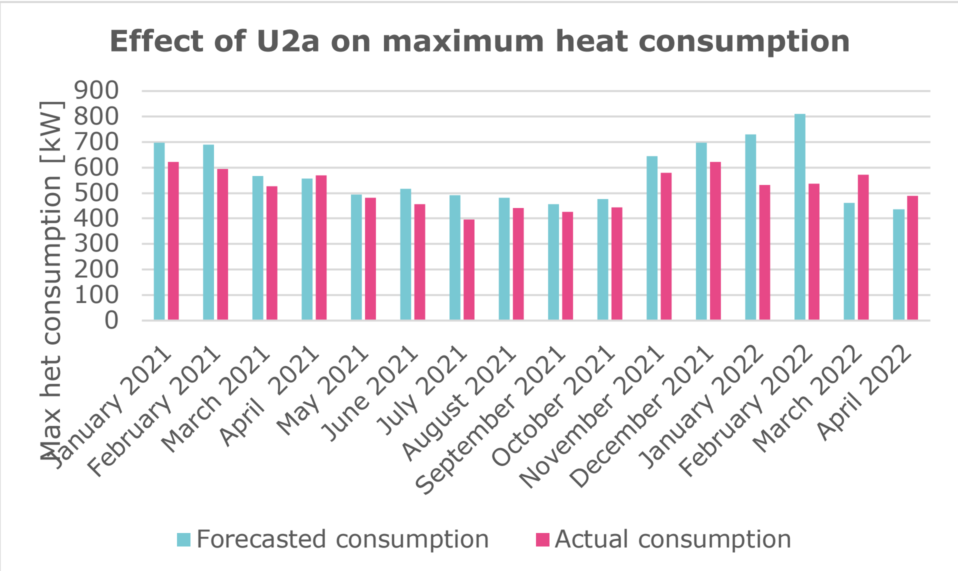

Figure 24: Effect of U2a on maximum heat consumption U2a

Table 30: Technical performance assessment of U2A

Smart Thermal Grid Cluster			
KPIs	Baseline	Target values	Achieved values
Peak demand reduction [%]	811 kW	15 % – 50 %	23%
Primary energy savings by cluster [MWh/yr]	781.48		145.22
Primary energy demand reduction [%]		Up to 10%	19%

Table 31: Environmental impact assessment of U2A

Smart Thermal Grid Cluster		
KPIs	Baseline	Achieved values
CO_2 savings [t CO_2/yr]	85.74	22.05
CO_2 reduction [%]		26%

U2B University campus area

Technical and environmental outcomes

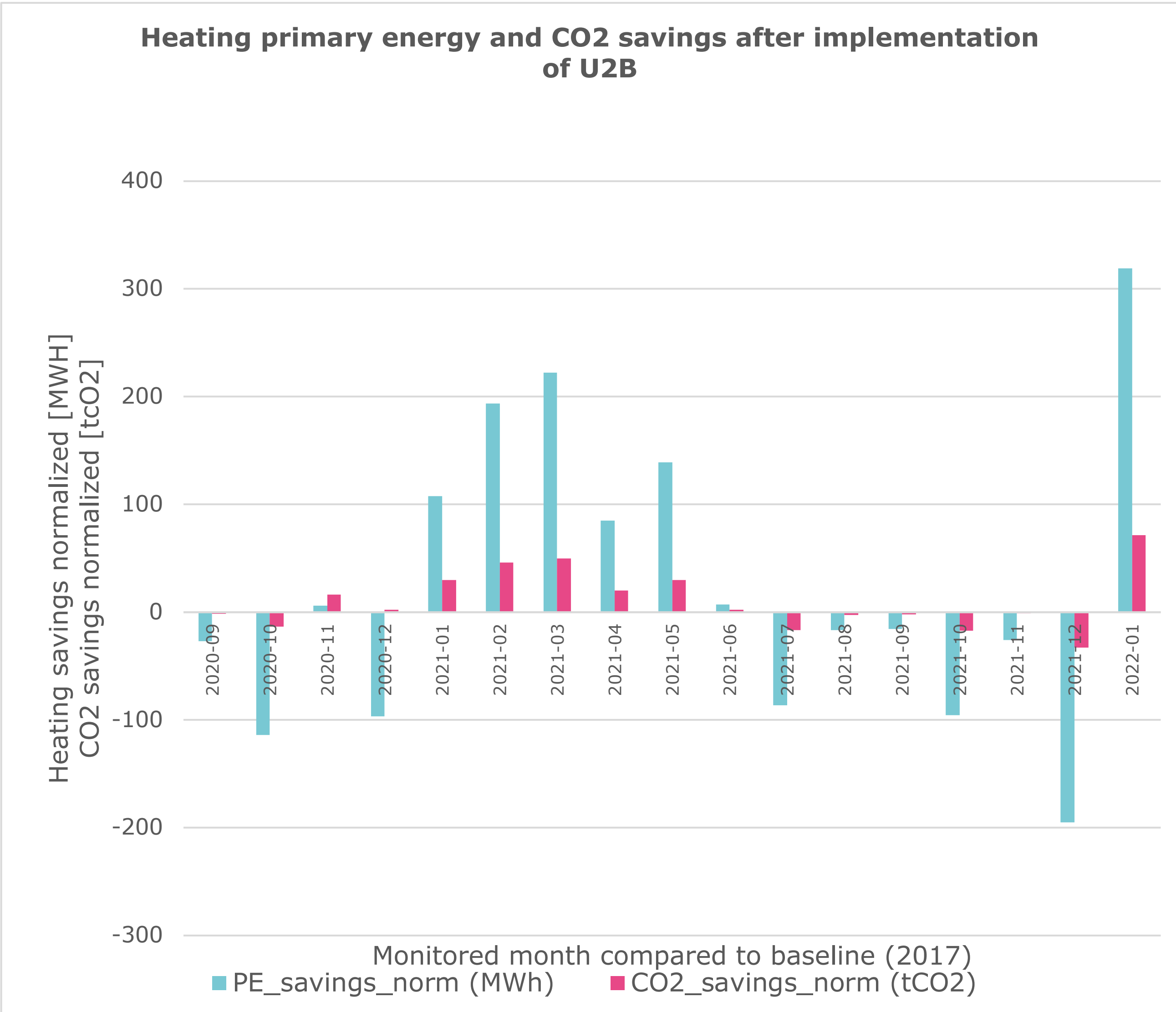

Figure 25: Heating energy and CO2 savings U2B

The installation of the peak load management system led to a peak shaving of 15.6% for the heating demand of the university campus area. This falls within the expected range of 15 to 50%. However, the weather data normalized thermal primary energy savings achieved for the monitored year 2021 only to 3.7%, in comparison with the 10% expected. A suggested interpretation for this gap is the fact that the primary energy savings targets in the implementation report have been set up for the whole U2 solution. It is important to note that the energy savings are not uniformly distributed over the year, and for some months the peak shaving solution may have even led to an increase in energy consumption at the university campus scale.

Table 32: Technical performance assessment of U2B

Smart Thermal Grid Cluster		
KPIs	**Target**	**Achieved value**
Peak demand reduction [%]	15%-50%	Heating: 15.6% Normalized with weather data: 15.7%)
Primary energy savings by cluster [MWh/yr]	-	Heating: 52.7 MWh (Normalized with weather data:215.2 MWh)
Primary energy demand reduction [%]	Up to 10%	Heating: 0.9% (Normalized with weather data:3.7%)

The implementation of the solution U2B in the university campus area has not only led to thermal energy savings but also to CO2 savings. Overall, the CO2 savings in the year 2021 compared to the baseline year 2017 are 85.1 tCO2 using weather normalized data. This corresponds to a reduction of 7.1% of CO2 emissions per year. No target was set-up during the implementation phase for the absolute and relative CO2 savings.

Table 33: Environmental impact assessment of U2B

Smart Thermal Grid Cluster		
KPIs	**Target**	**Achieved value**
CO2 savings [t CO2/yr]	-	52.3 t CO2/y Normalized with weather data: 85.1 t CO2/y
CO2 reduction [%]	-	4.4% Normalized with weather data: 7.1%

5.10. U4a - Gamification- Influence behavioural patterns

5.10.1. Description

Behavior change mobile application	Energy management and ICT

Figure 26: Umeå Energi's app

Description

The U4 solution aims to involve the tenants to achieve a more sustainable behaviour towards energy usage and other parts of their daily lives. The idea is to use gamification methods to encourage tenants to alter their habits and behavior. Through an App produced as part of the RUGGEDISED project, participants will be provided with information designed to inspire them to rethink their actions. This included:

- proposing challenges to encourage particular actions
- enabling continuous feedback to inform them of the results of their action
- holding group events to engage a larger number of participants and generate a bigger combined effect and a sense of accomplishment within the community

Expected impacts:

- Change in behaviour and habits concerning sustainability and energy use
- Increase awareness of the impact that one individual can have on energy use and CO2 emissions
- Long-term impact: reduction of costs for both tenants and real estate companies and reduction of CO2

5.10.2. Impact Assessment

The application has been tested over a year with a test group from selected buildings. During the testing phase the application was aiming to influence the sustainable behaviour and habits of the tenants, while it also collected the consumption data for the comparison with a gamification approach. In addition to that, interviews and user feedback was conducted regularly. The results of the testing phase have shown low participation rate (only 13%), which was less than anticipated. Nevertheless, the application can have an impact on the tenant's behaviour, but it cannot be stated if it has also led to energy savings due to the challenges and complexity of the measurement of individual consumption habits.
During the the course of the project, it also became apparent that in the "noise" of today's society with many competing applications, it is very difficult to attract and maintain the attention of the user community. To be successful over time, it is crucial to actively manage campaigns to attract and maintain user interest. Change in behavior does not come overnight, it is a process that takes time and requires continued engagement. There are no plans for upscaling and replication of the solution, as it is also quite

expensive to develop features and campaigns that are of low commercial value. The decision was therefore made to terminate the application after the test run period

More information on the surveys and interviews conducted with the users of the application can be found in the Implementation Report of Umeå and the full report on the solution.

The U4 solution is divided into two different implementations: U4A and U4B. The U4A is about the assessment of the new built Mariehöjd residential buildings and U4B treats the smart heating and cooling system of the hospital and physiology building in the university campus area.

5.11. U4b – Intelligent building control (Mariehöjd new buildings)

5.11.1. Description of the solution

Residential buildings with building standard beyond building code	Smart electrical grid

New Built Floor Area Residential	**8,211 m²**
Energy savings	**340 MWh/yr**

Description

U4A Mariehöjd comprises the newly built residential buildings "JK" and "GHI". Their construction was finished in 2017 / 2018 and their building standard goes beyond the relevant Swedish building code BFS 2015:3 (Boverket, 2019).

5.11.2. Impact Assessment

Technical and Environmental Outcomes

Figure 27 shows that the building standard used in the construction of Mariehöjd JK and GHI surpassed the relevant requirements stated in the building code. The monitoring also revealed that the buildings operate in a slightly more efficient way than the stated standard. This underlines the importance of high standards on the thermal performance buildings. The analysis also shows the feasibility if the set targets on energy consumption. The implemented solution has significantly lower energy consumption and greenhouse gas emissions compared to the design limits set by the Swedish building code. Table 34 indicates the performance assessment and calculated KPIs for the Mariehöjd buildings. It further highlights the achieved primary energy consumption reduction. It was refrained from calculating CO2 emission reductions, as the baseline - the Swedish building code BFS 2015:3 (Boverket, 2019) - only demands maximum annual energy consumption values on the overall building level. This did not allow to set an individual baseline for electricity and district heating consumption.

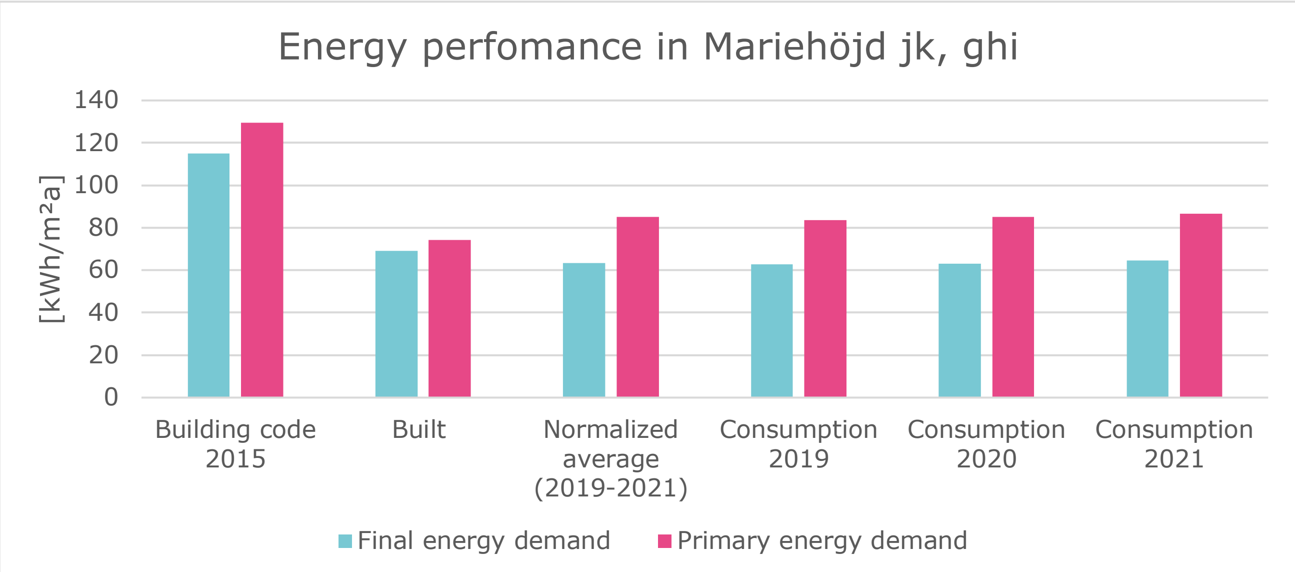

Figure 27: Energy performance comparison Mariehöjd

Table 34: Technical performance assessment of Mariehöjd buildings.

General assessment of buildings		
KPIs	Baseline	Achieved values
New Built Floor Area, Residential[m²]	8211	8211
Cluster of solutions to increase the energy efficiency at building and district level		
Energy Savings by Building Efficiency Measures[MWh/yr]	944	340
Energy Demand Reduction[%]	NA	36
Primary energy savings by building energy efficiency measures and street lighting [MWh/yr]	1062	363

5.12. U4b - Intelligent building control (Akademiska Hus AB)

5.12.1. Description of the solution

Smart heating and cooling system | **Smart Thermal Grid**

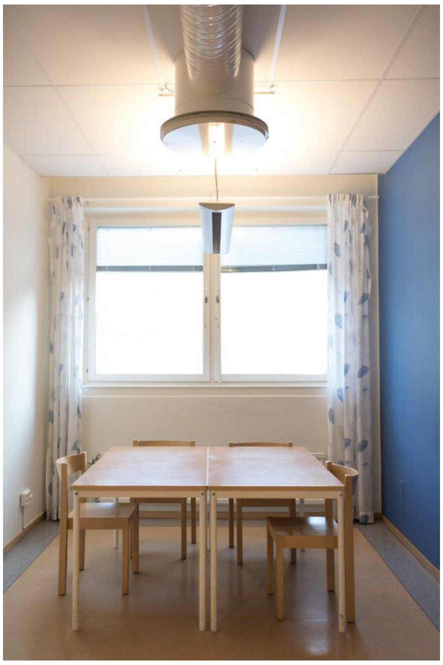

Figure 28: Sensors and HVAC devices in the building of U4b

Refurbished floor area	34,880 m²
Primary Energy savings	3,886 MWh/yr
CO2 Savings	90.46 t CO2/yr

Description

The U4B solution was installed by Akademiska Hus AB, which owns and operates the university and college buildings for the Swedish State. The solution includes smart control equipment to control air flow, room climate and presence-activated lighting in 130 offices at the University area in Umeå. The solution is installed in one of the large lab houses, the Physiology House, which includes both offices and laboratories and where ventilation is in operation 24 hours a day. The owner of the hospital in Umeå, Region Västerbotten, has also installed automatic smart control equipment in office areas. A smart system that regulates air flow, temperature and lighting, based on the presence and number of people in a given room, has been installed and was expected to lead to a reduction in heating and electricity demand. Moreover, the rooms were connected to a monitoring system which enabled better control of the overall system. The technical solution which is partly financed through the RUGGEDISED project is a part of a large package of measures in a large complex building at Campus Umeå.

The monitored buildings are:

- Hospital building
- Physiology building

Expected impacts:

- Reduction in heating and electricity demand
- Better control of the overall system

5.12.2. Impact Assessment

This solution was one of the solutions selected to undergo a social impact assessment during the project, realized through two batches of surveys distributed to stakeholders (students and workers) of Umeå university campus and the university hospital. These surveys were distributed between 2018 and 2019 and received 195 and 180 full responses, respectively. The general sentiment towards the solution was overwhelmingly positive, especially among younger users of the buildings. Although an important part of the survey participants did not know about the implementation of the solution in the concrete building, they were familiar with the solutions' concept and both in the pre- and post- assessments it was very positively perceived.

Looking at the upscaling potential of the solution, the installing of such devices in existing building complexes might not always be profitable. Besides the implementation costs, the operation also would require technical training of the staff to ensure the proper operation. One of the key learnings for future projects indicate that extensive renovations and the system should go along with profitability analysis. However, this solution can be easily replicated in new constructions in Sweden, considering the strict requirements regarding the ventilation. For other European cities, there are other requirements, and this could lead to additional costs.

Technical Outcomes of U4B

Overall, 34880 m2 of tertiary buildings have been refursbished within the solution U4B. This has led to a total of 3886.9 MWh of primary energy savings per year including the electricity and heating demand (including space heating and SHW) for the hospital building and the heating demand for the physiology building. Considering the data provided at building level for the solution U4B, it is impossible to distringuish the contribution of the smart solution from the refurbishment energy savings.

Table 35: : Technical performance assessment of U4B

General assessment of buildings		
KPIs	Target values	Achieved values
Refurbished Floor Area, Tertiary Buildings [m²]	36033	34880
Cluster of solutions to increase the energy efficiency at building and district level		
Final energy Savings by Building Efficiency Measures [MWh/yr]	-	District heating (normalized with weather data):: 924.6 MWh Electricity 1216 MWh
Primary energy savings by building energy efficiency measures [MWh/y]	-	District heating (normalized with weather data): 1017.1 MWh Electricity 2869 MWh

The implementation of the solution U4B combined with the energy efficiency improvements of the hospital and physiology building not only led to energy savings but also enabled the saving of 90.5 tons of CO2 per year.

Table 36:Environmental impact assessment of U4B

Cluster of solutions to increase the energy efficiency at

building and district level	
KPIs	Achieved values
CO2 Reduction Achieved by Building Efficiency Measures[t/yr]	District heating (normalized with weather data): 78.3 tonnes Electricity 12.16 tonnes

Hospital building - Region Västerbotten:

Overall, the calculations show that the solutions implemented in the hospital building and the refurbishments performed to increase the building's energy efficiency has led to a decrease of 76% of the electricity demand and 45% of the heating demand (including space heating and SHW) as highlighted in Figure 29. The monthly normalized consumption breakdown presented in Figure 30 is based on normalization factors provided by the Umea partners, and the sum of this monthly consumption leads to a slightly 42% reduction of the heating demand which is slighty different than the calculation based on the yearly Heating Degree Days.

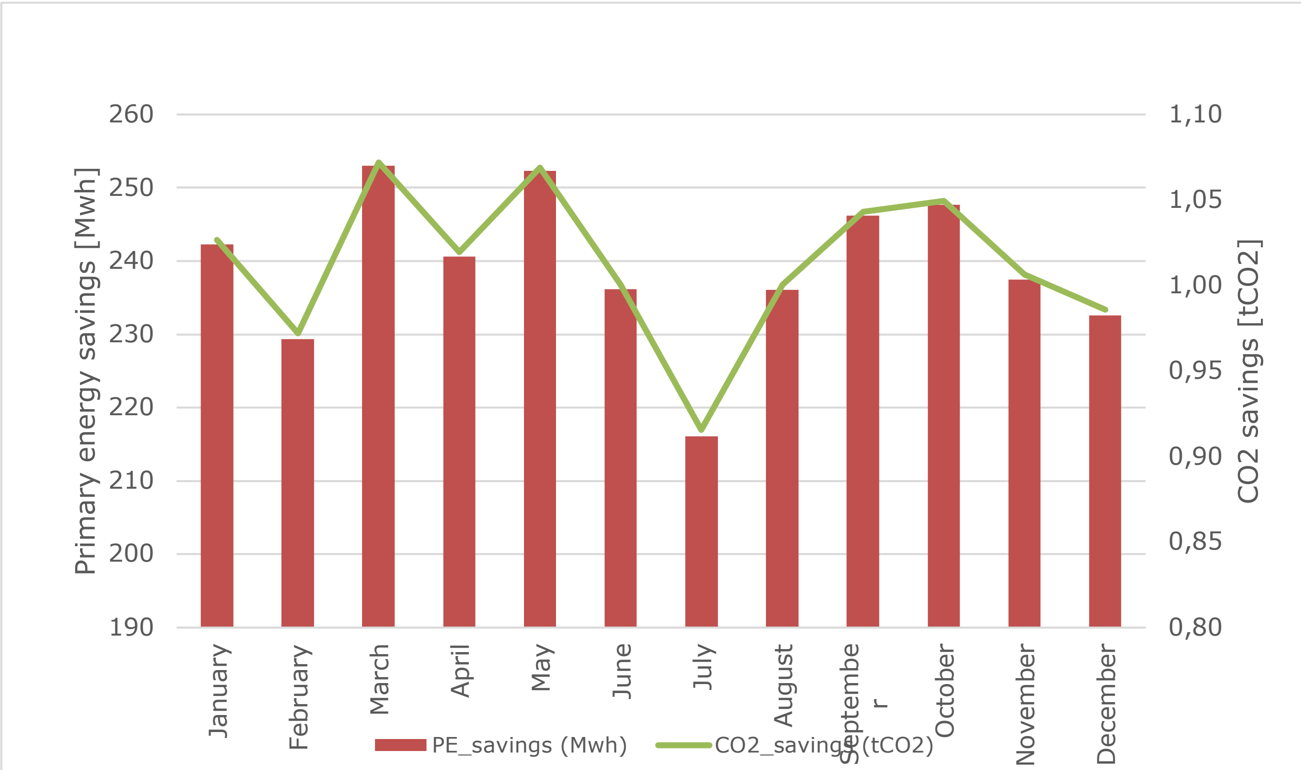

Figure 29:Primary energy and CO2 savings due to electricity savings (hospital building)

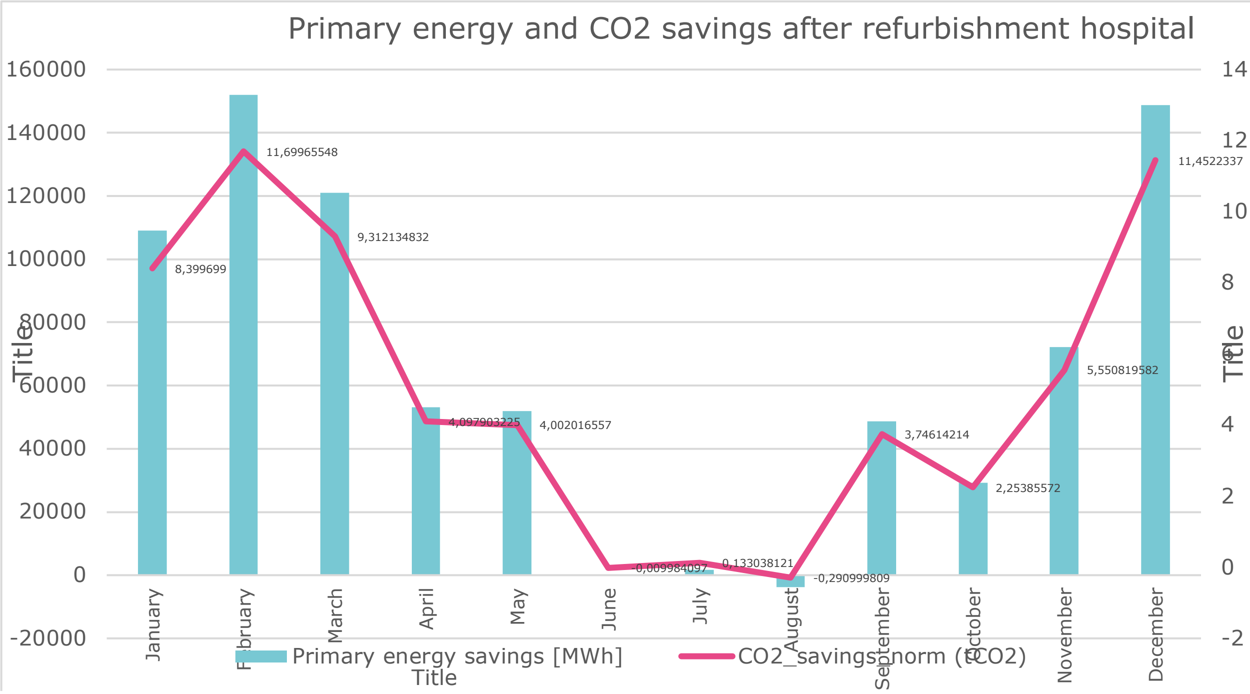

Figure 30: Heating primary energy and CO2 savings after the refurbishment of the hospital

The calculated energy savings are higher than the forecasted savings calculated in the best sheet as presented in Table 37. An explanation for this can be that considering the available data monitored at building level, it is impossible to distinguish the contribution of the solution U4B and the energy efficiency measures to these energy savings.

Table 37: Energy performance comparison with BEST Sheet

	Energy performance baseline (finalenergy) [kWh/m²year]	Energy performance monitored (final energy) [kWh/m²year]
BEST sheets	169	68
Consumption (heating consumption normalized with weather data)	150.1	59.1

Table 38: Technical performance assessment of hospital building - Region Västerbotten

General assessment of buildings		
KPIs	Target values	Achieved values
Refurbished Floor Area, Tertiary Buildings [m²]	21383	21383
Cluster of solutions to increase the energy efficiency at building and district level		
Final energy Savings by Building Efficiency Measures [MWh/yr]	-	District heating (normalized with weather data):: 730.7 Mwh

		Electricity 1216 MWh
Energy Demand Reduction[%]	-	District heating (normalized with weather data): 45% Electricity 76%
Primary energy savings by building energy efficiency measures [MWh/y]	-	District heating (normalized with weather data): 803.74 MWh Electricity 2869 MWh

The implementation of the energy efficiency measures and the solution U4B in the hospital building has not only led to energy savings, but also CO2 savings as highlighted in Table 39. Overall, the CO2 savings in the year 2021 compared to the baseline year 2015 are 61.9 tCO2 using weather normalized data. Considering the data set analysed, it is impossible to distinguish the contribution of the solution U4B from the contribution of the energy efficiency measures.

Table 39: Environmental impact assessment of the Hospital building - Region Västerbotten

Cluster of solutions to increase the energy efficiency at building and district level	
KPIs	Achieved values
CO2 Reduction Achieved by Building Efficiency Measures[t/yr]	District heating (normalized with weather data): 61.9 tonnes Electricity 12.16 tonnes
CO2 reduction [%]	District heating (normalized with weather data): 45% Electricity 76%

Physiology Building:

Overall, the calculations show that the solution implemented in the physiology building and the refurbishments performed to increase the building's energy efficiency has led to a decrease of 19% of final energy consumption per square meters to cover heating needs, between the baseline year (2016) and the monitored year (2021) based on the normalization with yearly Heating Degree Days. The same calculation based on the normalization factors provided by the Umea partners presented in Figure 31**Fout! Verwijzingsbron niet gevonden.** leads to a yearly final energy reduction of 22% to cover the heating demand.

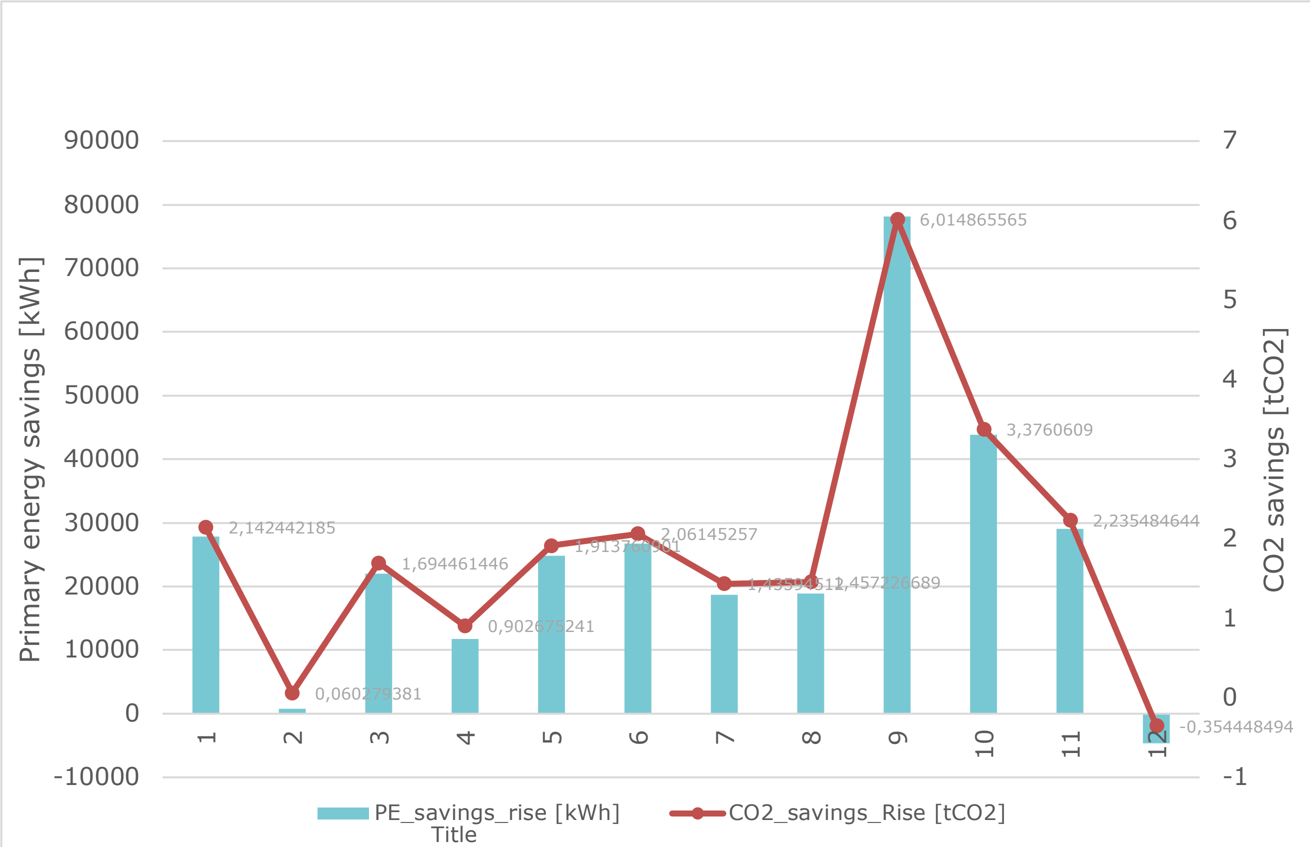

Figure 31- Heating primary energy and CO2 savings after refurbishment for the physiology building

For consistency reasons, the performance assessment has been performed with the yearly HDD normalization methodology and the aggregated numbers at solution and city level take into account these values. Moreover, the comparison between the value calculated for the energy performance of the baseline year (2016) and the value indicated in the best SHEET shows inconsistencies in the energy consumption. After further analysis, these inconsistencies have been attributed to the inaccurate estimate at the time of the proposal development.

Table 40: Energy performance comparison with BEST-SHEET

	Energy performance baseline (final energy) [kWh/m²year]	Energy performance monitored (final energy) [kWh/m²year]
BEST sheets	124	88
Consumption (heating consumption normalized with weather data HDDs)	71.1	57.9
Consumption (heating consumption normalized with Umea factors)	82.4	63.9

The implementation of the solution U4B in the physiology building, together with the refurbishment performed to increase the building's energy efficiency has led to primary energy savings of 213.4 MWh between the baseline year 2016 and the monitored year 2021 as presented in Table 37. Considering the available data monitored at building level, it is impossible to distinguish the contribution of the solution

U4B and the energy efficiency measures to these energy savings.

Table 41: Technical assessment of the Physiology Building

General assessment of buildings		
KPIs	Target values	Achieved values
Refurbished Floor Area, Tertiary Buildings [m²]	14650	14650
Cluster of solutions to increase the energy efficiency at building and district level		
Final energy Savings by Building Efficiency Measures [MWh/yr]	-	District heating (normalized with weather data): 193.9 MWh
Energy Demand Reduction[%]	-	District heating (normalized with weather data): 19%
Primary energy savings by building energy efficiency measures [MWh/y]	-	District heating (normalized with weather data): 213.4 MWh

The implementation U4B and the energy efficiency measures in the Physiology building not only led to energy savings but also enabled the savings of 16.4 tCO_2 per year.

Table 42: Environmental impact assessment of the Physiology Building

Cluster of solutions to increase the energy efficiency at building and district level	
KPIs	Achieved values
CO_2 Reduction Achieved by Building Efficiency Measures[t/yr]	District heating (normalized with weather data): 16.4
CO_2 reduction [%]	District heating (normalized with weather data): 19%

5.13. U5 - Climate smart bus station

5.13.1. Description of the solution

Climate smart bus station **Smart electricity grid and e-mobility**

Figure 32: Climate smart bus station

Description

The climate smart bus station is a new type of bus stop that contributes to the objective to reduce the city's environmental impact and emissions, while promoting the interaction of technology, people, and environment. The futuristic and unique design of the bus stop establishes public transport as a modern mode of transport in the smart city.

The innovative design of the bus stop gives passengers the opportunity to "rest and reflect" while waiting for the bus, and contributes to reduce the boarding time hence, of CO2 emissions. Moreover, it also a symbol for the Smart University District. The bus station is served by both electric and fossil fuel buses. Procurement was carried out as a design-and-build contract.

Expected impacts:

- Showcase modern mode of transport for a smart city
- Design aims to give the passengers the opportunity to 'rest and reflect' while waiting for the bus
- Contribution to reduction in boarding time and CO2 reduction

5.13.2. Impact Assessment

Due to the qualitative nature of this solution no quantitative monitoring could be performed, but the local team gathered some feedback on the bus station from passengers. The smart bus stop was the focus of the social impact assessment analysis regarding mobility solutions, as it was the solution with which residents had more interaction. This solution was estimated to impact mostly users living within a moderate distance from the campus (3-11km) and that would use the solution on a weekly basis. Regarding the users' perceptions on it, most of the respondents rated the sustainable mobility solution as yielding neutral to positive advantages to themselves and to the wider community. During the implementation of the solution, local partners conducted sixteen interviews with, of which 14 rated the bus stop with 3 or higher on a 1-5 scale. Although the number of interviewees was small and not statistically representative, the overall impression for passengers was positive. Only 2 out of 16 passengers experienced an alteration in their way of travelling, for example looking less at signs and instead listening to the sounds that reveals that the bus is arriving.
These interviews also showed a rather mixed impression of the bus stop by the passengers. While some of them found it "cool", futuristic, and different in a positive way, some others didn't appreciate specific

elements of design, in which some cases was considered unpractical.
Only minimal differences between the pre- and post-assessment were observed regarding this perception. Moreover, the bust stop was considered easy to use by users, and the experience equaled the initial expectations regarding the solution. There are also great opportunities for replication either as a full concept or in-part, e.g. the design of the innovative pods and the meditative light and soundscapes which are connected to a realtime GPS-system.

5.14. U6- E-charging hub and charging infrastructure

5.14.1. Description of the solution

E-charging hub and charging infrastructure **Smart electricity grid and e-mobility**

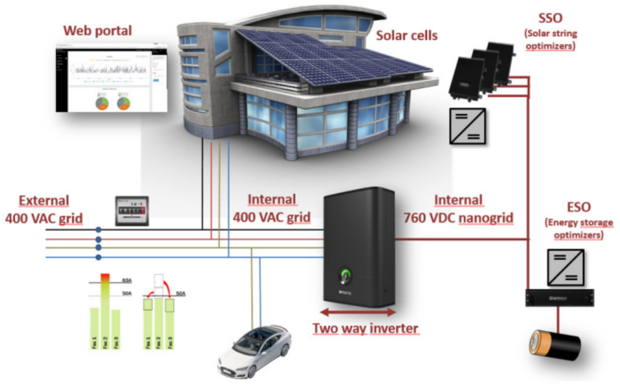

Figure 33: E-charging hub. Source: Ferreomp

Electricity generated by RES	17.5 MWh/yr
CO2 savings	159 t CO2/yr
Primary energy savings	34.6 MWh/yr

Description

Akademiska Hus has tested a charging hub for e-vehicles (see Figure 33 above). The main aim of this solution is to find a smarter energy system solution with lower climate impact by integrating grid owners and involving end users, providing smart energy to recharge electric vehicles with renewable energy sources.
As e-vehicle charging adds strain to the power system, different batteries and storage solutions were tested in the framework of this solution, such as a smart power control management-system, and a dynamic payment system for the charging. How the integration of small-scale photovoltaic (PV) installation within the overall system and how the battery storage can be upscaled were also elements explored during the pilot. The expected impacts of the solution were to reduce buildings' energy consumption and address systemic effects such as decreasing peak loads. The overall aim for the e-charging hub was to develop it in into an "Energy-hub", and to get enough information to make an assessment about how use patterns and loads can be useful to calculate the size of the battery plant necessary for different types of properties. In the future, Region Västerbotten will also install a charging hub for e-vehicles in front of the hospital in Umeå.
The EV-chargers targeted taxis waiting for customers at the hospital entrance, where the chargers were installed, with the objective to encourage taxi companies to invest in EVs. Additional positive effects in the long term would be the reduction of noise and improvement of air quality in the hospital area.

Expected impacts:

- Optimal distribution between building loads, battery storage and solar panels
- Knowledge on the size of battery plant for different types of properties

5.14.2. Impact Assessment

This solution was one of the solutions selected to undergo a social impact assessment during the project, realized through two batches of surveys distributed to stakeholders (students and workers) of Umeå university campus and the university hospital. These surveys were distributed between 2018 and 2019 and received 195 and 180 full responses, respectively. Between the pre and post-assessment, survey respondents reported a slight improvement on personal mobility situation thanks to the Ruggedised project interventions. While the majority of the social impact assessment focused on U5, respondents were also aware of the interventions related to U6 and partly this solution could impact in their overall perception.
Currently, there are no specific upscaling plans of the solution. However, the model is still being updated to ensure that the correct dimensions are defined and can be replicated after further developments.

Technical and environmental outcomes

Compared to the production of the PV system, the load induced by the EV chargers is very high. This leads to high self-consumption rates of PV energy and low exports to the grid, as Figure 34 indicates. The PV panels installed enabled the generation of 17,488 kWh in 2021 (Table 43). This has positively contributed to reduce the energy imports from the grid, avoiding additional CO2 emissions. The analysis also indicates that a bigger PV system would lead to further mitigation of electricity consumption from the grid, while keeping feed-ins at a moderate level.

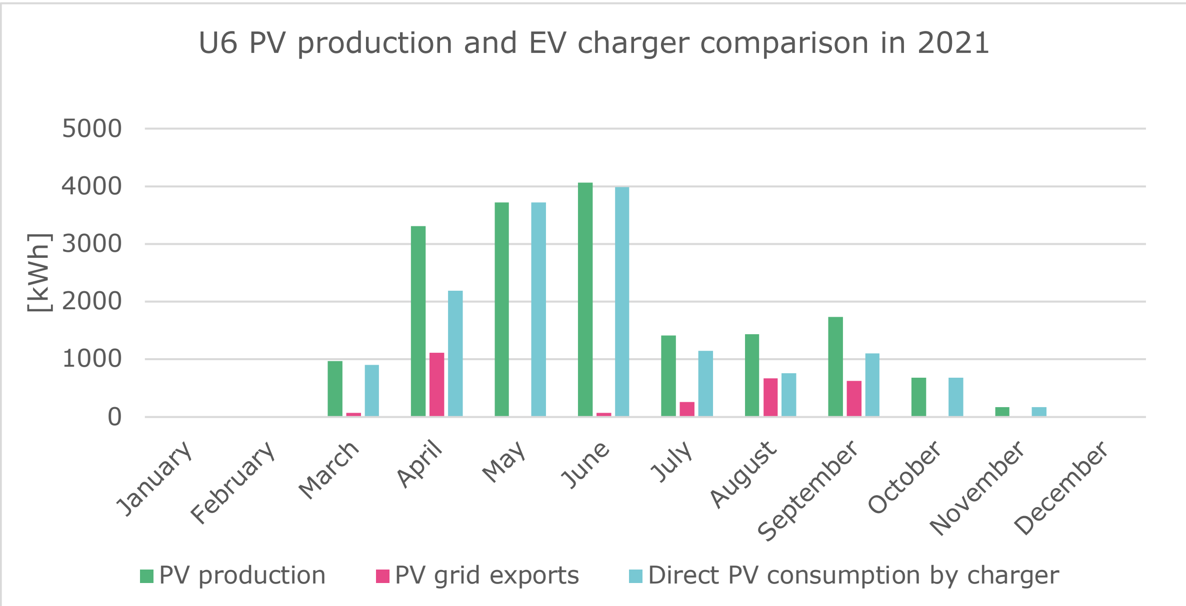

Figure 34: U6 PV and EV charger comparison

Table 43: Technical performance assessment of U6

Smart Electrical Grid Cluster		
KPIs	Baseline	Achieved values
Electrcity generated by RES [MWh/yr]		17.5

The implementation of the solution U6 has led to primary energy savings of 34.6 MWh. This corresponds to CO2 savings of 6.17 tonnes per year as highlighted in Table 44. The smart electric grid cluster refers to the effect of the PV system on the EV charging. The baseline for the smart electric grid cluster therefore refers to the situation without PV system, where the EV chargers would not be supplied by local PV.

Table 44: Environmental impact assessment of U6

Smart Electrical Grid Cluster		
KPIs	Baseline (initial situation)	Achieved values
Primary energy savings [MWh/yr]	582	34.6
Primary energy demand reduction [%]	-	6%
CO2 savings [t CO2/yr]	1.97	0.117
CO2 reduction [%]	-	6%
Mobility Cluster		
CO2 savings [t CO2/yr]	-[7]	159
SO2 savings [g SO2/yr]	-	6267
NOx savings [g NOx/yr]	-	100,277
PM10 savings [g CO2/yr]	-	5,640
Primary energy savings [kWh/yr]	812,540	230,087

[7] Value is based on diesel kilometres – there can be no baseline

5.15. U7 – Green parking pay-off for flexible parking

5.15.1. Description of the solution

Green parking pay-off for flexible parking | **Smart electricity grid and e-mobility**

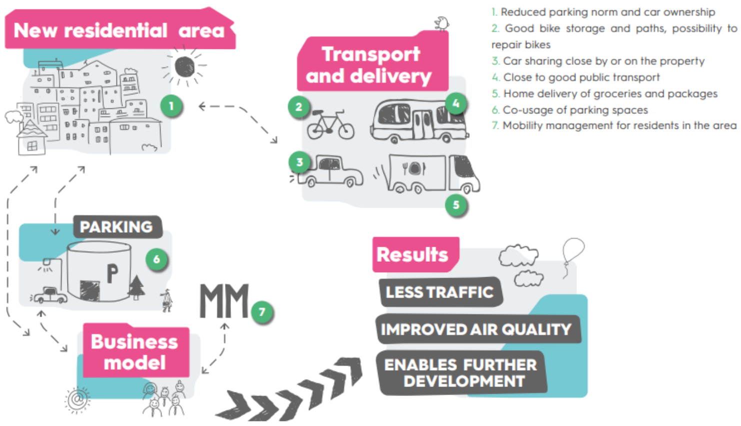

Figure 35: Flexible parking concept in Umeå

Description

To help manage air quality in the centre of Umeå, the local authority has decided that no new workplace parking spaces shall be built in the central urban area. Property developers are therefore offered the possibility to access alternative pay-off schemes for parking places through Umeå Parking (UPAB), the municipal parking company, when they get planning permission.

In order to enable more sustainable travel to and from work, in the framework of the RUGGEDISED project, property developers have been offered a reduced fee for the cost of the parking pay-off through the "Green Parking Pay-off" scheme. In this case, the developer signs an agreement with UPAB in which they agree to implement measures to support sustainable travel for the users of the building. The municipality of Umeå and UPAB implemented a parking pay-off scheme. The parking pay-off scheme means that property owners can buy parking spaces instead of building them on their own property. The property owner then gets the parking solution at a lower cost since they are technically collective facilities.

Expected impacts:

- This model allows property owners to take responsibility for the employee travel to and from the property – by offering car parking according to existing standards
- The property owners receive a reduced parking standard fee if they pay a fee to a mobility management fund (for e.g. car sharing, heated bicycle parking areas)

5.15.2. Impact Assessment

The Green Parking Pay-off can be used for businesses and housing within the city centre. The Green Parking Pay-off primarily applies to new and additional buildings, but a re-assessment to include older buildings may be relevant. The Green Parking Pay-off provides incentives for the property owner to contribute to sustainable mobility patterns. The model has already become a permanent model in Umeå and has a high potential for replication in other cities.

More information on Green parking-day off for flexible parking can be found in the Implementation Report of Umeå.

5.16. U8 – Smart City open-data decision platform

5.16.1. Description of the solution

Smart City open-data decision platform	Smart Open Data Platform

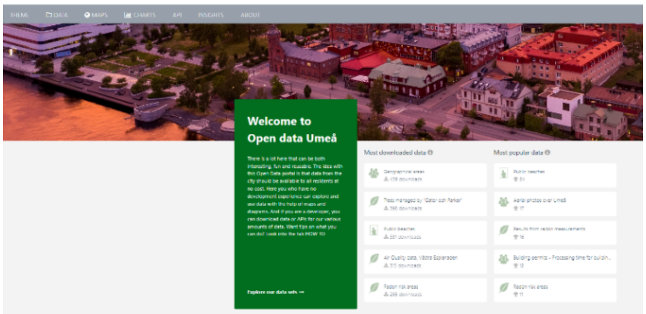

Figure 36: Screenshot from Open Data Umea platform

Description

The smart city open-data decision platform aims to provide real-time visualisation as well as static data to show the impact of smart city interventions. It will also provide a way to quickly access and combine different data sets to examine results and, as such, to enhance the possibility of making timely, well-founded decisions for the council as well as for citizens. Bringing together different data sets as part of one platform enables a more uniform approach towards decision-making and the potential for a real improvement of quality of life.

The portal became public in autumn 2019. On the open-data platform, users have the possibility to combine different data sets and administrators can create dashboards to visualise specific data set combinations.

Expected impacts

- Users can both download data and view it directly
- The portal is user-friendly and not only for developers
- Combination of different datasets

5.16.2. Impact assessment

The Smart City Open Data platform is seen as a benefit for many users from the different departments within the municipality but also other partners such as UMEA Energi, who shared their data sets about the results from their peak load shavings and energy consumption in the different areas of the municipality. Thus, the data sets can be used to focus on different energy savings campains to different areas. The portal will also be used by citizens e.g. for showing the public beaches in the city during the summer of 2020. In conclusion, the portal serves both citizens and public departments or other organisations to receive informative dashboards or to report the information in different domains. Many more examples of the value of the use of this platform has been proven.

The municipality is expecting more data to be published on the platform. Therefore, for the upscaling of this solution, more sensor data and data on climate and waste is planned to be included. The solution can be replicated by any other city as the platform is built as a part of a purchased product. The only challenge is to convince the different stakeholders to share and publish their data.

More information on the Smart City Open-Data Decision platform can be found in the Implementation Report of Umeå.

5.17. U9 – Demand Side Management

5.17.1. Description of the solution

Demand Side Management	Energy management and ICT

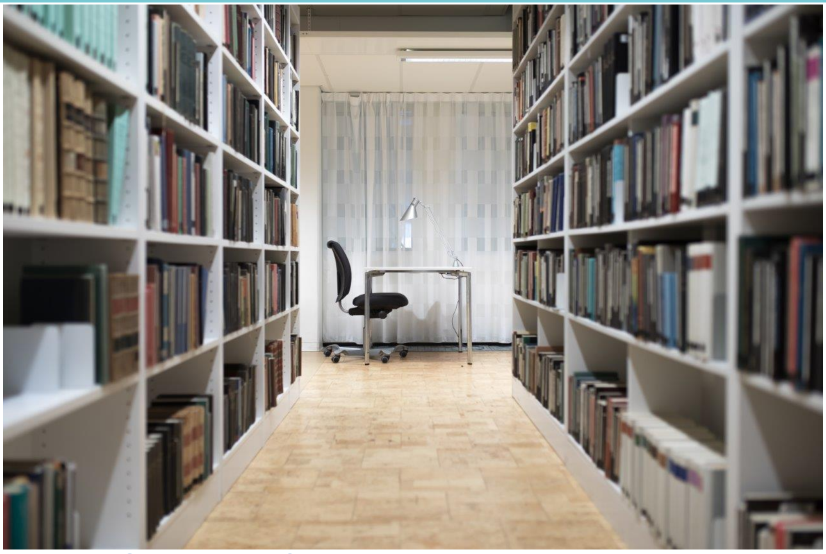

Figure 37: Sensors. HVAC devices in U4B

Description

For this solution, the demand side management system logs sensor data from different sources (i.e, indoor climate, electricity use and radiator heat data and HVAC devices detailing occupancy and indoor climate data, weather station data with outdoor temperature data and time schedule data from the University facility booking system) and aggregates it into a single platform. This platform enables a new kind of analysis that shows the use and energy status of a building. Research results have diminished the need for facility areas while increasing the efficiency of facility usage. The results have also improved the management tool: for example by showing optimal indoor temperatures, unnecessary energy use and the actual energy usage of bookable rooms. Research has further contributed to improving the measurement method by analysing the accuracy of the sensor when logging information. While the solution will affect the buildings in terms of better management of energy use, better indoor climate and more efficient facility usage, the people using the buildings are unlikely to notice a difference in comfort or use. For planners, operating and service personnel, as well as energy operating technicians, the project will make a difference.

Expected impact:

- Reduction of the energy useage and climate impact of buildings
- Optimisation of the facility services e.g. cleaning and waste management
- Decrease rental areas and reduce energy use by 5-30%

5.17.2. Impact assessment

About 1200 sensors have been installed in university buildings. Of these, 500 were installed during the demand side management project and the rest were installed during the upscaling phase. The analysis and the demand side approach have contributed to identifying the energy savings potentials of different types of energy systems. The results have also shown that the location of a sensor could affect the results and that the combining of sensors that are placed below the desk and in the ceiling provides the most accurate information if occupancy is to be measured. Another result from the analysis of the facility usage showed that about a third of the booked time, the classrooms were completely empty for at least half of the day and that the offices are used about 30% of working day.

Despite growing numbers of students and a new integration of a police academy, it was able to cut down the used area by 6 % corresponding to about 11,500 m2 between 2013 and 2020. Thanks to better visualisation and communication of actual occupancy, it was possible to transform 40 lecture halls to accommodate other needs. The calculated CO2 impact of avoiding to build new tanks to this manoeuvre is estimated to 1,320,000 kg CO2.

Out of the results of the tool, another 700 LoRa sensors have been installed and all HVAC at the Umeå Campus were included in the tool, so it covers all facilities at Umeå Campus. The model and the combination of the sensors and time scheduling can be used by any organisation, facility tenants or property owners and thus in any other building. More information on the demand side management tool can be found in the Implementation Report of Umeå.

5.18. Conclusions of Umeå

In the city of Umeå, a total of nine solutions have been successfully implemented and monitored, one business model has been developed and students or workers at the Umeå university campus and University hospital have provided insights into the user experience and awareness of the RUGGEDISED project.

Within the university district of Umeå 8 211 m² new floor area has been built for residential buildings and a total of 34 880m² floor area has been refurbished within the RUGGEDISED the last six years. The refurbishment of the hospital building and the construction of the new building Mariehöjd with high energy efficiency standards has led to final energy savings of 2 480 MWh per year.

Thanks to the electric grid solutions implemented in the e-charging hub and infrastructure (U6), 17 488 kWh/ year of electricity could be generated by renewable energy sources. Looking at the thermal grid cluster the peak load variation management and power control (U2) in the three buildings Samverkanshuset, Matematikgränd and Ålidhems HC contributed to a reduction of 23 % of the hourly peak demand and has achieved 145 MWh per year of primary energy savings.

Mobility solutions within Umea led to savings of 159 tonnes of CO_2, 6267 g of SO_2, 100,277 g of NO_x and 5,640 g of PM_{10} g CO_2 savings per year and they could contribute to the air quality improvement. Looking at the environmental impacts of the implemented solutions in the buildings at district level in total 90.5 t per year of CO_2 reduction has been achieved by building efficiency measures. Through smart thermal grid solutions a saving of 107.2 tonnes per year have been achieved.

Due to the proactive identification and handling of potential feasibility challenges, operational factors were hardly hampering implementation. The successful implementation of smart solutions is owed to the strong cooperation between the stakeholders such as the public authorities, local partners , and the roject team. Surveys conducted within the social impact assessment with 195 students and workers from the University campus and hospital show that the implemented solutions like the bus-stop or the demand-side energy management and intelligent control buildings have matched positively their expectations. All in all, important findings have been identified by the pre- and post-assessments. Moreover, a Business Models for the smart city connection to 100% renewable energy and geothermal heating/cooling storage and exchange was explored.

Thanks to the RUGGEDISED project and being a 'Smart City Lighthouse city,' the city could join influential national networks for smart cities that opened new opportunities for its smart development.

Other impacts and lessons learnt

In Umeå, The RUGGEDISED project has strengthened the public-private collaboration between the City, universities, research institutes, the private sector and the civil society. A close cooperation expanded to increase a deeper mutual understanding and has allowed the partners of RUGGEDISED to go above and beyond the original expectations of the project.

On the big scene, RUGGEDISED supported the city in engaging with the Swedish innovation program Viable Cities in which Umeå developed and signed the Swedish Climate Cities Contract. In 2022 Umeå was also chosen as one of the cities for the EU-mission for 100 Climate Neutral Cities. The governance group that was formed in the beginning of the project is now an established group governing the roadmap towards climate neutrality in Umeå and organising the local climate summit every year.

The development of the innovation platform within the project, has become permanent within the city administration with 3 full time employees. Also, the development of the smart city decision platform became permanent with one full time employed person. All 4 employees are women.

By testing and succeeded with new and innovative solutions in the project, the city reports having become bold and more willing to take risks to reach its sustainability goals. This has prepared the team and the city to understand what is necessary to become a climate neutral city. However, the most important highglight for the team regarding the project is that RUGGEDIESD has shown that it is possible and made the team and management all believe that they can become climate neutral by 2030.

6. Glasgow

Within RUGGEDISED Glasgow has implemented and monitored nine smart solutions in George and Duke Street Area. These solutions are distributed in four energy management and ICT, one smart and thermal grid, three smart electricity grid and e-mobility and one smart open data platform solution.

The following sections elaborate on the KPIs calculated at the city and solutions levels. The KPIs are based on the collected data from partners and the cities to assess the achieved impacts on technical (e.g. energy efficiency), environmental impact (e.g. reduction of CO_2 emission) and non-technical performances such as results of business model development for EV-Charging hub battery storage in a car park and user feedback of two stakeholders of the Drygate Flats and Duke Street Car Park.

6.1. Overview of monitored solutions

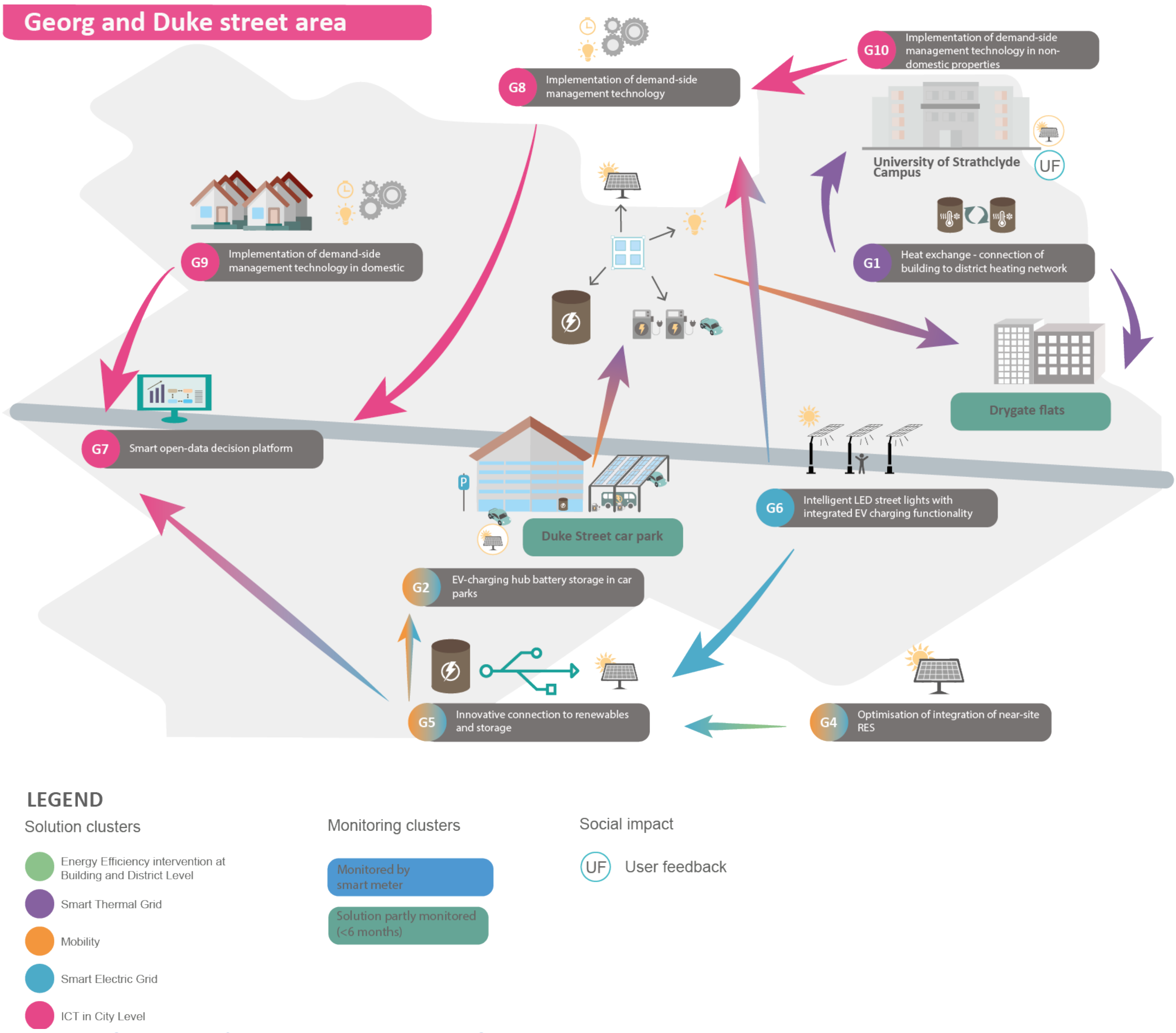

Figure 38: Overview of monitored solutions in Glasgow

Action areas and number of monitored solutions in Glasgow			
Smart Thermal Grid	Smart electricity grid and e-mobility	Energy management and ICT	Smart Open Data Platform
1	3	4	1

6.2. Technical and environmental outcomes

Table 45 and Table 46 show the technical and environmental KPIs calculated on the city level for Glasgow. Due to a late implementation of the solution and consequent lack of real data to measure its impact, simulations were conducted to estimate some values. Additionally, solutions that contribute to the respective KPI are indicated. Primary energy savings in Glasgow amount to 256 MWh per year.

Table 45: Technical performance assessment of Glasgow

Smart Electrical Grid Cluster		
KPIs	# of solutions	Achieved value
Electricity Storage[MWh]	G2,G9	0.641[8]
Electricity Generated by RES[kWh/yr]	G4	162,207[9]
Installed RES Capacity Electricity[MW]	G4	0.155[10]
Primary energy savings by cluster [MWh/yr]	G2,G4	191
Storage Energy Used[kWh/yr]	G2,G9	30,841[11]
Mobility Cluster		
Number of e-Hubs[#]	G3, G5, G6	1
Energy Savings by Mobility Measures, Total [kWh/yr]	G3, G5, G6	65,423

6.3. Environmental impact assessment

In total the city of Glasgow managed to save annualy 46 tonnes of CO2 and 191 MWh with the solutions within the smart electrical grid cluster. Within RUGGEDISED the implementation of mobility solutions have achived 28 tonnes of CO2 savings per year, while energy solutions contributed with 18.3 tonnes CO2 savings / yr.

[8] Entails simulated data
[9] Simulated data – only includes PV-system
[10] Simulated data – only includes PV-system
[11] Simulated data

Table 46: Environmental impact assessment of Glasgow

Smart Electrical Grid Cluster			
KPIs	# of solutions	Target value	Achieved value
Primary energy savings [MWh/yr]	G2-G6; G8-G10		191
CO2 savings [tonnes CO2/yr]	G2-G6; G8-G10		18.3
Mobility Cluster			
CO2 savings [tonnes CO2/yr]	G2; G5; G6		28
SO2 savings [g SO2/yr]	G2; G5; G6	18	2,097
NOx savings [g NOx/yr]	G2; G5; G6	58	33,551
PM10 savings [g CO2/yr]	G2; G5; G6	10	1,887

6.4. Business Model Impact Analysis

In this section, we provide the outline of the empirical material gathered and analysed in relation to the Multi-Level Perspective (MLP) framework and the Context and Critical Conditions (CCC) method, described in the methodological chapter of this report. In this use case, the focus is on the process of how the BM was developed for one solution in Glasgow, and its possibility to scale. However, the main aim of this exercise is to use the BM as illustrative cases on how a BM can facilitate a system transition, while exemplifying how the CCC-tool can be used.

Business Model: Case 3: Business model for EV-Charging hub battery storage in car (G2) in Glasgow.

The BM for this solution is a primarily an exercise in parametric techno-economic modelling to identify suitable business models for battery energy systems. What makes this case especially interesting is that it might be the first time in the UK this type of BM work has been done, partly because the roll-out of EVs and batteries is not that expensive in the UK at the moment. The most important national policy trend from the EV part, is the UK target of banning all new internal combustion engine cars from 2030. Meaning, that in about 8 years' time consumers will not be able to buy a petrol or diesel car, there will only be electric options.

Specifically, the need that was met with this delivery was:

- The commitment to support decarbonisation and reduction of emissions in the UK. To achieve this there need to be operating EV charging points.
- Secondly the owners of car parks will have to deal with people having different expectations in the future of what a car park can offer. Car parks will need to offer these charging services meaning that their entire business is likely to change.
- Thirdly cities often have constraints on the electricity network and issues with balancing the supply-demand on the network.

- Fourthly a market drive on how a revenue stream can be established from these types of technical solutions.

Five BM were simulated, seen in Table 47. Starting from the base case, each scenario (A-D), adds additional energy assets or markets to the model to test which are most beneficial. Scenario D which includes an additional service charge for charge point users is the most attractive business model highlighting the need for multiple revenue stacks to make battery systems economically viable. This analysis is in general, if not written otherwise, referring to scenario D.

Table 47: BM simulated in the delivery of the solution

	EV chargers	Solar PV	Battery	Retail market arbitrage	EV service charge	Ancillary services	V2G	Project 20-year balance (£)	Payback
Base case	•							-993,653	
A	•	•						-916,713	7
B	•	•	•					-1,187,872	19
C	•	•	•	•				-1,007,125	15
D	•	•	•	•	•			-562,655	10

Besides the financial results, including expenditure and income breakdown, the business case value proposition is more than just financial. The use of battery storage allows for:

- Renewable energy self-consumption – reducing consumers' reliance on grid imported electricity
- Remaining within grid constraints – helping to prevent electricity infrastructure from becoming overloaded
- Reduced carbon emission – use of renewable or low-carbon grid electricity
- Operation off-grid – become self-sufficient
- Back-up power – improve site resilience and counteract grid load-shedding events

It was described by the respondent that the BM is not necessarily innovative. Rather it is the combination of different things that is somewhat innovative: the individual component might not be innovative, but the combination of the different technologies, and how to operate them together could be innovative. However, this combination of different new technologies is challenging precisely because they are so new and they present a different mentality and mindset to business operations, compared to the one that local authorities and car park owners have. Moreover, the BM also means that new social networks between organisations that previously didn't have relations must be made, precisely for its innovaive combination of technologies.

Similarly to Umeå's BM, this BM represents an innovative way of handling a small system of energy solutions. The BM is also, a showcase of what type of BM might become the norm in the future where many types of different energy technology need to work together to provide services. This might put the collaborative aspects of BM for revenue-sharing at the forefront rather than single company BM. Which in turn requires a range of inter-organisational capabilities and new ways of thinking from energy market actors. The barrier in relation to transition thus relates to the mental model present on the market today. If the norm of how to construct a BM today is what we call "industry logic" (Bidmon and Knab's 2018), it creates a barrier toward an energy transition in the local context. Also, it might be the case that the BM and connected technology can have greater success in places where there are larger fleets of EVs along with more battery usage.

An enabling factor that could make the BM solutions a much better case is a further reduction in capital costs for specific technologies. Currently, batteries are still expensive. If this cost follows the current trend to go further down, then batteries might be an influential structural factor supporting similar types of BM solutions. Another important enabling factor in this solution is that it does not require a change in the behaviour of the residents in the district or users of the solution. It is a type of background system and doesn't change behaviour other than enabling people to have EVs. This constitutes another reason for which this BM has good scaling potential.

However, from the modelling of the financial perspectives, the BMs are closely tied to the context it was modelled towards. Moving the solution (the BM + technology), to another European city would change the entire model because the costs would be different. Revenues from solar PV generation would be different and the services for the grid would also change. The technical system can still work wherever you put it, in theory, but there might not be a case for it from a financial perspective.

There were not any clear opponents for this delivery and no clear hindrance in regulation or policy. However, what might be a barrier in future large-scale implementation of similar solutions is the need for specialised competencies. This is a barrier likely to be present in most European cities interested in this type of solution. Another important barrier to consider affecting the scaling potential, is how immature policy and regulatory aspects are. There are still a lot of open questions about how these types of systems of energy solutions are to be managed e.g., balancing on the energy grid, how it will be managed in the future and who is responsible for what. How these aspects are addressed will likely develop over time and can become a good example of a future more sustainable energy system.

One of the outcomes of the delivery, regardless of future implementation, was the learning that came out of the project. The model exercise demonstrated that this was a possible, sustainable and energy-efficient arrangement for Glasgow in relation to EV roll-out, which also could be economically feasible. Taking a similar approach in moving the work done in the delivery to other European cities would be a possible way of accelerating an energy transition.

To summarize. the scaling potential for this BM solution seems optimistic, it is only context dependent on a minor scale and can be one of the drivers of a city's sustainable energy transition. There are a lot of challenges, but they are most probably not isolated to context of the city of Glasgow.

6.5. Social Impact analysis

6.5.1. Focus of investigation

In Glasgow, the evaluation included the *electric vehicle charging infrastructure* for developing a business case for concentrated EV charging, *intelligent street lighting* that was integrated in the charging stations, and *demand-side management* solutions (DSM). The latter were comprised of domestic and non-domestic DSM, DSM lightning, and battery storage and received additional focus in the interviews of the stakeholders in Drygate Flats and Duke Street Car Park.

For this, a questionnaire was designed which described the services to the citizens and asked for their related expectations (see Section 2.3.3). Data collection was performed by the city of Glasgow at public events in Glasgow. For the analysis of citizens' acceptance and uptake of the implemented solutions, on the Glasgow site, we focused on the social impact assessment of the smart solution "*Domestic Demand-side management*". As reported above, this solution provided an automated service for the tenants that connected different services (battery, district heating) and used relevant information, such as humidity, the inner and outer temperature, and provide an automated system. Unlike with their previous, inflexible energy system, consumers could tell the system about their preferences regarding the heating times and enter exceptions (e.g., holidays).
The introduction of the service was prepared and accompanied by the analysis of requirements and feedback received by the tenants. For this analysis, no quantitative data from the questionnaire was collected, but the focus was on a qualitative analysis based on interviews with experts and stakeholders from the Glasgow site, to gather important learnings for successful introduction and gaining social impact.

6.5.2. Expectations and experiences

For all three of the use cases, the responses regarding expected benefits towards the citizens were overwhelmingly positive (Figure 39, left). Looking further into the perceived ease of use for use cases where it is applicable, that is *electric vehicle charging infrastructure* and *demand-side energy management*, we also observed that they were both predominantly rated as being easy to use, especially the former (Figure 39, right).

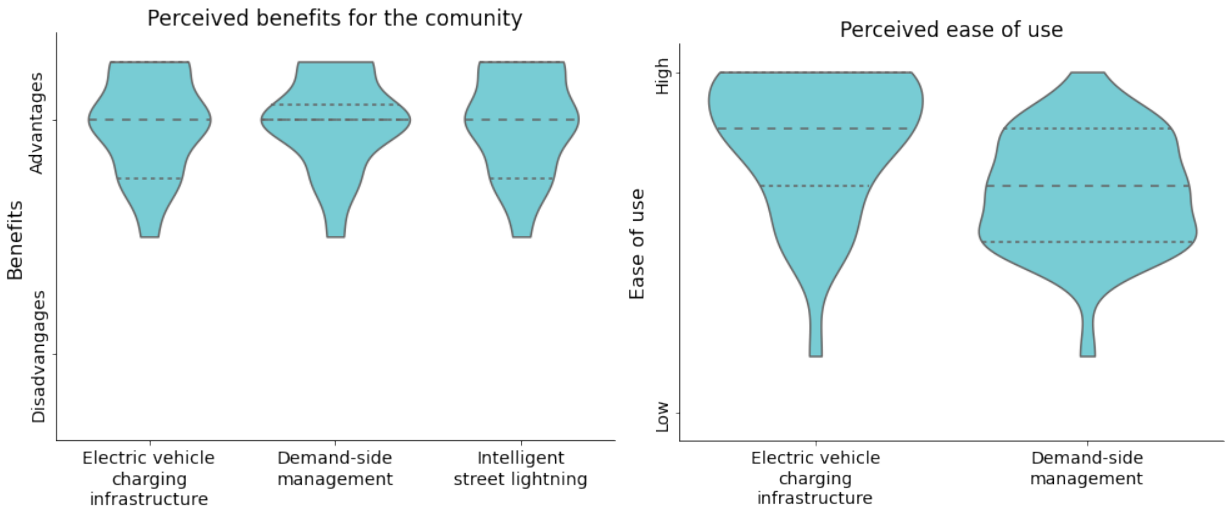

Figure 39: Perceptions towards the solutions' overall benefits (left) and ease of use (right)

Furthermore, when it comes to the solution's expected effects on adopting more sustainable behaviours, both solutions again received positive ratings, with the electric vehicle charging infrastructure being deemed as having higher change-evoking potential.
During the introduction of the *domestic demand-side management* (G9), important insights regarding a successful uptake and social impact could be drawn. One of the most striking contextual backgrounds of

this demonstration site was that many of the tenants have been living under severe constraints. The reported living conditions included extreme cases where a tenant remained in his sleeping bag during the day when it was getting cold. Also, there were reports that people who had to economize on heating did not want to have visitors, in order not to disclose their poverty. After introduction of the new service, tenants have been reported to be better enabled to put the heating on when they needed warmth.
One of the key features that tenants often mentioned was the systems' increased transparency, that is, with the new system tenants can get more insights into data relevant for their heating situation. They were not only able to see how temperature rises, but also humidity. Condensation and dampness are associated to many of the households of interest, as humidity condenses in the cold air on the surfaces. Being able to measure and observe this phenomenon, they were able to improve heating consistency. By keeping the moisture airborne and not letting it condense on the surface, this had a significant impact on the living quality. With rising energy prices, people even reported paying more than previously, but they were also getting more value for their money. Contrary to their previous experiences, energy spendings thus were not perceived to be "wasted".

6.5.3. Conclusions

From the perspective of social impact of sustainable energy solutions, the investigation within the Glasgow demonstration site yielded encouraging insights. These were not so much related to the data gathered in the conducted surveys, but from an analysis of the interplay between the key actors within the developed domestic demand-side energy system. Key stakeholders reported a "win-win-win" effect that had been achieved in this trial, with benefits for the building owner (having to invest only in new sensors and controls but not in the whole new heating system), the tenants (receiving a more efficient and flexible heating service) and the network provider (being able to aggregate large arrays of households).

6.6. Qualitative monitoring

The implementation of the different solutions in Glasgow and their deployment was analysed following the qualitative monitoring framework presented in Section 3.3. of this document, which includes the following aspects: i) Operational factors in deployment of smart solutions, ii) Cooperation, iii) Strategies, iv) Planning mechanisms, v) Innovation capacity.

Concerning the **Operational Factors** from the monitoring framework, the smart electric grid has come across quite some financial challenges. The construction of the pipelines (G1 and G3) proved financially infeasible and was therefore not deployed. Adding renewable energy sources other than PV was due to financial reasons not realised and less EV chargers were installed due to less capital funding than anticipated at the start of the project (G4 and G5). Moreover, the council encountered a variety of local arrangements and practicalities which influenced the deployment of the smart electric grid (e.g., Brexit, rapidly increasing material costs and positioning of the streetlights). In G9, fire regulations have led to adjustments of the original plan. With regards to ICT on City level (G7) the use of the platform is limited as other commercial platforms turn out to be competitive. Furthermore, managing, updating and operating the platform continuously turned out the be challenging for the city as they lack the capacity to do so. The operation factors led to many adjustments of the solutions and delays in the planning.

In terms of **Cooperation**, the strategic position of the project manager proved influential for the multi-level cooperation within the city. The project manager also has a management position, forming a direct link between strategy and operations, and was able to continuously connect between the project and the strategic policy developments in the municipal organization. The second important cooperation factor is the ability to work across silos, which was challenging given the siloed nature of the Glasgow municipal organisation. A primary team member was crucial for the cross-silo cooperation specifically needed for two smart solutions (G6 and G7).

At the **strategic level**, sustainability became one of the main priorities in Glasgow with the COP26. The idea is that everyone in the municipality, regardless of their daily tasks, should work on sustainability. Furthermore, a new role ''head of service sustainability'' was created because of COP26. The current ambition in Glasgow is to become a climate neutral city by 2030. The status of Glasgow as a Lighthouse city in the RUGGEDISED project provided the opportunity to promote the city and RUGGEDISED was then used as a reference to sell sustainability in general.

The **Planning Mechanisms** in Glasgow enabled the RUGGEDISED project and benefited from it. The sustainability ambition of Glasgow is embedded in the climate plan, the successor of the Sustainable Energy Action Plan (SEAP) and that sets the objective to reduce carbon emissions by 30% by 2020. Underneath the overarching climate plan sits the circular economy plan and the green economy plan. These plans all tie into one and run until 2030. RUGGEDISED is a case study in the climate plan and serves as a demonstration project for sustainable innovations (i.e. the district heating business model, the PV's and the batteries). The city considers the RUGGEDISED examples as valuable input for future policy developments. More concretely, Glasgow is now working on an EV network strategy in its city region. The pilots within RUGGEDISED with the smart streetlights and EV chargers from renewables and battery storage (G6) were very informative in this thinking and moving forward.

Lastly, the observations on the **Innovation Capacity** in Glasgow indicate the positive effects of a strong and committed leadership and ambitions. The Sustainable Glasgow network, consisting of various actors supporting climate ambition in Glasgow and with Councillor Aitkan at its head, has been very instrumental in the run up to COP26, engaging in sustainability networks and encouraging projects. The internal efforts to support innovation were also a positive aspect contributing to the implementation of RUGGEDISED project, especially those dedicated to improving communication across the organization, although the inertia of working in silos remained a challenge in some contexts. In terms of networking and integrating knowledge, Glasgow benefitted strongly from having strong and fruitful links with academia and other stakeholders that enable the city council to access new knowledge. As a learning organization, the city also strives to improve knowledge sharing and continuous improvement within and among projects occurs by evaluating and reviewing the projects. Moreover, the city council is developing a project management office for sustainability to bundle and disseminate sustainability knowledge and best practices. As elements to be improved for the innovation capacity of the council, the analysis highlights the need to break the work in silos, and plan in advance the stewardship of initiatives beyond the project duration, which can be hard in projects involving multiple departments and stakeholders.

Table 48 summarises the main factors that influenced the deployment of the smart solutions, based on the qualitative monitoring.

Table 48: Main deployment factors Glasgow

Deployment factors	Findings in Glasgow
Operational factors in deployment of smart solutions	• Financial challenges turned out to be an (unanticipated) barrier for deployment of several smart solutions. • Local arrangements and practicalities led to adjustments and delays.
Cooperation	• Strategic position of the project manager proved influential for the multi-level cooperation.

	• The RUGGEDISED project manager successfully coordinated with various stakeholders inside and outside the City Council such as developers, investors, citizens and businesses (e.g. via Sustainable Glasgow)
Strategies	• Sustainability is high on the city agenda (amongst others due to COP26), creating fertile ground for innovation projects like RUGGEDISED. • RUGGEDISED has had a strong influence on policy and strategy in Glasgow and is referenced in new policies and strategies
Planning mechanisms	• RUGGEDISED is included as demonstrator in the climate plan and several RUGGEDISED measures are considered inspiring examples. • Glasgow is now working on an EV network strategy in its city region inspired by the pilots within RUGGEDISED (G6).
Innovation capacity	• The most prominent innovation capacity is leadership; demonstrated through a powerful councillor. • Close cooperation with knowledge institutes and universities support knowledge exchange for innovation.

6.7. G1 – Heat Exchange

6.7.1. Description of the solution

Heat Exchange **Smart Thermal Grid**

Figure 40: Construction Site

Description

The city of Glasgow together with its partners have developed the contractual models required to allow public sector buildings to sell heat from one to the other, and for private industry to sell heat to local housing, either directly or via an intermediary, such as an Energy Services Company (ESCo). Given that technological options are at hand, the challenge of implementing the smart solution is a matter of organisational innovation.

Smart Solution G1 was completed in August 2018. The development of this Smart Solution led to the creation of a “Contractual model for implementation”. This has been recognised by all local stakeholders to be an accomplished piece of work that will enable more informed contract negotiations between generators and consumers of heat. The availability and use of this contractual model will support and facilitate an easier establishment of heat connections in the future.

The contractual model is now readily available for both public and private sector actors to utilize as the basis of any relevant negotiations. The contractual model also includes a guidance note that provides highly valuable information on procurement regulations. It was considered highly useful to local stakeholders to include this guidance note stating how procurement regulations will affect potential consumers, thus giving confidence to any potential heat consumer that they are acting within their legal requirements.

An immediate implementation of the achievements aimed in Ruggedised was unfortunately hindered due to issues outside the control of the actors involved in this Smart Solution activity. Thus, the physical district heating connections between Tennents Brewery and the Drygate housing (Case study one) and the University of Strathclyde and Glasgow City Council City Chambers (Case study two) did not proceed as expected at this time.

Expected impacts

- Enable future and developing networks to connect to neighbouring customers or providers
- Ability to efficiently use excess heat elsewhere
- Reduction of carbon emissions
- Key enabler for exploring heat connections

6.7.2. Impact assessment

During the life of the RUGGEDISED project, Glasgow City Council developed a Local Heat and Energy Efficiency Strategy (LHEES) in line with developing national guidance and methodologies. This strategy plans to designate opportunity zones in the city, based on areas that are conducive to exploring heat networks. The potential for other cities to use and replicate this solution is vast. This opportunity is particularly evident across Scotland and the rest of the UK, where district heating is still a relatively new concept and not yet an integral part of the heat network, unlike in other European cities where district heating is long established.

More information on the results of of the contractual models of this solution can be found in the Implementation report of Glasgow.

6.8. G2 – EV-Charging hub battery storage in car parks

6.8.1. Description of the solution

EV-Charging hub battery storage in car parks | **Smart electricity grid and e-mobility**

Figure 41: Charging in car park

CO2 savings	7 t CO2/yr
Peak demand reduction	40%
Primary energy savings	72.7 MWh/yr
Business Model:	Analysed → 6.4

Description

This solution comprised battery storage to support the integration of electricity generated by photovoltaics and wind turbines, which supported electric vehicle charging, and act as grid balancing mechanism. The technological and business case challenge was linked to the physical deployment and connection of battery storage onsite, as well as understanding how energy was purchased from local generators, provided to the battery, and sold by the storage provider either to local points of consumption or to provide grid balancing services.

Expected impacts:

- Change by capacity and timing to remain within the technical limits
- Saving in grid electricity costs
- Trading in future markets
- Maximise the social benefit of reduced street parking/charging
- Energy reserves for the fuel poverty

The electrical energy storage (EES) and the solar canopy was planned to be installed in 2019. Covid-19 and a formally ceased trading brought delays in delivery of the batteries. As a consequence, they just only became operational in Spring 2022.

6.8.2. Impact assessment

This solution was among the ones communicated and assessed during the social impact analysis. Citizens perceived the measure very positively and the expected benefits of this solution were extremely positive. Moreover, this was considered the intervention that could have the highest potential to adopt more sustainable behaviours, compared to the other ones assessed (G6&G8, G9&G10), because the increased availability of EV chargers would enable and incentivise the use of cleaner mobility solutions.
The Business Model (BM) assessment for this solution was conducted in 2022, and constituted one of the first cases in UK for which BM work had been done, due to limited EV charging roll-out in the country. The analysis indicated that while the BM defined for the solution was not particularly innovative, the combination of different technologies for the solution created new challenges for the actors involved, and that helped to explore and develop new mindsets and business operations for car park owners and city

authorities. The BM also required a range of inter-organizational capabilities and new ways of thinking from energy market actors in general.

The BM created represented an innovative way of handling a small system of energy solutions and could showcase what type of BM might become the norm in the future, where many types of different energy technology need to work together to provide services.

Overall, some of the conclusions of the assessment indicated that to make the system financially viable it was necessary to develop multiple revenue stacks. This has important implications for the replicability and scalability of the solution. In case of a sustained trend of reduction of the prices of batteries, this BM could be replicated in other cases. The solar PV capacity and service grid conditions could also strongly influence how this solution is replicated in other cities, from an economic perspective.

For the city of Glasgow, the solution was an interesting model exercise to demonstrate a possible sustainable and energy-efficient arrangement for Glasgow in relation to EV roll-out, which also could be economically feasible. In fact, Glasgow has six multi-story car parks owned by the wider council family, along with several other privately owned car parks. Hence, the replication potential for this solution is significant, with opportunities to provide grid balancing and support across the network as electric vehicle uptake increases over the coming years.

Technical and environmental outcomes

Due to a delays in the implementation phase of G2 and G4, both solutions are assessed on simulations for the proposed PV and battery systems. The corresponding EV charging consumption, however, is based on real measurements. Figure 42 indicates the effect of the proposed battery system on the EV charging hub in combination with the PV system from G4. The self-consumption of PV energy by the EV charging hub is greatly increased, which further reduces energy imports from the electricity grid. This effect implies an important decrease of greenhouse gas emissions related to the charging of electric vehicles at the charging hub. Additionally, the proposed battery would allow the installation of an even bigger PV system potentially further mitigating electricity imports.

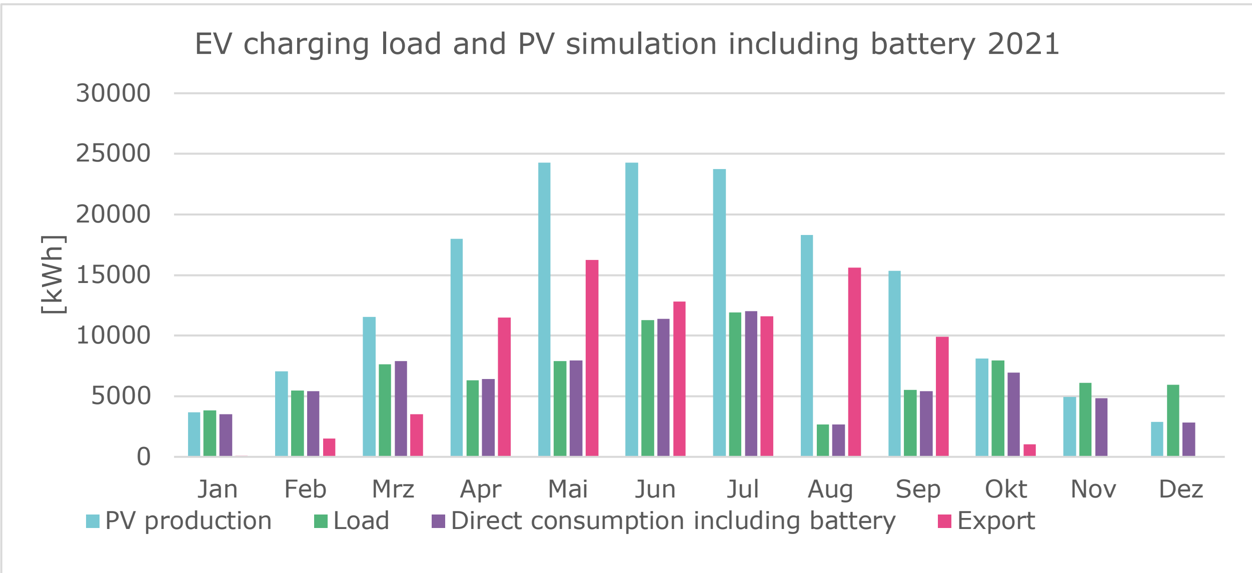

Figure 42: Monthly energy balances G2

The implementation of the battery storage system would also lead to decreased environmental impacts of the charging station compared to the situation in G4, where the PV canopy is not complemented with further flexibilization options. It must be noted that this assessment only includes environmental impacts resulting in the operational phase of using the battery storage system.

Table 50 indicate the calculated technical and environmental KPIs for the solution G2. Additionally, they provide information on the baseline information, if applicable. The reduction of primary energy demand due to the increased degree of self-supply, induced by the battery, can be highlighted. The implementation of an energy storage in combination with the PV canopy from G4 would lead to reduced primary energy demand by the charging hub, as more locally provided energy could be used for charging electric vehicles. Notably, also the peak electricity demand could be reduced significantly by providing a battery storage system that would allow to avoid grid imports in times of peak demand.

Table 49: Technical performance assessment of G2

Smart Electrical Grid Cluster		
KPIs	Baseline	Achieved values
Electricity Storage [MWh]		0.596[12]
Primary energy savings by cluster [MWh/yr]	88.23	72.7
Primary energy demand reduction [%]		82%
Peak demand reduction[%]		40%
Degree of self-supply by RES [%]		95%
Storage Energy Used[kWh/yr]		29,922

The implementation of the battery storage system would also lead to decreased environmental impacts of the charging station compared to the situation in G4, where the PV canopy is not complemented with further flexibilization options. It must be noted that this assessment only includes environmental impacts resulting in the operational phase of using the battery storage system.

Table 50: Environmental impact assessment of G2

Smart Electrical Grid Cluster		
KPIs	Baseline	Achieved values
Primary energy savings [MWh/yr]	88.23	72.7
Primary energy demand reduction [%]		82%
CO2 savings [t CO2/yr]	8.5	7
CO2 reduction [%]		82%

[12] Simulated data

6.9. G4 – Optimisation of integration of near-site RES

6.9.1. Description of the solution

Optimisation of integration of near-site RES **Smart electricity grid and e-mobility**

Figure 43: EV- charging point

CO2 savings	11 t CO2/yr
Primary Energy savings	118 MWh/yr
Peak demand reduction	34%

Description

This original solution set out to install a 200kW solar canopy on the roof of a multi-story car park. The power generated by the PV array would be fed directly to either the building; to support its electrical load, and energy storage system, to allow for storage of the energy for use at a later time, or directly to the electric vehicle chargers (ensuring that electric vehicles in the city were as renewably powered as possible).
The expected impact of this solution was to maximise the utilization of locally generated renewable energy, minimising import and export to the electrical grid, thus minimising the CO2 emissions associated with the operation of the car park and the charging of electric vehicles. The connection to the energy storage system would ensure that the maximum value should be gained for the power generated by offsetting the comparatively expensive costs of electricity imported from the grid to support charging.

Expected impacts:

- Maximise the utilization of locally generated renewable energy
- Minimal export to the electrical grid
- Minimising the CO2 emissions
- Maximum value should be gained for the power generated by offsetting the comparatively expensive costs of electricity imported from the grid

6.9.2. Impact assessment

The Business Model (BM) assessment for this solution, closely linked to G2, was conducted in 2022. The analysis indicated that while the BM defined for the solution was not particularly innovative, the combination of different technologies for the solution created new challenges for the actors involved, and that helped to explore and develop new mindsets and business operations for car park owners and city

authorities. The BM also required a range of inter-organizational capabilities and new ways of thinking from energy market actors in general.
Overall, some of the conclusions of the assessment indicated that to make the system financially viable it was necessary to develop multiple revenue stacks. This has important implications for the replicability and scalability of the solution. In case of a sustained trend of reduction of the prices of batteries, this BM could be replicated in other cases. The solar PV capacity and service grid conditions could also strongly influence how this solution is replicated in other cities, from an economic perspective.
For the city of Glasgow, the solution was an interesting model exercise to demonstrate a possible sustainable and energy-efficient arrangement for Glasgow in relation to EV roll-out, which also could be economically feasible. With six other multi-story car parks owned by Glasgow City Council, and several other privately owned car parks, there is a significant replication potential for this type of technology

Technical and environmental outcomes

Due to a delays in the implementation phase of G2 and G4, both solutions are assessed on simulations for the proposed PV and battery systems. The corresponding EV charging consumption, however, is based on real measurements. The introduction of the proposed PV system would allow to supply a great share of EV charging demand directly by renewable energy, as times of charging demand and PV supply often overlap. The introduction of the proposed PV system can therefore help reducing the greenhouse gas emissions related to the charging of electric vehicles at the charging hub. The self-consumption of PV could, however, be increased by the use of battery systems, as shown in solution G2.

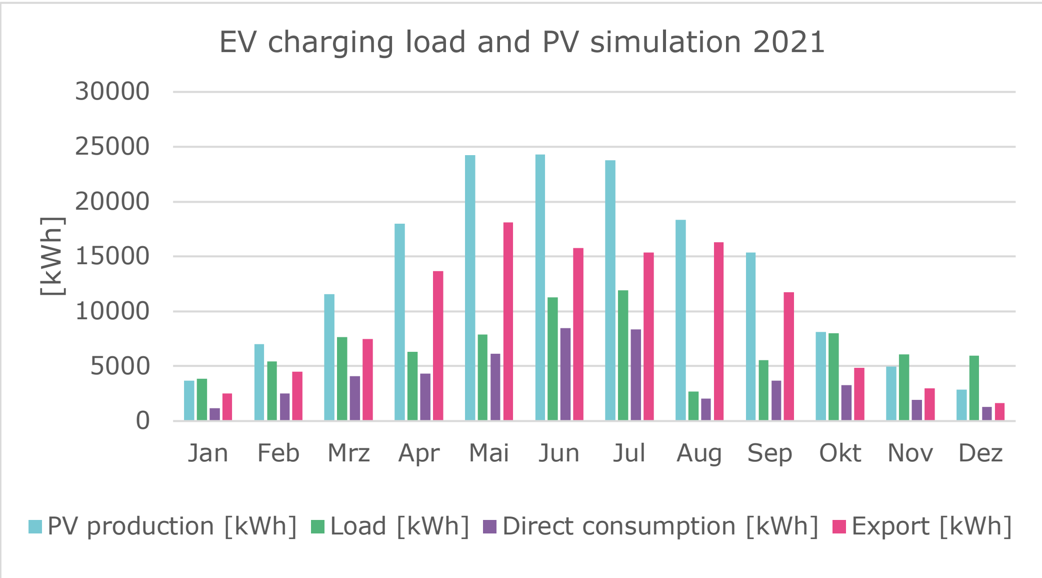

Figure 44: PV and EV charging hub balances G4

Table 51 and Table 52 indicate the calculated technical and environmental KPIs for the solution G4. The achieved primary energy reduction of a 57% induced by the PV system is to be particularly highlighted.

Table 51: Technical performance assessment of G4

Smart Electrical Grid Cluster		
KPIs	Baseline	Achieved value
Installed RES Capacity Electricity[MW]	-	0.155
Primary energy savings by	206	118

cluster [MWh/yr]		
Primary energy demand reduction [%]	-	57%
Electricity generated by RES [kWh]	-	162,207
Peak demand reduction[%]	-	34%
Degree of self-supply by RES [%]	-	57%

Table 52: Environmental impact assessment of G4

Smart Electrical Grid Cluster		
KPIs	Baseline	Achieved value
Primary energy savings [MWh/yr]	206	118
Primary energy demand reduction [%]	-	57%
CO2 savings [t CO2/yr]	19.9	11.4
CO2 reduction [%]	-	57%

6.10. G5 - Innovative connection to renewables and storage

6.10.1. Description of the solution

Innovative connection to renewables and storage	Smart electricity grid and e-mobility

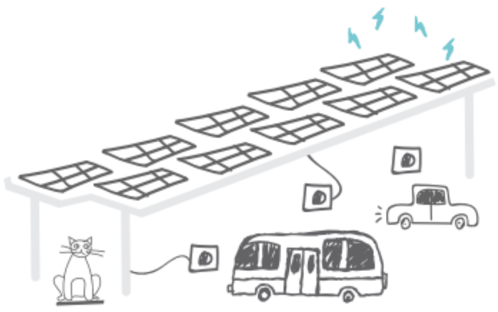

Figure 45: Sketch of the car park

Highlights and facts of G5

CO2 savings	28.04t CO2/yr
Energy savings	65.4 MWh/yr

Description

This smart solution is linked to the deployment of a grid scale battery storage solution (G2), the deployment of renewables that will provide power for the newly installed charge points (G4) and the data from this will be collected and analysed via the Data Based Decision Platform (G7). It involved utilising some car parking spaces in the multi-story car park to install electric vehicle (EV) charging points, increasing the number from four fast chargers and one rapid charger to 12 fast chargers and five rapids. The challenge was to develop the business case for concentrated deployment of EV chargers, alongside the connection of those chargers to renewable technologies and battery storage. The charge point installation at Duke Street car park supports current EV drivers in the city as well as encouraging other car users to switch to electric, and will enable taxi companies in the city to switch to using electric vehicles, facilitating Scotland's phase out of new petrol and diesel cars by 2032. The charging infrastructure is funded by Transport Scotland and RUGGEDISED with the innovative connection to renewables and storage.

Expected impact:

- Different options for electric vehicle users by allowing them to access a less charger
- Placing less of a demand on the grid
- Nearby residents living to the integrated points have the option to connect/charge for a longer period of time.

6.10.2. Impact assessment

The Business Model (BM) assessment for this solution was conducted in 2022 in combination with G2 and G4, given the combination of technologies to provide one solution. The analysis indicated that while the BM defined for the solution was not particularly innovative, the combination of different technologies for the solution created new challenges for the actors involved, and that helped to explore and develop new mindsets and business operations for car park owners and city authorities. The BM also required a range of inter-organizational capabilities and new ways of thinking from energy market actors in general.
The BM created represented an innovative way of handling a small system of energy solutions and could showcase of what type of BM might become the norm in the future, where many types of different energy technology need to work together to provide services.
Overall, some of the conclusions of the assessment indicated that to make the system financially viable it was necessary to develop multiple revenue stacks. This has important implications for the replicability and

scalability of the solution. In case of a sustained trend of reduction of the prices of batteries, this BM could be replicated in other cases. The solar PV capacity and service grid conditions could also strongly influence how this solution is replicated in other cities, from an economic perspective.
For the city of Glasgow, the solution was an interesting model exercise to demonstrate a possible sustainable and energy-efficient arrangement for Glasgow in relation to EV roll-out, which also could be economically feasible.
Besides the combined energy system with the other solutions (G2, G4), The upscaling of this solution will be explored at various sites across the city. The results can support the private company in creating their own EV – charging hub in the city and the Glasgow City Council is also exploring this option in the future. This solution is seen as highly replicable both across Glasgow, Scotland and the UK.

Technical and environmental outcomes

Figure 46 shows the EV charging events measured in G5. The months July and June are found to have a notably higher consumption than the rest of the year. Electric vehicles are more energy efficient than their diesel counter parts and are also related to lower environmental impacts related to their direct operation (International Energy Agency, 2022). Accordingly, their charging and related vehicle kilometres are related to lower greenhouse gas, PM10, SO2, and NOx emissions compared to diesel vehicles.

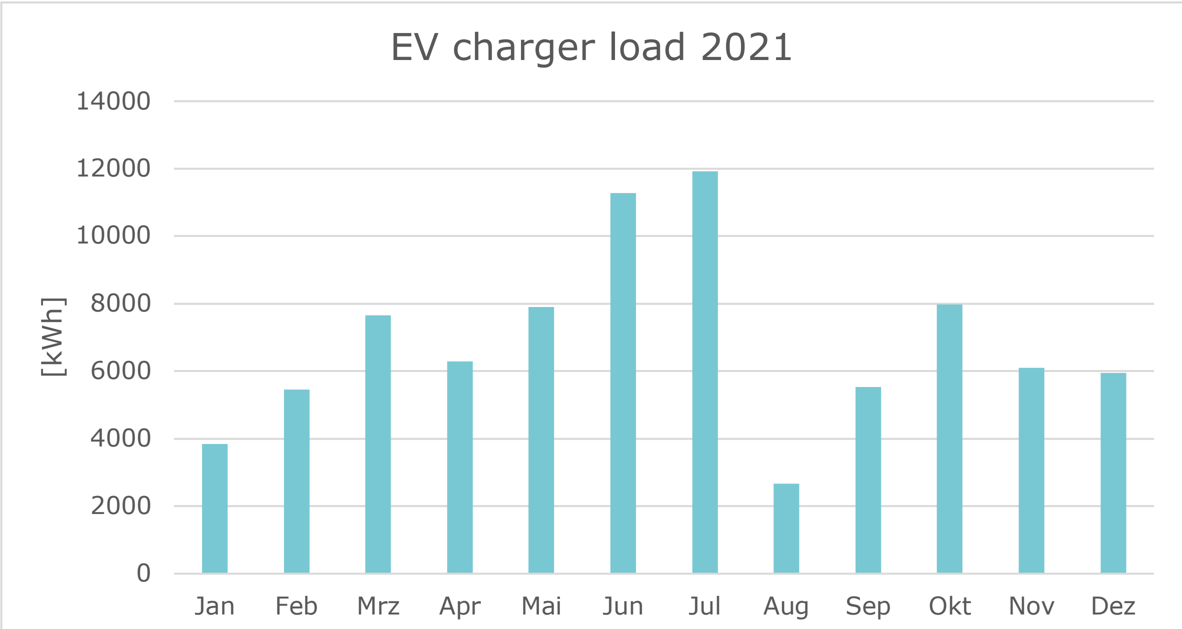

Figure 46: Measured charging events G5

Table 53 and Table 54 indicate the calculated technical and environmental KPIs for the solution G5. The achieved CO2 reductions by the use of electric vehicles account to up to 28 tCO2/yr. In view of these results, solutions G4 and G2 indicate the possibilities for further reductions by using solar energy and battery systems.

Table 53: Technical performance assessment of G5

Mobility Cluster		
KPIs	Baseline	Achieved value
Energy Savings by Mobility Measures, Total [kWh/yr]	271,863	65,423

Table 54: Environmental impact assessment of G5

Mobility Cluster		
KPIs	Baseline	Achieved values
CO_2 savings [t CO_2/yr]	48	28.04
SO_2 savings [g SO_2/yr]		2,097
NO_x savings [g NO_x/yr]		33,551
PM_{10} savings [g CO_2/yr]		1,887

6.11. G6 & G8 - Intelligent LED street lights with integrated EV charging functionality and Demand-side management technology in street lighting

6.11.1. Description of the solution

Intelligent LED street lights with integrated EV charging functionality and Demand-side management technology in street lighting — **Energy management and ICT**

Figure 47: Street lighting in Glasgow. Source: City of Glasgow

Highlights and facts of G6 & G8

Installed LED street lighthing	> 300

Description

With approximately 70% of Glasgow households residing in flats, access to charging infrastructure can be challenging. This is both a technical challenge and business case related. The intelligent street lighting with integrated electric vehicle (EV) charge points serves as a test for the city, where the streetlights remain on the toe of the pavement, therefore allowing charging infrastructure to be installed whilst minimising the impact on pedestrians and ensuring street furniture is kept to a minimum. The main objective of this solution was to test how Demand Side Management practices could be implemented regarding City Street Lighting. For instance, if the city lights could be dimmed while still providing enough illumination and make energy savings at the same time.

The three charging units installed are 7kW fast chargers as the expectation is that their use will be for businesses or domestic users with long duration parking requirements. The integration of EV charging into the street lighting column is funded by Transport Scotland and the street lighting was funded by the ERDF. Having street lighting with integrated chargers is a new concept for the city.

Expected impact:

- Energy efficiency through switch to LED luminaires
- Overall carbon reduction of 60%

6.11.2. Impact assessment

Over 300 intelligent LED street lights have been installed within the project district, where the columns with integrated EV charging were the last to be deployed. A central management system, an IoT Edge router and a wireless communication network has been installed and trialed. This allows the transfer of the data to the data-based decision platform.

The solution underwent a social impact analysis during its implementation process. In order to assess citizens' perceptions on a selection of solutions implemented in the city (G2, G6&G8, G9&G10), they were asked via a questionnaire that was distributed in public events in Glasgow and that explained the project, the tested solutions and requested their opinion.In general, for all the solutions analyzed in Glasgow, the expected benefits of the overall interventions for the citizens were overwhelmingly positive. The qualitative monitoring also indicates that an important learning in general, but especially from this solution, was the importance of the figure of a knowledge broker to ensure its implementation, as an actor that can connect different people across departments.

The new street lights with integrated chargers are the first of their kind in the city and are already being rolled out throughout the smart street and across the whole city. The replicability of this solution is very high at both national and international level. In order to succeed in case of a wider roll-out of this solution, the qualitative monitoring highlights the importance to count with a knowledge broker in the team that can understand the needs of different teams and departments, offering them a transdisciplinary perspective and ensure a correct communication and coordination.

More information on the results of the implementation of the intelligent LED street lights with integrated EV charging functionality and Demand-side management technology in street lighting solution can be found in the Implementation report of Glasgow.

6.12. G7 - Smart open-data decision platform

6.12.1. Description of the solution

Smart open-data decision platform	Smart Open Data Platform

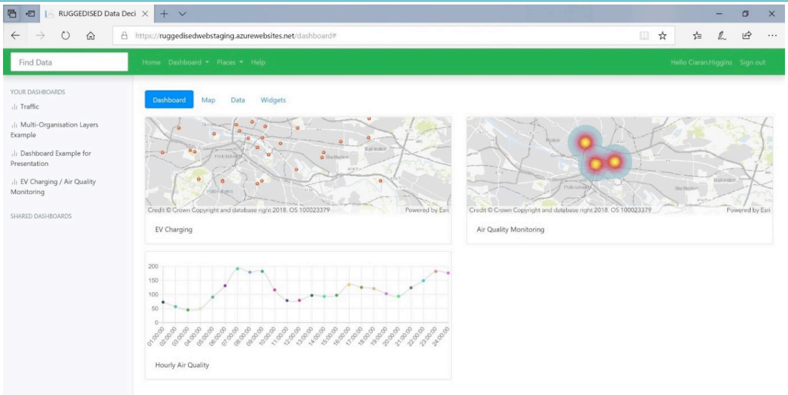

Figure 48: Demonstration of the Data. Source: Implementation report of Glasgow

Description

The data-based decision platform (DBDP) pulls together existing open data sets, along with the data generated from the project district to create a dashboard that allows users to analyse and present the data in a meaningful way without the need of data analysis. The idea behind the system is to allow individual users to customise their own dashboard, which will allow them to view all the chosen data sets at once in order to ensure the most efficient use of time, planning and resource across the city. Although there are many commercial tools available on the open like this one, Glasgow City Council (GCC) needed a tool that can integrate with our own systems to aid officers in their work.

Expected impacts:

- Opportunities for new business models (energy storage and sharing; EV charging for electric taxi's as well as for generating unforeseen business cases)
- Cross reference of datasets
- Create visualisations
- Provide information on business models
- Contribution to spatial planning of actions to support the Glasgow's Climate Plan and the Green Deal.

6.12.2. Impact assessment

This particular Smart Solution attracted a lot of attention and generated a number of potential use cases that will be additional to the upscaled deployment of the solutions delivered in the project. The DBDP can, via API's, ingest data created by the project, as well as existing open datasets that will have the potential to better inform strategic and, potentially, operational decision making. In addition to that, a data sharing agreement has been negotiated between Scottish Power Energy Networks (SPEN) and Transport Scotland (TS), thus allowing the former to fully understand the use of EV charges by vehicle type and frequency, and the latter to know how the network is coping with the growing charging infrastructure. The data generated, and the outputs created from the combination of data, is already playing an important part in shaping partners approach to Electric Vehicle charging in the city and it informs Glasgow City Council's strategy for transforming vacant and derelict land sites into Electric Vehicle charging hubs.
This solution exists already as a city wide platform and can be replicated. However, at the market level international firms have already developed similar systems that can compete with it. However, there is potential for replication in other cities or across Europe.

More information on the results Smart open-data decision platform can be found in the Implementation report of Glasgow and the deliverable 4.5 ‘Decision support Platform (ICT solution) for informing strategy and decision making’.

6.13. G9 - Demand-side management technology in domestic buildings

6.13.1. Description of the solution

Demand-side management technology in domestic buildings — **Energy management and ICT**

Highlights and facts of G9

CO2 savings	**0.09 t CO2/yr**
Storage energy used	919 kWh/yr

Description

The challenge was in developing the Central Management System of Glasgow to integrate domestic properties into a 'smart grid', thus allowing demand-side management events to be triggered that benefit both the grid and the residents. In essence, meaning the domestic properties become capable of soaking up energy when the renewable production is high, or share energy, when renewable production is insufficient. Deploying technology is not enough, and it is essential to ensure that a full understanding of the potential of demand-side management is achieved in a domestic scenario. This includes exploring the potential to activate cheaper tariffs for residents when renewable generation exceeds demand. The impact of local storage was also analysed.

Expected impacts:

- Increase of the overall use renewable energy in the grid
- Facilitation of a study into the alleviation of fuel poverty through deployment of domestic battery storage

6.13.2. Impact assessment

The solutions G9&G10 underwent a social impact analysis during their implementation process. These solutions provided an automated service for the tenants of the building that connected different services (battery, district heating) and used relevant information to provide an automated system. Besides gathering quantitative data on social perceptions, the analysis focused on the information gathered via qualitative interviews with experts and stakeholders from the demo-site. For all the solutions analyzed in Glasgow, the expected benefits of the solution for the citizens were overwhelmingly positive.
This solution reported a particularly positive social impact and improved perceptions, and shows that energy interventions can improve the lives of socially disadvantaged populations. During the analysis it was identified that some tenants had experienced severe constraints in terms of energy access before the intervention, and had reported to be unable to warm their household and being cold in some occasions. After the introduction of the solution, tenants reported to be better enabled to put the heating on when they needed warmth. Moreover, one of the positive impacts of the solution perceived by tenants was the increased transparency, and tenants could understand better their consumption and adjust it. Despite the increase of electricity bills due to the global context, they considered getting more value for money.
The city of Glasgow is aiming to retrofit all their domestic and non-domestic buildings to a net zero

standard. Hence, there is a huge opportunity to upscale this solution if it proves to be the most viable on the market. Due to a large variety of housing stock in the city, it is likely that this solution can be explored in tandem with other solutions such as installing insulation and improving glazing in older properties.

Technical and environmental outcomes

The Figure 49 below indicates the use of the concierge office battery during hours of the day, and shows the battery discharges during typical household electricity demand peaks. The battery is charged during times of low electricity import cost and discharged during times of high electricity export / import prices.
However, the assessment indicates that the use of the battery in G9 had negative effects on the operating cost and CO2 emissions, due to apparent energy losses within the charge-discharge cycle that are much higher than anticipated.

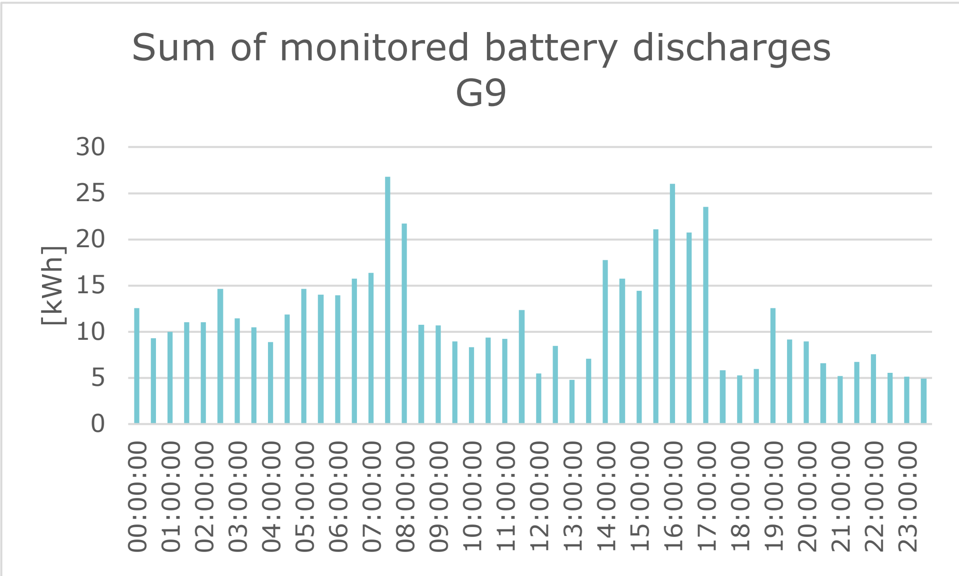

Figure 49: G9 battery discharges

Table 55 and
Table 56 indicate the calculated technical and environmental KPIs for the solution G9. The reasons for negative environmental impacts are discussed above.

Table 55: Technical performance assessment of G9

General assessment of buildings		
Smart Electric Grid Cluster		
KPIs		Achieved value
Storage Energy Used[kWh/yr]		919

Table 56: Environmental performance assessment G9

Smart Electrical Grid Cluster		
KPIs		Achieved value
CO2 savings [t CO2/yr]		-0.09

6.14. G10 - Demand-side management technology for non-domestic properties

6.14.1. Description of the solution

Demand-side management technology for non-domestic properties	Energy management and ICT

Figure 50: Non-domestic buildings in Glasgow. Source: Unplash: Fredrika Carlsson

Description

Non-Domestic buildings are a major contributor to CO2 emissions in cities and understanding how they can work harmoniously with other resources to deliver DSR services is an important learning for Glasgow, and cities in general.

This solution examines how non-domestic buildings can be used for demand-side management and to act as part of a 'smart grid'. The system involves data uplink via 3/4G routers to a centralised hub operated by Siemens. Control is handled via roaming 3/4G connections, which communicate with the Building Management System (BMS) controller within each building and relay signals to/from a dedicated Demand Side Management controller (DSMc) when seeking to perform a demand-side instruction, such as dropping unnecessary loads. Note that the BMS is always in control of the connected building loads and when an instruction is received from the DSMc, and that local environmental conditions are assessed before any loads are curtailed. If the BMS is able to shed load, a positive response is provided back to the DSMs. If it is not possible to shed load, a negative response is sent.

Expected impact:

- Increase of the reliability and ease of communications connections through the use of the mesh radio system allied with the ISL rollout
- Knowledge on how a larger fleet of buildings across a city can be implemented cost effectively.

The implementation of demand-side management is not new. The connection to the ISL mesh radio, a dedicated comms network across the city centre that will be used to control lighting as well as the other controllable loads in the RUGGEDISED project, is novel. It is hoped, it will be a key asset in the future for further Smart City developments in Glasgow. The number of different loads under the control of a single demand-side management controller is also novel as all previous control has been via a dedicated system that only deal with one load type. Having different loads, which consume energy in different ways increases the possibility for demand-side management at different times of the day and under differing environmental conditions.

6.14.2. Impact assessment

The solution G9 and G10 underwent a social impact analysis during its implementation process. This solution provided an automated service for the tenants of the building that connected different services (battery, district heating) and used relevant information to provide an automated system. Besides gathering quantitative data on social perceptions, the analysis focused on the information gathered via qualitative interviews with experts and stakeholders from the demo-site. For all the solutions analyzed in Glasgow the expected benefits of the solution for the citizens were overwhelmingly positive.

More information on the results of Demand-side management technology for non-domestic buildings can be found in the Implementation report of Glasgow.

6.15. Conclusions of Glasgow

The city of Glasgow successfully implemented and monitored nine smart solutions. Of these, two (G2 and G4) have been simulated, one business model for the EV-charging hub storage in car park has been analysed in depth, and stakeholders in Drygate Flats and Duke Street Car Park have been interviewed for giving insight into the user experience and awareness of the RUGGEDISED project.

Within the demonstration area of George and the Duke Street area of Glasgow, the assessment shows that 191 MWh primary energy per year could be saved by smart electrical grid solutions. Within the thermal grid solutions the installation of solar canopies on the roof of a multi-story car park (G4) a simulation estimated a generation of 162,206 kWh per year of electricity by renewable sources. The capacity of installed RES encompasses 155 kW. Additionally, it is estimated that with the installation of the PV system in (G4) a CO2 reduction of 11,4 tonnes per year could be achieved. By the implementation of smart electric grid cluster solutions such as in G2, G4 and G5 a total of 18.3 tonnes of CO2 and 190 MWh of primary energy have been saved per year.

For the EV-Charging hub battery storage in the car park a suitable business model for the battery energy systems has been explored. Five business model scenarios with different assets have been simulated and assessed. The modelling exercise revealed the city of Glasgow that the EV roll-out was a possible sustainable and energy-efficient measure with economical benefits. Thus, the upscaling potential of BM of scenario with most efficient assets and value is seen as optimistic but should be always considered in a broader city context.

Citizens have been asked about their expectations and experiences with the implemented solutions ‘electric vehicle charging infrastructure’, ‘intelligent street lighting’ and ‘demand-side energy management’. In addition to that experts and stakeholders have been interviewed to get an insight on the learnings and social impact. All in all, the results are mainly positive, especially from the analysis of the key stakeholders' interviews. Tenants, building owners and the network provider benefit from the demand-side energy management and thus the solutions have achieved a ‘win-win’ effect. From the city perspective, the smart-open decision platform developed within RUGGEDISED assists public officials to analyse and present the data in a meaningful way and pulls together different open data sets allowing cross-referencing.

Through the RUGGEDISED project sustainability has been put high on the city’s agenda, which created a fertile ground for innovation projects. The innovation capacity is the leadership, which is demonstrated and supported by powerful councillor. Alike the other lighthouse Cities a close cooperation with knowledge institutes for the knowledge exchange is crucial to implement successfully the project.

Other impacts and lessons learnt

Following on from RUGGEDISED, and as part of the ongoing climate work of the City of Glasgow, the city is looking to invest multiple millions into growing its renewable energy generation and linking it to battery storage, learning important lessons from the work undertaken in RUGGEDISED. Based on the work undertaken in this project, the city intends to deliver between £4-8M in solar and battery storage in the Glasgow City Council estate. This will not only create significant volumes of renewable energy, with maximised consumption in-site and minimum export, dealing with the climate emergency as well as the cost of living crisis, but will create a programme of work over at least 2 years, sustaining jobs across the city in this industry. The city i salso currently working on a pilot to transform its capped landfill sites into solar PV farms with over 50MW of soar and 120MW of storage, providing renewable energy and grid support service, again informed by the work of RUGGEDISED. This work also intends to use innovative cable routing, through repurposing of existing infrastructure, such as canals and unused water pipes, to run cables and reduce installation costs and transferring those savings to the end consumer.

The city will also be putting significant effort into growing district heating networks, developing heat network zones in the city that will support and enable the development of renewable heat delivery through district heating to public, private and domestic sectors, utilising the work in RUGGEDISED for the district heating contracts. This work will create a work programme that will be at least 8 years long, with early predictions suggesting 500-1000 jobs being created to support the development of renewable energy centres, utilising river source heat, heat form waste, and potentially geothermal heat, as well as to install the distribution network, connect buildings, and retrofit where required.
The city will also be further developing its approach to financing its transition to a net-zero carbon and climate neutral city, and is developing a 'Green New Deal' for Glasgow. This will look at innovative ways to bring in funding to the city to support the predicted £40B required for the transition. This finance will seek to blend public and private funding to help finance the transition. In addition, the city has established a Just Transition Commission to ensure that the transition is managed in a way that makes sure that no sector of society is further disenfranchised by the transition.

The Sustainable Glasgow network is, as the city's innovation platform, crucial to the delivery of the transition and is central to a very important development and evolution of the very location of the RUGGEDISED Smart Street, located in an innovation district in the city centre. Based on the work of RUGGEDISED, the development of the climate plan, the pressure of the climate and ecological emergency, and the newly published Adaptation Plan for the city, the District where the Smart Street is located has now developed a plan to become the city's first Climate Neutral Innovation District (CNID). This CNID has completed its phase 1 feasibility study and includes the installation of an extensive and innovative district heating network, utilising the River Clyde, which bisects the city running through the very heart of the city and way the basis of the shipping industry in the city that allowed Glasgow to become a global port, before the demise of the industry and the last transition the city went through. The CNID also includes reduced vehicular access, enhanced EV charging infrastructure, again benefitting from the work of RUGGEDISED through its street-lighting integrated charging, and green and blue measures to enhance adaptation to the climate impacts of increased precipitation and the urban heat island effect. The delivery of the CNID will have a significant impact on the community living in the district and within the proximity of the district, as well as influencing other such zones in the city. It is expected that it will create hundreds of jobs, significant gross value added to the city, and require at least £500M in investment to deliver. The specific detail in relation to these benefits is being calculated in phase 2 of this work.

The city also committed to developing a digital twin, further building on the data-based decision platform developed in the project and learning much from the experience of another Lighthouse city in the project, Rotterdam. This is going to be a strategic commitment for Glasgow City Council in its new administration.

Finally, the city has established a new Climate and Sustainability Board and Programme Management Office to ensure the appropriate governance to deliver on our climate aspirations and to provide the necessary support in the delivery of the actions required to achieve our goals.
In short, RUGGEDISED has been a catalyst to much of the innovative thinking and technology deployment, as well as to the management and governance associated with their delivery, and its legacy will be felt for years to come on our journey to our 2030 target of being net-zero carbon and to becoming a climate neutral city.

7. Overall conclusions

The project **RUGGEDISED – Designing smart cities for all**, intended to implement a total of 32 smart solutions in the three demonstration districts in the city of Rotterdam, Umeå and Glasgow. In total five solutions have been cancelled and some have been adapted or summarised to new solutions or solution numbers. This report contains the results of the evaluation and monitoring of 27 smart solutions for which data is available, and that have shown their impacts and benefits as well as the barriers and potentialities in the technical, environmental, economic and social dimensions. The calculated KPIs and the results of the non-technical outcomes of the project provided lessons learnt on new approaches, technologies and the process with the aim to help cities to achieve the overarching goal of climate neutrality of cities at the district level.

Overall, the monitoring and impact evaluation exercise of RUGGEDISED provides, through a set of quantitative KPIs on energy efficiency, energy savings, the production and use of local RES and CO2 reduction of energy and mobility, an assessment of how the tested technologies can contribute to building more net-zero and sustainable cities. Through a qualitative analysis of contextual factors affecting the implementation of these solutions, the monitoring of the project has also provided valuable insights into which elements at the institutional level (such as strategies, planning mechanisms, leadership, or regulations) are most important to ensure the implementation and scalability of solutions. Additionally, for a selection of solutions implemented during the project, a business model (BM) analysis and a social impact analysis have also highlighted the importance to consider how the implementation of new technologies affects both the involved stakeholders and citizens, and how their behaviours and incentives can ensure the smooth deployment of solutions or must undergo important changes to enable them.

The quantitative assessment of the implemented solutions has provided for each city an estimate of the reduction in CO2 emissions, energy savings and increased use of RES and energy efficiency. Some key highlights at the project level from the results presented in these chapters are:

Energy efficiency at the building and district level

In the RUGGEDISED project, 20.797 m² of residential floor area and 43.854 m² of tertiary buildings have been built. Moreover, RUGGEDISED managed to refurbish a total of 58.244m² of floor area. The increase of energy efficiency at the district scale could be achieved by energy efficiency measures in buildings, with the installation of street lighting and waste management interventions. The goal has been reached by an annual saving of 776 MWh by waste management and 21,993 MWh by street lighting and building energy efficiency measures.

Leverage of thermal energy

Thermal energy grid solutions, such as the heat pumps supplied by the geothermal storage in the AHOY building in Rotterdam, or thermal performance buildings of Mariehöjd in Umeå, have generated a total of 325,340 kWh thermal energy per year. By the deployment of the solutions within the thermal energy grid cluster an annual saving of 1 109 MWh of primary energy is estimated.

Reduction of the consumption of energy

Within the electrical grid cluster, the installation of photovoltaic systems and panels, and battery storages supporting the integration of electricity by PV and wind turbines contributed to the decrease in energy consumption in particular for e-vehicles. Hereby, 3 MW of RES capacity electricity could be installed and by that, an annual saving of 26,834 MWh of primary energy has been achieved at the project level. The electricity generated by RES by RUGGEDISED solutions amounts to an annual sum of 2,623 MWh. The measurements not only indicate a reduction of the primary energy consumption, but also a reduction of 9,370 t CO2 emissions to mitigate climate change. In addition to that, the testing and evaluation of the solutions delivered insights on the potential roll-out and upscaling of the technologies.

Rollout of electric vehicles

The roll-out of 55 e-vehicles and two e-Hubs has been successfully implemented in the districts. The assessment of the mobility measurements showed that in total 5,210 MWh of energy savings per year and a 2.218 t CO2 reduction have been achieved. Not only the mobility cluster contributed to the CO2 but also improved the air quality of the demo sites by an SO2 saving of 23,464 g, 376,129 g of NOx and 21,128 g of PM10.

In addition to the quantitative evaluation, the social impact assessment of the different solutions has also provided interesting insights regarding the direct and indirect effects of new technologies on citizens and other individuals interacting with the technology. Over a small selection of solutions that had been successfully implemented, several surveys were conducted to understand and compare what were the expectations of users before the installation of the technology and what were their experiences after it was installed. As many of the technologies assessed did not directly impact the life or activities of the users, one interesting finding was that the deployment and operation of these solutions had a minimal disruption in the lives of citizens, and that enjoyed moderately positive expectations and experiences.

These findings indicate that these solutions can be easily replicated or escalated in similar conditions and more likely will not generate opposition. Moreover, these insights also show how important it is to consider communication activities when implementing similar solutions to the ones observed, both to make the value of the investments more visible, and also to motivate other stakeholders to adopt similar solutions.

Along the same line, the implementation of these smart solutions also offered the opportunity to observe how new technologies and methods affect their environment. In these regards, the monitoring team also conducted a Business Model (BM) analysis of three use cases with 7 smart solutions. Within this analysis, it was assessed to which extent the pilots were generating transformative approaches among local stakeholders that could lead to a paradigm shift in energy production and consumption in cities. The results of this analysis on a selection of solutions indicate that the pilots did challenge the established operational model and forced stakeholders – mostly city administrations and energy companies, to collaborate more closely and explore new roles. While these changes were not sufficient to change the operation of their relations at a larger scale, they were useful to explore potential new models and identify ground rules useful for future interventions. Additionally, the qualitative analysis conducted during the project (further developed in D5.6.) addressing the factors affecting the implementation of solutions has shown how important contextual and institutional factors such as regulations, strategic frameworks or innovation capacity of the city are to ensure the experimentation with new technologies, their correct operation, and their potential for scalability.

Finally, an effort for documenting the monitoring process was also conducted during the project. The importance of documenting the monitoring process is of particular relevance in the case of a project that has been executed in particularly exceptional times such as RUGGEDISED, as it allows tracking the effects of the different situations and contextualising the results of the analysis. For instance, the implementation of several solutions was strongly affected by the effects of the Covid-19 pandemic, which broke out in early 2020 and led to several lockdowns and operational challenges for all organisations in all the countries participating in the project. Understanding how these situations have affected the implementation of the different solutions, and the availability of relevant data is of key importance to understanding the overall impacts of the project and contextualising the analysis.

The current multiple crises have shown the importance of innovative projects like RUGGEDISED and pose a challenge for cities to accelerate the transition towards climate neutrality more than ever. The effort for documenting the process has been essential for future adaptations and upscaling of projects. While the overall evaluation exercise has shown the positive effects of the project to reduce CO_2 emissions and increase energy efficiency in urban districts, it has also helped to identify some of the main challenges and potential solutions for the deployment and scaling of similar solutions in cities, such as building new collaborations and BM, increasing communications with the public, and building frameworks to enable interoperability of the different solutions.

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