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TOWARDS SMART ZERO CO₂ CITIES ACROSS EUROPE
VITORIA-GASTEIZ ✚ TARTU ✚ SONDERBORG

Deliverable 7.13 - Evaluation: Assessment of the overall performance
WP7, Task 7.5

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[1] PU = Public

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Abbreviations and Acronyms

Abbreviation/Acronym	Description
ANSI	American National Standards Institute
API	Application Programming Interface
APP	Application software
ASHRAE	American Society of Heating, Refrigeration and Air-conditioning Engineers
BEI	Smart Electric Bus (from the Spanish "Bus Eléctrico Inteligente")
BEMS	Building Energy Management Systems
CDD	Cooling Degree Days
CHP	Combined Heat and Power
CIOP	City Information Open Platform
DEMS	District Energy Management Systems
DHW	Domestic Hot Water
ECM	Energy Conservation Measure
EN	European Norm
EPD	Environmental Product Declarations
EU	European Union
EV	Electric Vehicle
EVO	Efficiency Valuation Organization
FEV	Full Electric Vehicle
GPS	Global Positioning System
HDD	Heating Degree Days
HEMS	Home Energy Management Systems
ICT	Information and Communication Technologies
ICEV	Internal Combustion Engine Vehicle
IoT	Internet of Things
IPMVP	International Performance Measurement and Verification Protocol
ISO	International Organization for Standardization
ITU	International Telecommunication Union
KPI	Key Performance Indicators
LCA	Life Cycle Assessment
LH	Lighthouse

Abbreviation/Acronym	Description
M&V	Measurement and Verification
n.a. / N.A.	Not applicable
NGO	Non-Governmental Organization
OECD	Organization for Economic Co-operation and Development
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied
PV	Photovoltaic
RES	Renewable Energy Source
RSS	Really Simple Syndication
SCIS	Smart Cities Information System
SmartEnCity	Towards Smart Zero CO2 Cities across Europe
SMS	Short Message Service
ToC	Table of Content
WP	Work Package

Table 1: Abbreviations and Acronyms

0 Publishable Summary

This report presents the results of actions implemented during the SmartEnCity project. The acquisition of monitoring data in the three Lighthouse cities followed the evaluation methodology developed at the start of the project. The evaluation methodology consists of seven protocols on: energy assessment, information and communication technologies, life cycle assessment, mobility, social acceptance, citizen engagement and economic performance[2], as well as an evaluation procedure. The city impacts are divided into four blocks of indicators, namely: environmental impacts, economic impacts, employment impacts and impacts related to city's policies[3].

Apart from presenting the indicators and results, this report also presents two sections that have been included to better depict the results obtained. First, section 3 makes a revision of the follow-up process carried along the project so a better framework is given for this report, which also provides a last review for the actions and interventions carried out in the last part of the project, focusing on those carried out in the second half of the project.

Section 4 provides a non-technical summary of the main results achieved in each of the Lighthouse cities, while specific figures and indicators are depicted later in section 5 where more detailed KPIs, values and graphs are presented for those readers wanting a higher level of detail on the results.

Finally, section 6 presents deviations from the original plan and the lessons learnt to support other cities working on the monitoring and evaluation of smart city actions.

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[2] See Deliverable 7.3: Evaluation protocols, SmartEnCity, 2017.
[3] See Deliverable 7.4: City impact evaluation procedure, SmartEnCity, 2017.

1 Introduction

1.1 Purpose and target group

SmartEnCity project aims to contribute to Smart Zero CO_2 cities in Europe with an extensive set of activities such as retrofitting of buildings and district integrated interventions, developing sustainable urban mobility, engaging citizens etc. Based on the data coming from many different sources, the impact of the different actions is then evaluated through different KPIs and city impacts that were defined and described at initial stages of the project in previous deliverables[4].

The **purpose** of this deliverable is to show the results of the evaluation performed on the three LH cities based on the mentioned indicators and the data gathered along the project.

This deliverable is **targeted** to both internal and external (other European cities, companies, universities, think-thanks, etc.) stakeholders interested on the evaluation results of the SmartEnCity project actions. Section 4 provides a summary of results for the general public.

1.2 Contributions of partners

This deliverable content has been collected by many different partners that have worked in a collaborative way. Section 4 and 5 have been developed by the different LH teams and then put together and harmonized to the better possible extent. The following Table 2 depicts the main contributions from participant partners in the development of this deliverable.

Participant short name	Contributions
CAR	Deliverable coordination, content for sections1, 2, 4, 5 and 6, final shaping of the document.
VIS, MU, CAR	Content from Vitoria-Gasteiz for sections 4.1, 5.1, and 6
CAR, TAR, TREA, UTAR, ET	Content from Tartu for sections 4.2, 5.2 and 6
ZERO, PLAN, ET	Content from Sonderborg for sections 4.3, 5.3, and 6
TEC	Content for section 3 and 6, and revision of consolidated version

Table 2: Contribution of partners

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[4] See in particular deliverables D7.3, D7.4 and D7.9, SmartEnCity, 2017.

1.3 Relation to other activities in the project

The following Table 3 depicts the main relationship of this deliverable to other activities (or deliverables) developed within the SmartEnCity project and that should be considered along with this document for further understanding of its contents.

Deliverable Number	Contributions
D3.1, D4.1, D5.1 and D3.2, D4.2, D5.2	City diagnosis and baseline have been described in D3.1, D4.1 and D5.1 by each LH city (input for sections 5.1, 5.2 and 5.3), and baseline calculations that are presented in integrated planning reports before the interventions start for every LH city (D3.2, D4.2 and D5.2).
D7.1, D7.2	D7.1 KPIs Definition for Pre-intervention Data Collection and D7.2 KPIs Definition for information.
D7.3	D7.3 SmartEnCity Evaluation Protocols compiles the holistic methodology developed for the evaluation of the performance of the interventions carried out in the three LH cities participating in the SmartEnCity project. This methodology consists of seven protocols where each protocol covers the description of the objectives to be evaluated and the methods to be applied. These are represented by a set of KPIs which will be used as tool to quantify the results reached after the execution of the interventions and actions. Specific procedures are described for each city and further advanced in this deliverable regarding data quality.
D7.4	D7.4 City Impact Evaluation Procedure defines the procedure proposed for the estimation of the impacts and performance of the actions at a city level by means of high-level indicators that allow explaining the impact of the integrated actions. Data collection and quality procedures advanced here related to impact measurement described in D7.4.
D7.6, D7.7, D7.8	Monitoring programmes (D7.6, D7.7 and D7.8) aim at the definition of a comprehensive and complete monitoring program in three subthemes: 1) district intervention, 2) vehicle and urban mobility, and 3) integrated infrastructure, that define the necessary requirements for monitoring and metering the actions selected in these three fields.
D7.9	Data collection approach report identifies the procedure to collect the information for evaluating the impacts in each city based in the protocols and indicators defined in deliverables D7.3 and D7.4. Apart from data collection insights, data quality aspects are also covered in this deliverable.
D7.12	The monitoring summary report makes a review of the overall methodology for data collection and data quality in the lighthouse cities and includes the monitoring programmes upgrade.

Table 3: Relation to other activities in the project

2 Objectives and expected impact

This deliverable aims to provide a summary of the evaluation results obtained based on the data gathered and the analysis of such data done.

In the SmartEnCity project an entire work stream was dedicated to monitoring and evaluation, creating a methodological framework for the evaluation of the interventions implemented in the course of the project. This included the development and customization of protocols covering different evaluation topics, including: energy assessment, ICT, life cycle analysis (LCA), mobility, social acceptance, citizen engagement, and economic performance. Each one contains a set of key performance indicators (KPIs). Apart from them, a set of city level indicators is also evaluated. On the basis of the agreed protocols, cities installed the monitoring equipment and gathered the data as input for the KPIs calculation and performance analysis.

As a public deliverable, this report helps to disseminate more widely the evaluation methodology and how it was applied to different types of interventions (e.g. district renovation, sustainable mobility actions, citizen engagement actions, etc) and in different cities.

3 Monitoring the implementation of interventions

The objective of this section is twofold:

- to review the follow-up process carried along the project;
- to review the interventions carried out until the end of the project, focusing on those carried out in the latter half of the project.

At this point of the project, all interventions were planned to be completed, and therefore the follow-up process finalized. As a final summary of this process, it is presented how and when the implementation measures have been developed and if the implementation of monitoring and data collection systems have been appropriate, checking the compliance with the main guidelines.

Three issues have been considered important to be monitored at this stage:

- the implementation of the planned interventions,
- the implementation of the monitoring campaigns, and
- the implementation of the evaluation approach established in WP7,

In spite of the delays in implementing in all three lighthouse cities, all interventions have been finalized as was foreseen, with slight modifications that are descried within this section.

3.1 Follow-up process

The follow-up process has been a continuous supervision of the implementation measures in the three LH cities. This process focused on the whole live cycle of the implementation measures, ensuring that the tenders were adequate, the construction works were executed to the required standards and within the deadlines, and finally guaranteeing that the monitoring and data collection included all relevant parameters for a proper evaluation of the benefits obtained.

The main outcomes from this follow-up process are included in deliverables D7.5, D7.10 and D7.11, where the status of the interventions was summarised at the end of different implementation phases. The follow up activities (and the deliverables summarising the result of this process) were conducted in a close cooperation with the demonstration teams, who were in charge of managing and following-up the different interventions and actions in each LH city. At specific implementation phases, the status of the interventions was reported in the above-mentioned deliverables with the purpose of communication with the EC and of proposing actions for risk mitigation and minimization of delays.

As the project has ended, so does the follow-up process with the conclusions included in following sections.

3.2 Vitoria-Gasteiz

The work carried out in Vitoria-Gasteiz along the project is summarized based on the last updated information, mainly extracted from deliverable D3.10 'Vitoria-Gasteiz - Demo Intervention Summary Report'.

One of the main pillars of work in Vitoria-Gasteiz is **building retrofitting.** In this lighthouse city, 26 buildings with 302 dwellings have been retrofitted with a total investment of 6.8 million € without significant deviations.

The retrofitting process consisted of three phases. The project designs for the *early adopters* were completed by November 2017, with construction works starting in June 2018. The works were finished in December 2018 with the installation of the monitoring sensors in each dwelling, recording monitoring data since then for electricity consumption, temperature, and humidity.

The project designs for the *intermediate phase* were developed from May 2018 to August 2018. In December 2018, retrofitting works tender was launched to contract the construction companies that would be in charge of the refurbishment. In parallel with the retrofitting works, the infrastructure to monitor the comfort conditions and energy consumption was deployed in the dwellings. Furthermore, 15 more buildings joined the project during the *last reporting period*, before the project ended in July 2021. In parallel with the retrofitting works, the infrastructure to monitor comfort conditions and energy consumption was deployed in the dwellings.

The second main pillar was the deployment of a new **district heating** system based on biomass, for which the tender was published in July 2019. However, in September, the tender was declared void and it was necessary to explore new options to reduce the investment and adapt the district heating network project to the number of connected homes. In November 2021, another option was studied that could represent a new energy model for the city of Vitoria-Gasteiz, as it would involve taking advantage of the infrastructures of the civic centres to create heating networks using biomass.

Finally, after the new specifications were published, GIROA was the only candidate to tender, which finally seemed to clear the way for the deployment of the project in accordance with local regulations, including data acquisition of thermal energy meter readings from both the production plant and the thermal energy meters in the homes. A total of 302 dwellings were added to the project. Due to a replication objective, the heating network was designed with potential for growth in mind so that other buildings could be added to the network in the future.

Mobility actions are the third pillar of the global intervention, including the deployment of touristic electric vehicles and last mile logistic electric infrastructure (Q2-2018), electric vehicle fleets and charging infrastructure (Q1-2020), as well as the implementation of an electric bus line and associated charging infrastructure (Q3-2020).

In order to properly assess the mobility actions, incoming convoys are being monitored in terms of both performance and energy consumption since Q3-2020 through monitoring devices installed in each e-bus until the end of the project. Moreover, charging has been also monitored by devices installed at the charging units (immediately upon each deployment as with the e-buses).

On the other hand, **ICT** plays an essential role in the implementation and monitoring of the different actions. In order to ensure a proper operation of the whole system, the '**Urban Management System' platform** was deployed from the first stages of the project. Once the sensors were placed in position (dwellings, charging infrastructure etc.), data started to been gathered on the platform. The configuration and deployment of the ICT infrastructure and City Information Open Platform (CIOP) have been in general terms in line with the initial

scheduled planned. Minor adjustments had to be made to follow the natural development of the other actions that affected the CIOP deployment, in particular the data acquisition from sensors and systems.

3.3 Tartu

As for the Vitoria-Gasteiz case, the demonstration activities in Tartu included **building retrofitting, integrated infrastructures** and **mobility actions,** with a roll-out of a CIOP that ensures a proper monitoring and assessment of the activities.

In the **building sector**, 18 houses comprising 664 apartments were upgraded, including retrofitting and deployment of RES, from mid-2019 to mid-2020, reducing energy consumption by more than 66%.

In parallel, two new infrastructures were developed; on the one hand, a new **district cooling network** was deployed to meet consumer demands for thermal indoor comfort. The new district heating and cooling system created in Tartu is using residual heat from cooling for producing hot water, which will be supplied through the existing district heating network. On the other hand, high efficient **street lighting** with advanced control solutions based on data from sensors was deployed and commissioned.

Finally, the **mobility actions** included a rental service of e-bikes with dedicated parking stations; the deployment of a public electric vehicle charging infrastructure; bike sharing; 64 new bio-gas buses; and the installation of solar energy for charging of EV batteries.

All these demonstration actions generated different datasets from GPS information from buses, street lighting, environmental sensors and traffic counters. Very soon quick-chargers and EV-battery re-use will be connected to the platform.

3.4 Sonderborg

The demonstration activities in Sonderborg in the building sector focused on the **energy efficient upgrade** of 51 buildings with 815 apartments. The data monitored include electricity consumption and heat consumption for a proper performance assessment of the intervention.

Department	Street	No. Buildings	No. Apartments	Built area m²
SAB – 22	Kløvermarken	19	432	32.421
SOBO – 11	Borgmester And.	8	88	8.420
B42-10	Skriverløkken	5	87	6.960
B42-12	Sundquistgade	3	16	2.300
B42-13	Ringbakken	4	48	4.320
B42-21	Morbaerhegnet	10	120	9.600
B42-28	Vissingsgade	2	24	2.160
		51	815	66.181

Regarding the **integrated infrastructure action,** the original planned DH demo action was replaced by a solar cell battery storage project, engaging 11 housing association departments to retrofit 86 apartment buildings with solar PV and battery solutions. The data monitored focus on the electricity production from the solar panels.

Regarding **mobility actions,** 44 biogas buses were already operating and monitored since Q2-2017. Additional 6 buses were purchased to cover the transport needs. In parallel, 24 EON charging-points were installed and monitored since M49.

An overall CIOP to control and visualized the demonstration activities was implemented in summer 2019 with information collected by more than 700 sensors. Because the **ICT** partner VG left the project and Telia took over this task, all data loggers installed are being exchanged. These new loggers are now sending to Telia's CIOP

4   General overview of the assessment results

This section provides a non-technical summary of the main results achieved in each of the Lighthouse cities, while specific figures and indicators are depicted in section 5 for those readers wanting a higher level of detail on the results.

One general aspect to be remarked before diverting into the three LH cities results, is the interesting comparative we've been able to see in SmartEnCity on how each city has approached its City Information Open Platform (CIOP) development.

Although initially three different approaches were foreseen for each CIOP, after the withdrawal of the partner initially responsible for the CIOP in Sonderborg, it was decided to adopt there the same structure as was developed for Tartu. This has been the first replication outcome of the project, but inside the project itself. In this way, and while taking into account the needed adaptation to each city, there are now two CIOPs developed in a centralized way by one main partner, but interconnecting many different systems some from third parties, and a totally different third one (deployed in a collaborative way by different project partners and covering different aspects of the city and also connecting to different data sources).

4.1 Vitoria-Gasteiz

As explained afterwards, the different key performance indicators are the basis for the definition of other high-level indicators, which are useful to extract more information concerning the effect of the interventions at city level.

To give a first number in relation to the scale of the actions deployed in Vitoria-Gasteiz, it is important to emphasize that 302 dwellings in 26 buildings were retrofitted and connected to the district heating systems. In addition, three tertiary buildings are also connected nowadays with a heating load equivalent to 386 extra dwellings.

In relation to the number of new electric vehicles (EV) within the SmartEnCity project, a total of 5 e-vehicles, 6 e-bikes and 13 e-buses are now circulating, replacing the corresponding combustion-engine vehicles that would be travelling if those electric vehicles and buses had not been considered in the scope of the project. Such action has avoided the emission of 210 585 kg CO_2-eq so far during the project life.

Concerning investments, 46% of the total cost of the retrofitting and the DH connection works have been covered by the dwelling owners, 22.9% by EU funding, 26.7% by the Basque Government, and finally 4.4% by the Vitoria-Gasteiz Municipality.

Regarding new regulations in the city linked with the SmartEnCity project, it is important to notice that a special plan for the Coronación neighbourhood has been prepared, and a provisional approval of the 'Structural Specific Modification of the General Development Plan' of Vitoria-Gasteiz has been achieved. Besides, a 'Real Estate Tax' reduction of 50% for those dwellings getting an 'A' rating on the Energy Certificate (all SmartEnCity retrofitted dwellings) has been achieved, as well as a 50% tax reduction on the construction works. Besides, it is important to highlight the high level of co-governance between institutions has been achieved throughout the entire project life.

The share of renewable energy production in the district has changed significantly in the course of the project. Before implementation of the works on the district heating network, all

energy used in the district was coming from fossil fuels. With the available data for the last year in which the network is running, an average value of 69% of the renewables based heat was produced thanks to the use of biomass. This value can appear as low, but it is due to the works that had to be done over a two-month period on the chimney of the biomass boilers, forcing the system to work with the back-up gas boilers. Ignoring those months when works on the DH chimney was performed, we obtain a renewables ratio of 85%, which indicates a more accurate performance level to be expected in the long term. But even more, there are several months with renewables ratios of 90% or higher, with a maximum share of renewables based heat production of 97% in November 2021.

In terms of thermal energy consumption, the overall monthly load profile shows a decrease in the maximum values as the years were passing by and the number of refurbished buildings was growing.
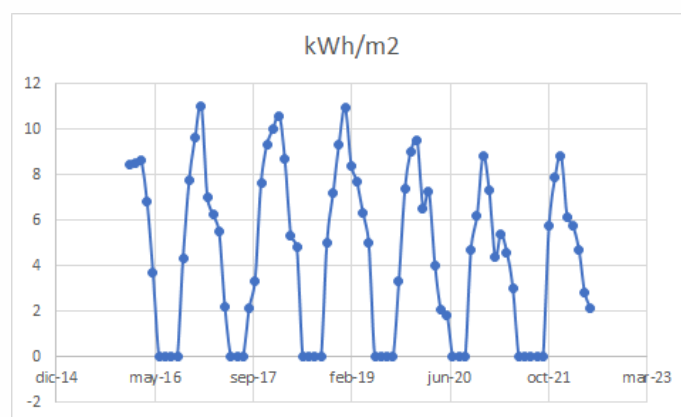
Figure 1. Thermal load profile for Coronación district

In this same line, and in relation to CO_2 emissions, the total value of building related CO_2 equivalent emissions (gas+biomass) during the first semester of 2022 (last six months of the project, thus latest values) the emissions were less than half of the values obtained for the rest of the years, confirming the tendency.

With regards to comfort, the following indicators were monitored[5]:

- Internal air temperature.
- Internal humidity.
- Thermal comfort.

As a summary it can be said that the average temperature values in the dwellings are close to the ideal temperature for a home.

For the internal humidity, the mean values range between 40% and 70%, which is close to the ideal humidity levels for a home. Humidity is higher in those houses with isolation, which is an expected behaviour.

Finally, regarding thermal comfort, the calculations proposed by the standard ASHRAE55 have been used, using the following indicators: PMV (Predictive Mean Value) and PPD (Predicted Percentage of Dissatisfied). An improvement in comfort values has been achieved, with the insulated dwellings obtaining ratings between 'slightly cold' and 'neutral', while dwellings without isolation are directly in the 'cold' range.

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[5] These indicators and monitoring results are explained in more details in section 5.1.1

Concerning ICT solutions, different developments have been deployed in Vitoria-Gasteiz in order to provide information (especially to citizens) and support the decision-making process to the different roles involved (i.e. citizens, ESCOs, Municipality…). Different developments from different partners have been adapted and deployed in a collaborative way to try to cover different aspects of the city. All the involved partners have stablished a fruitful collaboration defining the proper methods to make their developments communicate with each other (i.e. APIs definition). Although most of the services are energy-related (i.e. monitoring of consumption and comfort conditions at home app, data analysis of comfort conditions for ESCO, etc.), there is also one social service which offers local news about Vitoria-Gasteiz based on Really Simple Syndication (RSS).
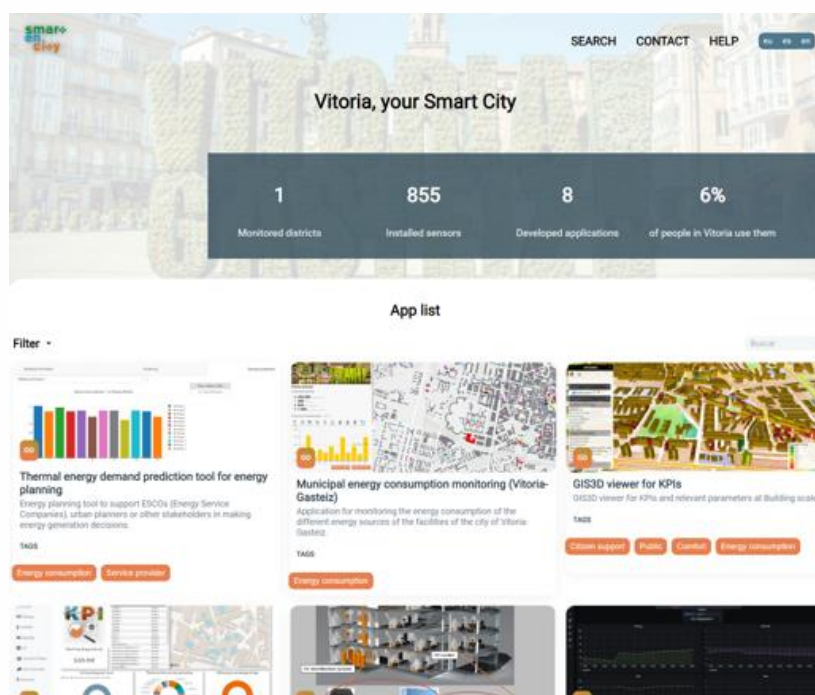
Figure 2: Headings of Vitoria-Gasteiz CIOP landing page

All the developments have been widely deployed, having a 100% of physical equipment for data acquisition connected in most of the corresponding data bases or applications. It is worth mentioning that 2 741 home energy management systems (HEMS) are connected to the municipal buildings' energy usage monitoring tool, and 855 connected to the app about comfort conditions, the installation and management support tool and the ESCOs app. Besides, 1 946 building energy management systems (BEMS) are connected to the municipal energy usage tool, and 300 to the other aforementioned three tools.

It is important to note that all the data has been anonymized when published as open data-sets in order to follow GDPR principles.

When speaking about the different analyses done to check the impacts of the measures implemented in Vitoria-Gasteiz, a Life Cycle Analysis (LCA) for energy refurbishment helps to know the impact associated with each stage and impact avoided in regard to the current state.

The aim of using this protocol has been to evaluate the potential environmental impacts with and without the retrofitting process and the district heating installed in this Spanish demo

case. Thirteen environmental categories have been assessed and nine of them were identified as key performance indicators. All of these indicators are strongly related with energy consumption and efficiency, so they are sensitive indicators suitable for the purpose of the actions involved in the project.

The LCA here developed has included the assessment of new materials manufacturing and construction, replacement operations, use phase and end of life for the whole building's interventions. One might expect that adding those operations may lead to an environmental burden (defined as any activity affecting the environment negatively), but it has been shown that there is no major increase of this environmental burden as a result of the interventions in the Vitoria-Gasteiz demo case. Instead, some environmental indicators shown an important decrease when comparing the baseline and project scenarios. For instance, the Global Warming Potential decreases by 50% and the Cumulative Demand Energy decreases by more than 60% on average.

When a life cycle approach is considered, the energy reduction achieved due to a complete renovation strategy (such as proposed by SmartEnCity) offsets the impact of the new materials and operations. The purpose of this simplified assessment has therefore been to analyse how far it is interesting to strive for an energy retrofitting to reach its optimal environmental performance over a life cycle and, as presented in section 5.1.3, it is quite clear that the energy retrofit is advantageous from an environmental point of view.

Concerning **mobility**, the following actions have been carried out in Vitoria-Gasteiz:

- Converting a circular bus-line with the highest number of passengers in the city into a modern and clean electric bus transit line (BEI intervention).
- Promotion of electro-mobility both for public and private entities. In this case, multiple e-vehicles have been added to the fleets of Vitoria-Gasteiz Municipality (2 e-vehicles), GIROA (1 e-vehicle) and VISESA (2 e-vehicles).
- Deployment of an e-bike sharing station with 6 e-bikes.

As the data providers of the different mobility services have provided different types of data, it has been not possible to calculate certain KPIs (e.g. the ones concerning occupancy), but the most important one (emissions avoided by travelled distance) has revealed quite good results. For example, a total of 5 237 $kgCO_2eq$ have been avoided due to the use of the aforementioned e-vehicles in Vitoria-Gasteiz Municipality, GIROA and VISESA fleets along the project lifetime. In the case of the e-bikes, and based on the number of kilometres travelled by the them, a total of 1 607 $kgCO_2eq$ have been avoided.

Social Acceptance and Citizen Engagement KPIs required a common approach because of their especial characteristics. Any protocol where the citizen is the main character should be treated with special attention. The inherent human factor of these abovementioned protocols increases the complexity of retrieving the information and extracting conclusions. Here we do not have smart meters or sensors to get the information like in other more "technical" protocols, and so, it is necessary to address directly the citizens and get close to them to understand their opinions and concerns.

Because of that, it was necessary to translate the KPIs initially designed to obtain the information into understandable questions that a regular citizen could answer. Beside of that, the special characteristics of the people living in the demo site (high percentage of elderly and migrant citizens) added new dimensions to the challenge. Age and digital breach as well as cultural and idiomatic barriers had to be overcome.

Following some learned lessons related to citizen engagement, a personal assistance point was set up in Centro Cívico Aldabe, in the heart of the district, to attend to the citizens and complete the data retrieved by means of the telephone survey.

At the same time, personal data protection was a critical aspect of the implementation and to do so, the team checked all the agreements signed with the participants to be sure that they offered the required protection. In addition to that, we prepared and signed a new agreement with the consultancy firm that carried out the survey so they were able to manage correctly all personal and contact data that they needed to accomplish their task. In any case, surveys always remained anonymous and only aggregated and treated data were used to extract conclusions.

The following main conclusions can be drawn from the data analysed:

- Two thirds of the respondents are older than 55 years.
- Almost all the respondents are owners of the dwelling that participated in the project.
- In general terms, surveyed people have a high level of satisfaction with the project, especially in terms of comfort and aesthetics and with the information received during the project.
- Necessary effort for citizen engagement was much bigger than expected during the proposal preparation and it required flexibility to adapt the plans to the reality.
- Finally, citizen engagement activities gained importance during the accession[6] phase and arisen as one of the key points of the project. As a result, a previously not foreseen accompanying process was set up in the last phase of the project to give continuity to the citizen engagement strategy defined during the accession phase. This decision showed to be very profitable in terms of citizen satisfaction and endorsement.
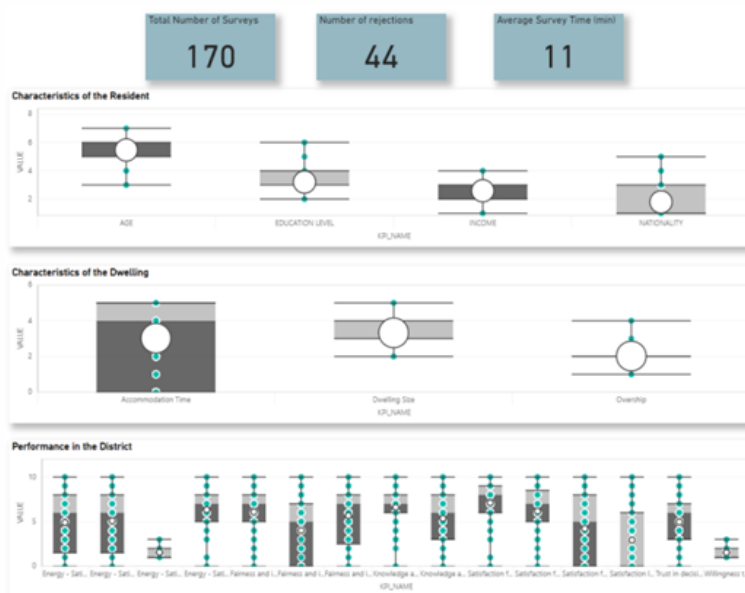
Figure 3: Summary of the answers from the questionnaire as they are shown in the KPIs visualization

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[6] The accession phase, was the time period while the different potential Communities of homeowners (buildings) proposed to join the project were deciding whether to join the project or not.

The economic analysis reveals that the number of years to get payback for customers is long (35 years) with a 60% grant but can become much shorter (15 years) if the project manages to obtain a 80% grant. The hypothesis of 80% may be optimistic but not impossible since the project already got 60% and grants from Gobierno Vasco and Ensanche 21 are still unknown.

However, customer save 38% on their energy bill each year, although district heating maintenance costs are higher than individual gas boiler maintenance. Nevertheless, a central heating plan enables to improve energy efficiency and to reduce energy consumption by 28% and so customer bills.

Four scenarios of annual costs evolution for 20 years have been compared: reference scenario (SmartEnCity project), optimistic scenario (SmartEnCity with 80% grants), gas scenario (before implementation of SmartEnCity) and gas crisis (without SmartEnCity implementation). Despite incertitude for payback period for customers, the evolution of annual costs analysis shows that the costumers will pay less in the long-term thanks to the biomass district heating compared to the gas scenarios. Besides, the hypothesis of the evolution of costs assumes only a moderate increase. They could be worse and so lead to a better payback in the end.

Some of the main results in relation to the city impact indicators are listed below:

- District renovation: Retrofitting 26 buildings with 302 dwellings resulted in 2021 in 472 MWh of energy consumption (-88.7%) and 150 tCO2-eq savings (-88.5%).
- Sustainable mobility actions: Annual savings of 824.5 tCO2eq, which includes 817.7 tCO2eq for 13 e-buses, 5.2 tCO2eq for 5 e-cars and 1.6 tCO2eq for 6 e-bikes.
- Renewable energy in DH network: average value up to 85% with monthly peaks of 97%.
- The total amount invested in smart city measures is EUR 49.7 million. This includes EUR 6.9 million for the building retrofitting and the DH connection as well as EUR 42.8 million for the e-charging infrastructure and e-vehicles.

4.2 Tartu

The SmartEnCity project in Tartu aimed to accomplish the following goals:

1. Demonstrate a comprehensive approach to **retrofitting** outdated panel buildings according to near zero energy standards.

2. Boost the liveability of the town through smart solutions (**increasing the share of renewable energy**, intelligent **street lightning, biogas buses, bike-share system, EV charging stations, Tartu smart city portal, reusing old EV batteries, cooling system** and other).

3. **Engage the citizens** in creating a high-quality living environment that inspires **environmentally aware decisions** and new patterns of behaviour.

In terms of **retrofitting**, the main idea of these activities was to turn the Soviet-time "khrushchyovkas" into "smartovkas" that offer an energy-efficient and high-quality living environment to the pilot area residents. Overall, 18 buildings with 664 apartments and 35 218 m² (net area) of space (34 402 m² of heated space after retrofitting) were refurbished.

Approximately 1 500 people benefitted from retrofitting. The main goals of retrofitting were achieved (Table 4). Retrofitting increased the average energy performance of the buildings by 60%. Their total energy demand was reduced by 36%; space heating energy consumption was reduced by 54%. Buildings emitted 2 040 tCO_2 annually before retrofitting, after renovation annual CO_2 emissions are 980 tCO_2 (-52%). Emission of energy sources used in the buildings were reduced by 52%.

In addition to the saved energy and emission factor change, an added amount of approximately 430 tCO_2 of savings are coming from **renewable electricity** exported to grid. In total 18 PV-stations were installed with a total peak power of 554 kWp. In the coming years, a slight increase in energy efficiency and energy savings is expected as most of the buildings are in their first commissioning years after retrofitting. Optimizing the systems (ventilation, heating) for better efficiency can be done based on buildings' operation feedback.

For residents, the perceptions of indoor air quality and thermal comfort are very important. Measured with questionnaires, the thermal comfort level was achieved in the wintertime. The share of people who report the indoor temperature to be appropriate in winter has increased (from 37% to 56%). As Estonia had an exceptionally long summer heat wave in 2021, the thermal comfort in summer was not achieved according to residents' perceptions (for further details see section 5.2). In the retrofitting project, no active or passive cooling measures were foreseen, because overheating simulations done by the project designer based on standard summer temperatures did not show any need for this. In line with climate change, adding passive or active measures would be the next step in the future for apartment buildings. There is a lot of potential to use solar panel production for active cooling. The majority of residents is satisfied with the ventilation; satisfaction with the air quality has also increased when compared with pre-reconstruction time.

	Goals	**Results**
Energy savings	30% decrease of total energy consumption	36% decrease
	50% decrease of heat energy consumption	54% decrease
Emission reduction	50% reduction of CO_2 emissions	52% reduction
Comfort level	Indoor air quality achieved	Achieved by measurements and residents options
	Thermal comfort achieved	Achieved in wintertime, not achieved in summer time

Table 4. Results of main goals of retrofitting action

In addition to satisfaction with the indoor climate, the renovation also increased economic satisfaction. The costs to residents of the renovation is 348 €/m². The majority of the respondents (72%) report a reduction in their heating bills. In terms of economic investment, the majority of the respondents (53%) is satisfied with the monthly repayment of the reconstruction loan. 33% of respondents are willing to invest in energy-saving solutions in the future. In general, more than 70% of respondents agreed that the energy-efficient renovation

of apartment buildings was a worthwhile undertaking and none of the residents would like to live in an unrenovated building.

Such a comprehensive retrofitting project has environmental impacts and this is measured by a **Life Cycle Analysis (LCA)**. The LCA of the renovation actions in Tartu used standard methods, considering a simplified scheme because of the complexity of the renovation actions. Two different scenarios have been studied and compared; the baseline (the normal behaviour of the apartment buildings functioning before SmartEnCity project) and the project scenario (the apartment buildings functioning after project interventions) and they present significant differences in terms of environmental impacts.

Applying the developed LCA protocol, it has become evident that the stages referred to in the assessment as raw materials supply, transport and manufacturing of the components of the retrofitting materials as well as their waste processing for final destination (only for the elements selected in the project scenario), have a limited environmental impact. On the other hand, the operational energy use category, that is, the energy use by the systems integrated in the buildings during their operation (post-intervention), is the phase that has the greatest effect on life cycle impacts.

The main reason that this 'use phase' dominates the two scenarios is the environmental impact of the building's operational energy use. With this impact being reduced in the project scenario compared to the baseline scenario, the SmartEnCity interventions play an important role in decreasing the overall life cycle impact.

The Cumulative Energy Demand was also reduced considerably due to the implementation of the SmartEnCity energy measures. The project scenario in the case of Tartu demo site achieved a reduction of more than 35% of the Cumulative Energy Demand compared to the values obtained if no measures would have been implemented.

To summarise, the SmartEnCity scenario resulted in very positive environmental impact.

Apart from pilot area retrofitting, there were numerous city-level actions, especially regarding **mobility**. Five new public 50kW fast EV **charging stations** have been installed in public locations to cover the demand generated by the future EVs (rentals, taxis and private use). There have been 8 098 recharges using 125 100 kWh in an average year. Next, **old batteries from EV**'s can be reused for storing energy. EV taxis of private company OÜ Takso are partially recharged with the **renewable energy** that is produced on site with PV panels ($300m^2$) and stored in old EV batteries. 60 new **biogas buses** are serving Tartu citizens, which means that from 2020 onwards 100% of public transportation buses run on biogas. The annual capacity of the regular public transportation service is currently 3.6 million line

kilometres.

Last but not least, a **bike-share system** was implemented and it is a real success story in Tartu. On 8th of June 2019 Tartu City launched a bike sharing (450 bicycles + 69 parking stations) and electric bike rental system (300 electric bicycles) consisting in total 750 bicycles and 69 parking stations, being the e-bike rental part of the bike-sharing system. Total investment in the bike sharing system was about 2.200.000 € and was financed by the city of Tartu. For the establishment of the electric bike rental system, the SmartEnCity project has financed the amount of 697 500 €. From the start (June 2019), there have been almost 3 million rides and over 7 million km cycled with bike-share bikes. Bike sharing is mainly

addressed to people who need to travel 2-5 km and it is a great alternative to driving a car. There are 300 e-bikes available for rental. Bikes can be unlocked by using the web application or mobile app, or by tapping the contactless Tartu bus card on the bike's sensor. It is possible to get the required information from the e-bike in real time. Thanks to the batteries, the bike is able to stay in connection with stations and server for a long time, giving a wide autonomy. All smartness is integrated into the bike. The average occupancy for the bikes is 1.79 people per vehicle per day. As bikes are equipped with a GPS device, a huge spatial mobility dataset is generated every day, which is valuable for different stakeholders, promoting research, education and new project proposals.

In total 7 037 tCO_2 emissions saved annually due to sustainable mobility actions over the life of the project.

Among the mobility solutions related to the SmartEnCity project, public transport is the most used. 80% of Tartu residents have used biogas buses (68% of pilot area residents), 45% bike-share (31% pilot area residents) and 11% EV fast chargers (3% pilot area residents). Those who have used public transport are mostly satisfied with the solution, and this applies to the bike-share system as well. The use of EV chargers is very low and also the willingness to purchase electric vehicles in the future among the pilot area residents.

The data produced by city sensors, infrastructure and API-s (smart street lightning, buses, bike-share bikes, traffic sensors, smart home system, etc.) feed **Tartu's smart city portal** (CIOP). This is an ICT solution based on IoT technologies and collects city level, building level and personalized apartment level data to one platform. The real-time data is gathered centrally in a secure distributed cloud platform where it is analysed. While city level data is open to everyone for use, personalized apartment level data is protected and follows GDPR principles. All the pilot area dwellings and buildings (100%) are connected to the CIOP. Currently there are more than 2 800 HEMS, 18 BEMs, 321 **smart lighting** equipment, all mobility actions (buses, bicycles, EV recharges) and traffic sensors integrated to the CIOP. There are 12 open data datasets available in the smart city portal. The current number of registered users to the web application is 62.

To achieve a smooth retrofitting process and the social acceptance of the project activities, **citizen engagement** activities were crucial. The main focus was to involve the housing associations in the renovation process. The main target groups of citizen engagement were residents of the pilot area and citizens of Tartu. The strategy was mostly focused on informing, consulting, involving and co-creating with the citizens, the latter most notably through the artwork creation and selection for each renovated house. The engagement of the residents took place through housing association meetings, where SmartEnCity team members were present, residents information events, smart home trainings and smart house ambassador program. Citizens (including residents) were informed about the project through public campaigns (includes public campaigns about bike sharing, SECAP, art tours, etc.), thematic events (includes citizen information events, smart home trainings, smart home ambassador program trainings, technical meetings with housing association boards), newspaper articles (150 articles) and television (7 TV-shows). Overall, the SmartEnCity project was mentioned in the media 220 times. Additionally, regular newsletters and mailing lists were used to inform and engage with residents, and most events, even those targeted at pilot area residents, were open to all interested citizens. The end goal of Tartu was to have well-informed citizens who feel that they have and they can contribute to the development of Smart Tartu.

Surveys showed that 40% of Tartu citizens had heard of the SmartEnCity project. The most well-known action is the bike-share system – 90% of citizens are aware of this mobility solution. A third of the respondents felt involved in the renovation process, and a third did not feel involved. 58% of the respondents are satisfied with the information provided by apartment association, 44% of the project team and 36% of the construction company. The main source where people received information about the SmartEnCity reconstruction project of their apartment building was the apartment association (73% of respondents), followed by information retrieved from the mailbox of the apartment (36% of respondents) and tarktartu.ee website (30% of respondents).

Some of the main results in relation to the city impact indicators are listed below:

- District renovation: Retrofitting 18 buildings with 691 apartments (= net 35 000 sqm) resulted in 2021 in 6 420 MWh of energy consumption (-37%) and 911 tCO2e savings (-52%).
- Sustainable mobility actions: Annual savings of 7 037 tCO2eq which includes 711 tCO2eq from 300 rental e-bikes, 5 250 tCO2eq from 60 bio-gas buses and 1076 tCO2eq from the bikeshare system with 450 bikes.
- Renewable energy usage / production total increase of 107 245 / 15 445,5 MWh/a
- Renewable energy in DH network: increased from 79% to 83%.
- The total amount invested in smart city measures is EUR 21,8 million.

4.3 Sonderborg

One of the main ICT developments carried out in Sonderborg is the CIOP and, in order to gather the data needed by this platform (specially the one related to the energy assessment), data loggers have been installed in all the three housing associations, which are monitoring data and reporting it to the CIOP. There have been challenges with some of them i.e. sudden stop in operation, change of external main meters (outside of the scope of the SEC project) and hence loss of signal, etc., but these challenges have been resolved. All housing blocks originally included in the Sonderborg demo have been connected to the CIOP. Following a project amendment, additional activities related to more solar PV+battery storage solutions were implemented; these are currently being connected to the CIOP.

The difference in the level of electricity consumption (see Figure 4) in the three housing associations is due to the difference in the number of dwellings. The electricity consumption is higher during winter months due to the need for more lighting etc. All three housing associations installed solar PV plants on apartment blocks. The total electricity consumption is the sum of the electricity bought from the public grid and the electricity provided by the solar PV plants.
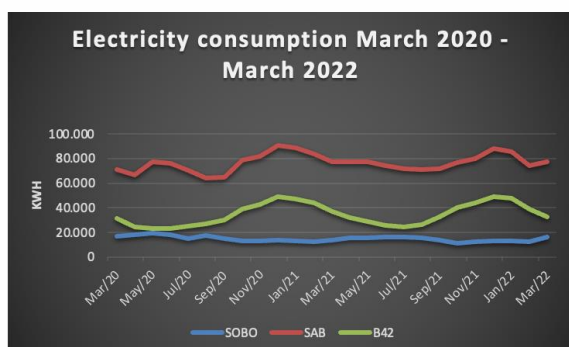
Figure 4 Electricity Consumption March2020-March2022 (Sonderborg)
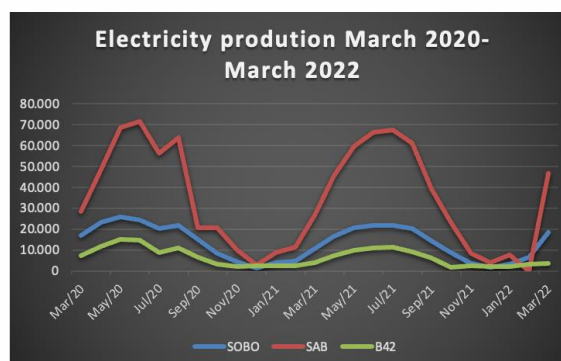
Figure 5 Electricity production from installed solar PV plants (Sonderborg)

The size of the solar PV plants installed during the 1st Energy retrofitting phase of the project varies between the three housing associations (see Figure 5). The plant in SAB Housing Association with 3 000 m² solar panels in this phase is much bigger compared to the other two housing associations. Therefore, the variation during the year seems bigger in the curve with the actual vertical axis. SOBO has in this phase 950 m² solar panels installed, and B42 has 700 m² solar panels. All the curves have the same variation during the months from summer to winter. The solar plants in SAB and SOBO cover about 30% of the total electricity consumption in the departments.

Concerning the district heating consumption (see Figure 6), the curves vary naturally during the year (summer/winter). The department involved from SAB with 432 dwellings (across 19 buildings) is much bigger than the other involved departments like SOBO with 88 dwellings (across 8 buildings). Housing association B42's apartment blocks have a low heating consumption, because B42 focused on reducing the heat loss through facades, roofs and windows. Furthermore, B42 has installed new low energy ventilation systems. SOBO has also new windows, LED lighting and new effective heating automatic systems in addition to the solar PV plants. SAB has focused on solar PV plants and LED lighting.
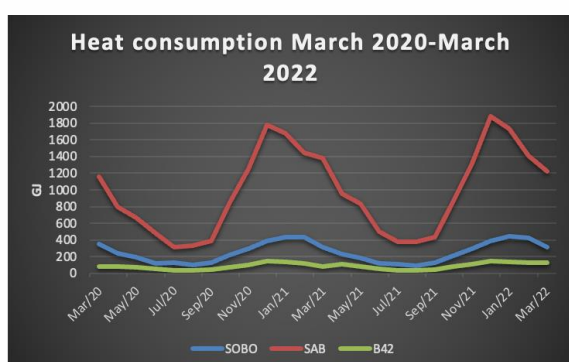
Figure 6 District heating consumption in the involved apartment blocks in the 3 housing associations (Sonderborg)
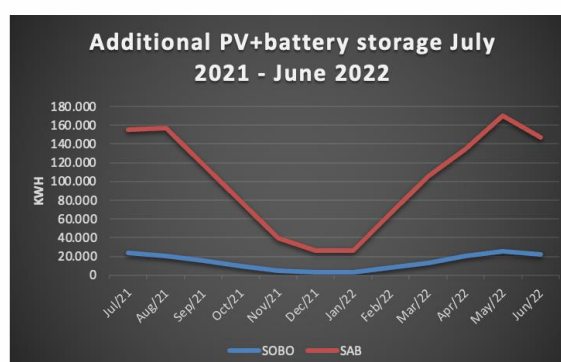
Figure 7 Solar electricity production from solar PV + battery systems (Sonderborg)

Following amendments to the project, in a 2nd phase, additional solar PV and battery systems were installed on 86 apartment blocks in 11 departments in SAB and SOBO housing associations. The battery solutions are a new technology used in housing blocks. The solar PV production curves follow naturally the summer/winter periods. The solar PV systems installed in SOBO are relatively small compared to the systems in SAB. In this 2nd phase,

SOBO has 1,020 m^2 solar panels and 125 kWh battery capacity. SAB has 7050 m^2 solar panels and 925 kWh battery capacity. B42 has not been involved in this 2nd part of the demo project. Due to the difference in the size of systems in SAB and SOBO the variation of the solar-batteries electricity production during the year looks smaller for SOBO compared to SAB, using the actual vertical axis (see Figure 7).

Total installed solar PV panels in the housing associations (1st plus 2nd phase of the project) are thus:

	1st phase	2nd phase	Total
SAB	3000 m^2	7050 m^2	10050 m^2
SOBO	950 m^2	1020 m^2	1970 m^2
B42	700 m^2	---	700 m^2
			12720 m^2

Also, total installed battery capacity in the housing associations (all on the 2nd phase of the project):

SAB:	925 kWh
SOBO:	125 kWh
In total:	1 050 kWh

Concerning ICT (see Figure 8), the CIOP has been widely adopted, especially in the last six months, when a total of 5467 devices were connected to the platform. As a consequence, the size of the total amount of data generated increased a lot, growing 5 times from M48 to M74 (Figure 9). No maintenance hours were recorded because there are three virtual machines with load balancers running in parallel in two physical sites. This configuration makes also possible to achieve a response time of 20ms.
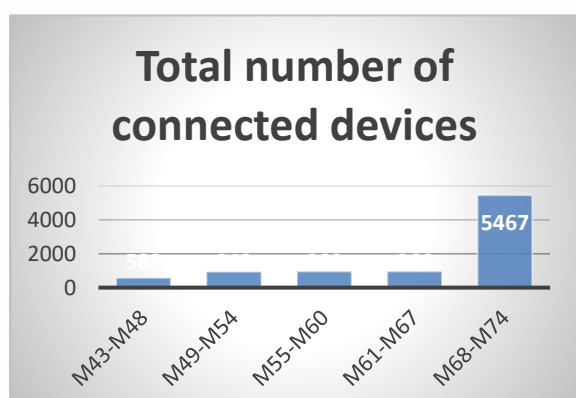
Figure 8 Total number of connected devices (CIOP - Sonderborg)
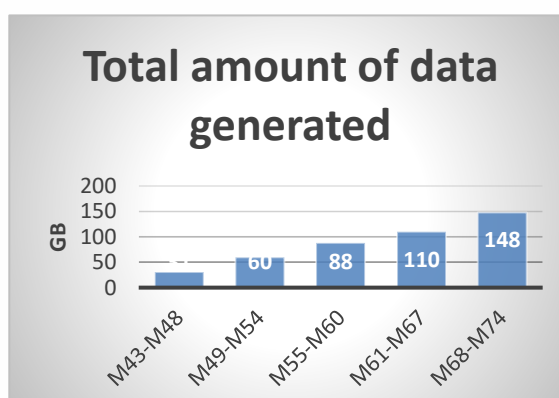
Figure 9 Total amount of data generated (CIOP - Sonderborg)

It is important to note that all the authentications are controlled by the Data Access Layer, which is in charge of securing the data and ensuring the GDPR compliance.

As aforementioned, such a comprehensive retrofitting project has environmental impacts and this is measured by a LCA, which in this case provides analysis of the environmental impacts in a life cycle perspective from the buildings in Sonderborg where SEC retrofitting-interventions have been implemented in comparison to the same buildings without SEC retrofitting-interventions implemented.

In general, the results show that the reduced energy consumption in the buildings' use phase as a result of the SEC retrofitting-interventions, has a more significant environmental impact in a life cycle perspective, than the extraction of raw materials, processing, transportation and end-of-life treatment of the materials for the SEC retrofitting-interventions (insulation, photovoltaics and batteries).

Thus, the LCA indicators show an increased environmental impact for maintenance including transport and end-of-life treatment for the Sonderborg buildings, but an overall decreased environmental impact from the Sonderborg buildings in a life cycle perspective (see Figure 10).
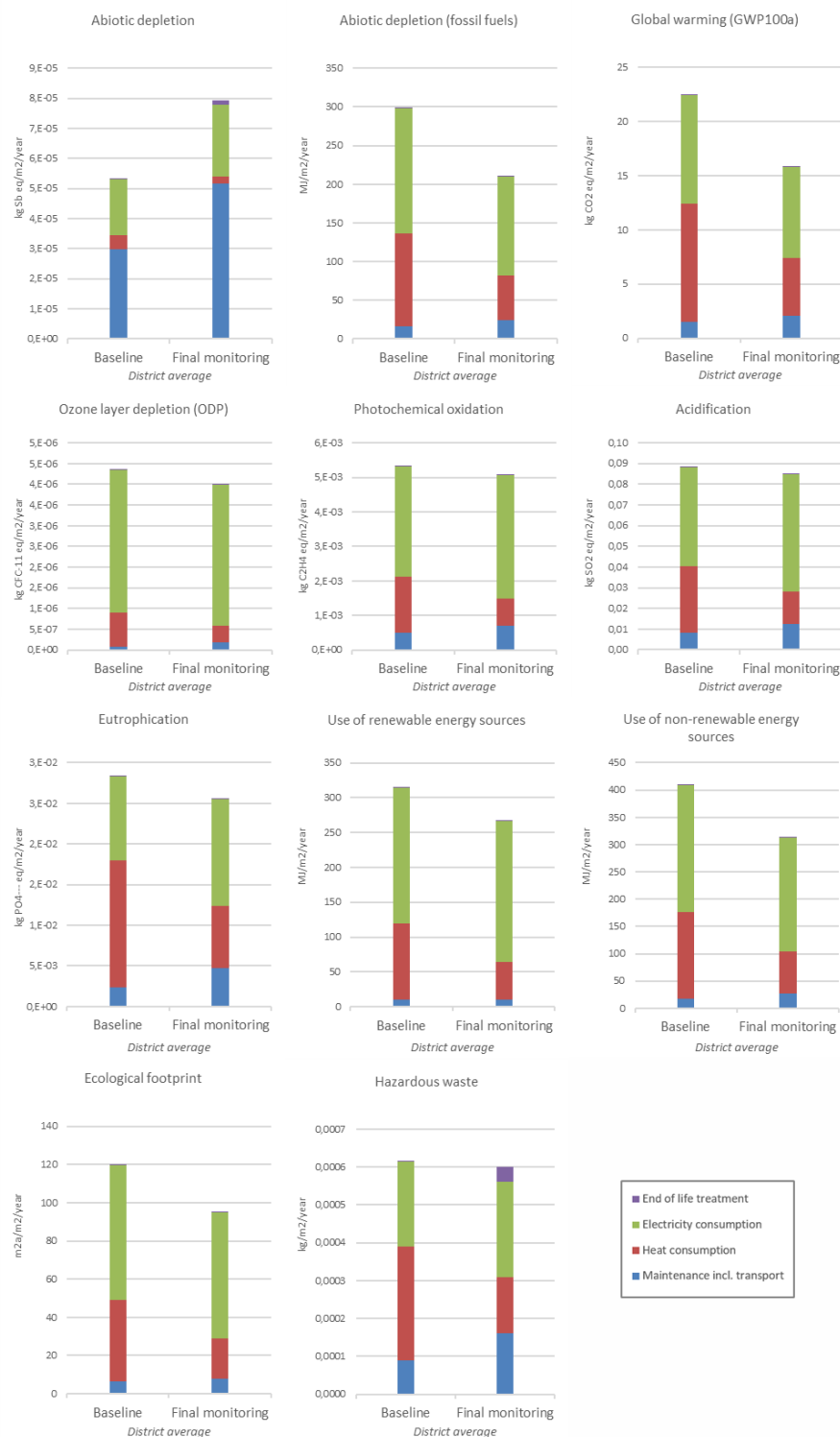
Figure 10 Comparison of indicators for baseline and final monitoring (Sonderborg)

Regarding SmartEnCity mobility actions in Sonderborg, both public transportation and e-mobility transition for private car users' actions have been carried out.

44 modern biogas-fuelled buses have replaced old diesel buses making public transportation a pleasant journey experience and allowing citizens to bring on board up to two bicycles for

modal-shift. COVID-19 have had a major impact on public transportation – still leaving the number of passengers down by almost 30% compared to post COVID-19 times.
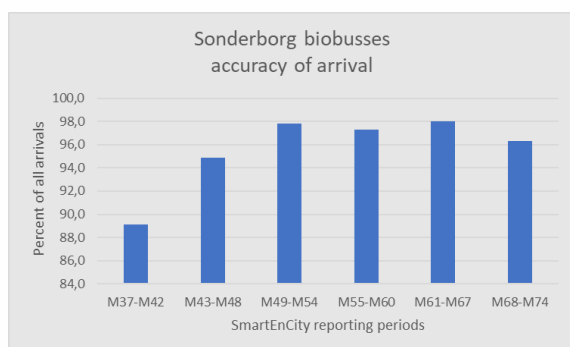
Figure 11 Sonderborg biobuses accuracy of arrival
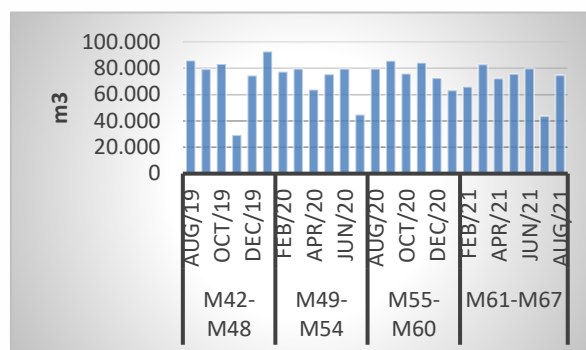
Figure 12 Biomethane consumption from 44 biogas buses in Sonderborg
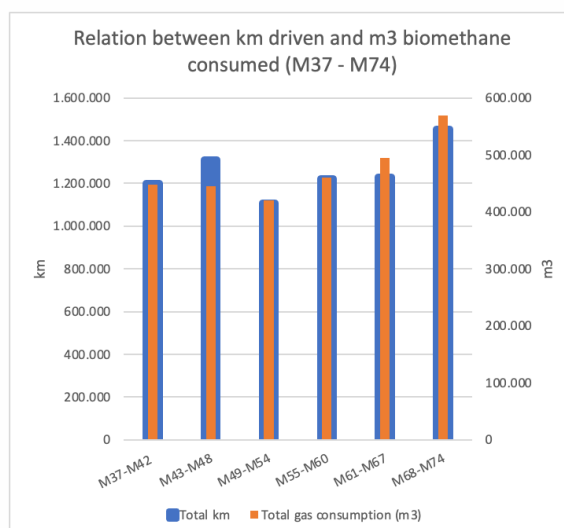
Figure 13 Relation between km driven and m^3 of biomethane consumed

The frequent measurement of accuracy shows that "accuracy of bus-arrivals" have increased and stabilized at a very high-level since the buses were implemented in June 2019 (see Figure 11).

As shown in Figure 12, consumption of biogas reported by the municipality are varying not only with (reported) km-driven, but indicate a minor stock-related mistake in the measurement of km or gas reported, which is currently being further investigated.

Figure 13 shows that there is overall a good correlation between the km-driven and the consumption of biogas. The average factor of gas-use per. km driven is 0.38 m^3 – very much in sync with the standard calculation for petrol-use in driving a passenger bus, which is 0.37 litres per km driven.

24 public chargers have been installed as part of the SmartEnCity project in public spaces supporting the growing interest for e-mobility. An additional six chargers we installed initially by the project, but failed due to technical reasons and were not replaced.

The 24 EoN EV-chargers are all installed in public places like central located parking spots in the city centre of Sonderborg, close to companies and close to cultural/sport facilities – testing the response/use from different society applications.
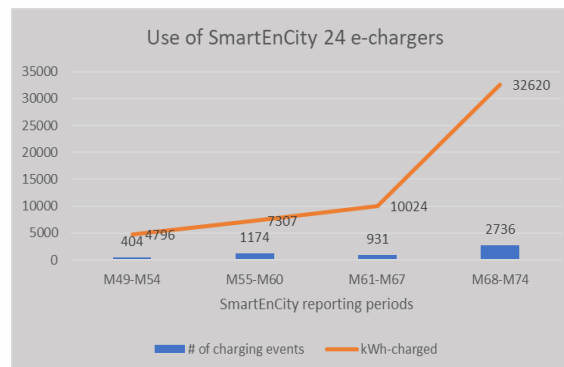
Figure 14 Use of the e-charger installed in the scope of the project (Sonderborg)

The use of the 24 installed EV-chargers have increased since their installation. As shown in Figure 14, the charged kWh-capacity have increased a lot in the last reporting period, signalling that the chargers have become important part of the EV-charging infrastructure.

During the same four reporting periods, the number of e-cars (BEV+PHEV) registered in Sonderborg have grown by a factor of 3.5 from 427 cars by M54 to 1,903 cars by M74. The SmartEnCity EV-chargers are however also used by tourists vising Sonderborg driving an e-car.

Daytime/night-time use has not been analysed, but will be as part of the next step EV-charging infrastructure analysis initiated by the municipal admin.

As the main conclusion concerning mobility aspects, the change of buses has been successful as technology, and is "ready" for scaling up. As for the 31 EV-chargers scheduled to be implemented as part of SmartEnCity, the "charging with the wind/sun" technology was not ready and simpler, but fully operational, EV-chargers had to be installed. The EV-chargers are now an important part of the fast growing Sonderborg e-car transition and infrastructure.

Two SmartEnCity surveys were implemented, focussing on social acceptance and citizen engagement. They targeted resident-families living in apartments of the SAB, SOBO & B42 housing associations involved in the energy retrofit program. The first survey (#1 on social acceptance) was carried out in June/July 2019, the second survey (#2 on citizen engagement) in May/June 2022.
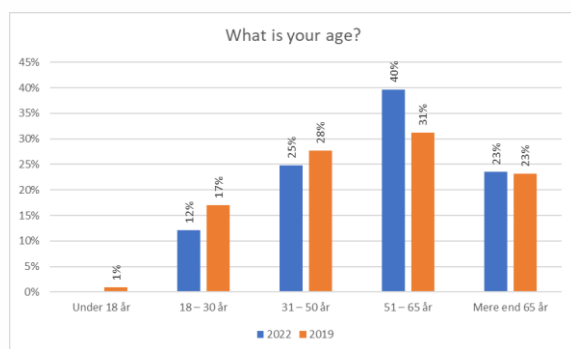
Figure 15 Sonderborg's social acceptance & citizens questionnaires. Information about age.
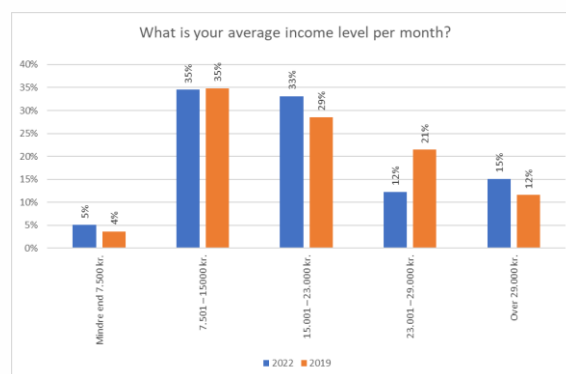
Figure 16 Sonderborg's social acceptance & citizens questionnaires. Information about income level.
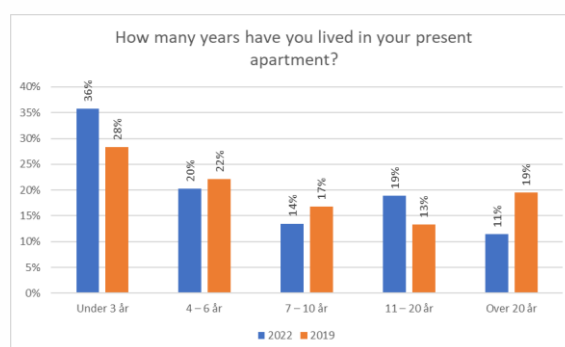
Figure 17 Sonderborg's social acceptance & citizens questionnaires. Information about home/apartment shifting.

The social acceptance survey was based on a paper-questionnaire (815 questionnaires were distributed by ProjectZero staff and 112 received, feedback percentage = 14%), while the citizen engagement survey was based on an electronic survey distributed to all email-named residents in the target-group (app. 1,200 questionnaires were distributed electronically by the three housing-administrations and 177 receive, feedback percentage = 15%). Demographic variables are "similar" for both surveys, reflecting that same population are contained in both surveys. However, both surveys show that approximately 30% of the respondents have moved-in within the last 3 years (see Figure 17).

The age-feedback received from both surveys are very similar, but reflect that majority of people living in house associations are "older people" (see Figure 15).

The feedback received, reflect that majority of people living in the house associations are low income people/families (see Figure 16). However, the feedback from both surveys are very similar.

The residents high-frequency of shifting home/apartment (in the two surveys) within 3 years is impacting the feedback received and the longer term "memory" of climate actions taken by the individual departments including the residents "remembered" engagement in the decision-making. The high frequency of change is confirmed as a general challenge by all three involved housing associations (SAB, SOBO, B42).

The additional survey-questions in section 5.3.5 focuses on knowledge about climate & environmental changes, and reflect potentially that what citizens considered common

knowledge in 2019, is now considered more complex and therefore the residents are more reluctant to score themselves high on knowledge.

The residents are surprisingly low in their evaluation of the impact on energy bill or comfort and seem not to remember the energy retrofit measures except for very visible initiatives like rooftop mounted PV-panels and battery storage (which were implemented in the last 14 – 16 months). Reasons might be that more than 36% of the respondents (see above) have lived in their apartments less than 4 years – and several deeper retrofit initiatives took place more than 3 years back.

Social acceptance is important for all climate action projects, especially for Sonderborg's ProjectZero. The aforementioned surveys confirm that all projects have been "accepted" by the residents and their 1,800 families involved in the SmartEnCity energy retrofit measures. However, the feedback received indicates that the social involvement bar is constantly changing as also the climate challenge; therefore, the house associations need to make social acceptance and citizen engagement of energy and climate measure their new DNA and constantly survey and integrate it into the strategies, goals and communication of the house associations.

The SmartEnCity advisory board (held in June 2022) reviewed and concluded the lessons learnt and the SAB housing association have already taken such more ambitious engagement first steps based on the learning from the SmartEnCity project. It is expected that more housing associations will follow this example.

It is important to notice that the feedback received at both surveys shows a surprising low level of resident involvement in the decision-making process (see Figure 18) which is further confirmed by additional survey questions.
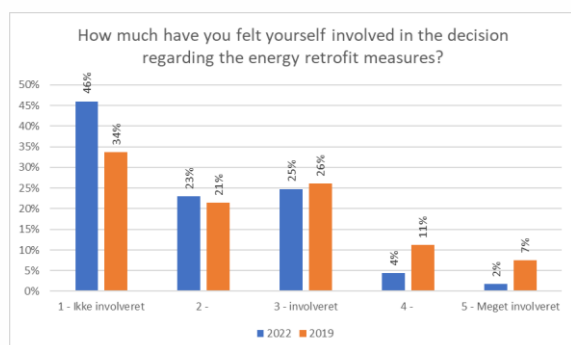
Figure 18 Sonderborg's citizen engagement survey – decision making involvement
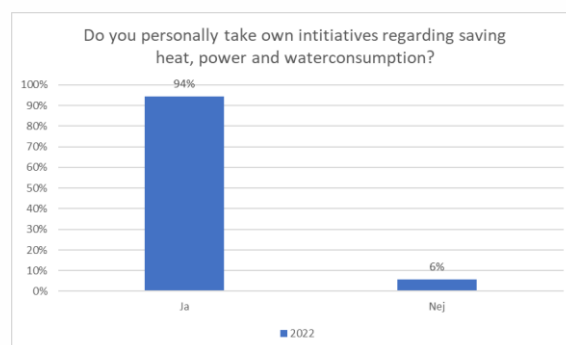
Figure 19 Sonderborg's citizen engagement survey – personal initiatives level

According to housing association decision making rules, a majority of residents showing up at the noticed/called annual meeting is able to decide based on a voting, meaning that the attending residents will decide and not the majority of the department-residents.

As energy-retrofit has been a low involvement issue for many residents, residents might choose to not-participate in the voting. Other residents might have experienced (from the past), that projects presented at the annual meetings are economically sound and viable, and do therefore expect the projects to be implemented. Thereby the residents become silent participants in the approval process.

The feedback shown in Figure 18 indicate that residents, even not taking active part in the formal decision making process (showing up at the annual residents meeting), the actually care and take own initiatives regarding saving heat, power and water (see Figure 19).

Figure 20 shows the residents ambition to continue the saving energy journey. The answer might potentially be positively influenced by increasing energy-prices.
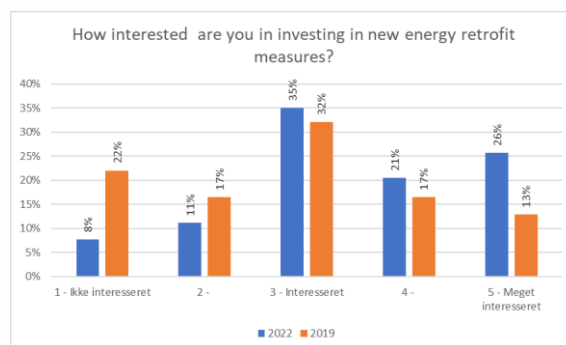
Figure 20 Sonderbog's citizen engagement survey – potential interest in new energy retrofit investments

As a conclusion regarding citizen engagement, it can be said that it is important for all climate action projects, specially for Sonderborg's ProjectZero. The implemented survey´s confirm that all the actions have been "accepted" by the residents and their 1,800 families involved in the SmartEnCity energy retrofit measures. As surprising is the lack of formal participation in decision meetings and thereby silent acceptance of made decisions, as surprising is the very positive feedback regarding residents own actions and wanting more. However, the feedback received indicates that the social involvement and citizen engagement bar is constantly changing as also the climate challenges; therefore, the house associations need to make social acceptance and citizen engagement of energy and climate measures their new DNA and constantly survey and integrate it into the strategies, goals and communication.

Focusing on economic performance, it is important to notice that the three housing associations have different economic performance due to the solutions implemented. A short summary on economic performance per housing association is provided below:

- SOBO: The investment costs are 61.8 Euro/m^2. This basically includes new windows, heating automatic and solar PV systems. The cost saving rate is 40 % primarily due to the reduction in electricity consumption by the solar PV systems.

- SAB: The investment costs are 26.3 Euro/m^2. This mainly includes solar PV and battery storage systems. The cost saving rate is 40 % primarily due to the reduction in electricity consumption by the solar PV systems.

- B42: The investment costs are relatively high (212 €/m^2), because they include long term energy retrofitting measures such as insulation of outer walls, new windows, new ventilation systems and fewer solar PV systems compared to SAB and SOBO. The cost saving rate is 23 %, lower than SAB and SOBO due to the longer-term investments.

The main results in relation to the city impact indicators are listed below:

- District renovation in 1st phase of the project: Retrofitting and PV panels installation on 51 buildings with 815 dwellings (= net 66 000 sqm) resulted in 2021 in 1570 MWh of energy savings (-25%) and 203 tCO2eq carbon reduction (-35%). Out of these total savings, 870 MWh are due to energy efficiency measures in buildings (district heating savings), and 700 MWh are due to solar PV panels installed in this 1st phase (electricity savings).

- Installed solarPV+battery systems in 86 buildings with 1639 dwellings in 2nd phase of the project resulted in 1410 MWh of electricity savings and 285 tCO2eq carbon reduction.

- In total, 12,720 sqm solar PV panels and in total 1,050 kWh battery capacity were implemented.

- In total, 2 980 MWh in energy savings and 485 tCO_2 emissions reduced annually due to the implemented energy saving measures. Out of those, 2110 MWh due to solar PV panels.

- 44 biogas buses and 24 EV-charging points (plus additional 6 points not functioning)

- 2 406 tCO_2 per year saved due to the replacement of diesel buses

- Accuracy of bus-arrival (within 5 minutes to schedule) is higher than 96% of all arrivals

- Citizens have participated in the climate transition journey; a majority have approved almost all the investment measures presented and citizens are actively implementing own initiatives and want more initiatives for the future.

- The total amount invested in smart city measures is EUR 23 million, including EUR 12,6 million in district renovation and PV/battery investments and EUR 10,4 in biogas buses and EV-charging points.

5 Specific results for the evaluation protocols and city impact indicators

Once given an overall description of the results obtained for the three LH cities, this section illustrates the specific results obtained on each LH following the protocols structure and KPIs defined for each one in D7.3 (with extended info on D7.9) and the city impact indicators as described in D7.4 for each LH.

5.1 Vitoria-Gasteiz
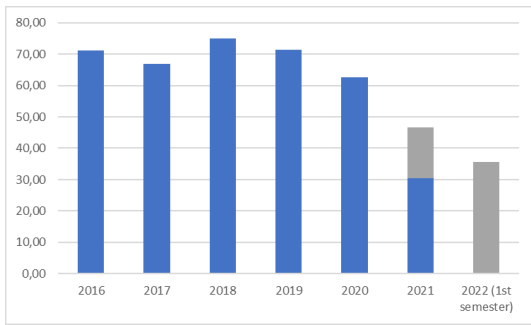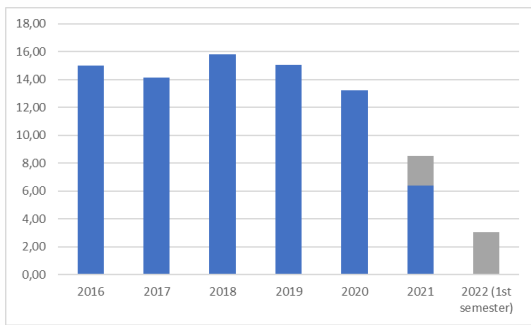
This section shows the results of the evaluation made for the actions in Vitoria-Gasteiz. The results are discussed across the different protocols described on deliverables D7.3 and 7.4, namely Energy Assessment, ICT, Life Cycle Analysis, Mobility, Social Acceptance, Citizen Engagement, Economic performance and City impact.

5.1.1 Energy Assessment Protocol

Table 5 below contains the different energy related KPIs calculated for Vitoria-Gasteiz actions based on the data gathered by many different partners. The KPIs related to comfort are afterwards explained in more detail to be better understood.

KPI	Value						
Delivered energy (for buildings) (kWh/m²year)[7]	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022 (1st sem.)**
	59.49	56.00	62.69	59.72	52.45	39.42	31.27

	(kWh) monthly values for the DH boilers			
Delivered energy (for energy supply units)		Gas	Biomass	Total
	Jul-21	26.630	7.964	34.594
	Aug-21	11.990	32.170	44.160
	Sep-21	3.700	27.630	31.330
	Oct-21	12.510	98.341	110.851
	Nov-21	5.970	211.782	217.752
	Dec-21	277.690	12.456	290.146
	Jan-22	227.690	73.801	301.491
	Feb-22	55.240	192.243	247.483
	Mar-22	21.250	204.878	226.128
	Apr-22	33.480	164.295	197.775
	May-22	15.430	107.570	123.000
	Jun-22	29.260	62.210	91.470

KPI	2016	2017	2018	2019	2020	2021	2022 (1st sem.)
Primary energy – Gas carrier (for buildings) (kWh/m²year)	71.09	66.92	74.91	71.37	62.68	30.40	----

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[7] For the calculation of values per m², the total area considered for Coronation district is 22070,12 m², corresponding to the sum of the conditioned built area of the dwellings without including the thickness of the existing interior walls.

KPI	Value						
Primary energy – Biomass carrier (for buildings) (kWh/m²year)	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022 (1st sem.)**
	----	----	----	----	----	16.21	35.68
	Values bearing in mind the percentage of biomass/gas used on the DH boilers						
Primary energy - total (for buildings) (kWh/m²year)	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022 (1st sem.)**
	71.09	66.92	74.91	71.37	62.68	46.61	35.68
CO2 equivalent – Gas carrier (for buildings) (kgCO2/m²year)	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022 (1st sem.)**
	14.99	14.11	15.80	15.05	13.22	6.41	----
CO2 equivalent – Biomass carrier (for buildings) (kgCO2/m²year)	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022 (1st sem.)**
	----	----	----	----	----	2.11	3.07
	Values bearing in mind the percentage of biomass/gas used on the DH boilers						
CO2 equivalent – total (for buildings) (kgCO2/m²year)	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022 (1st sem.)**
	14.99	14.11	15.80	15.05	13.22	8.52	3.07
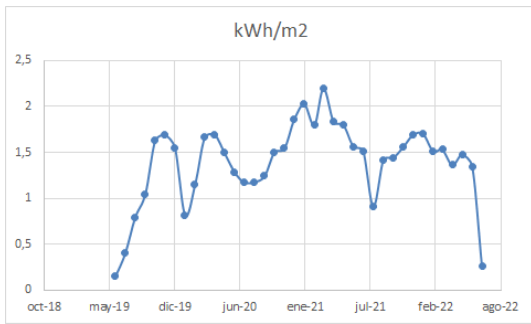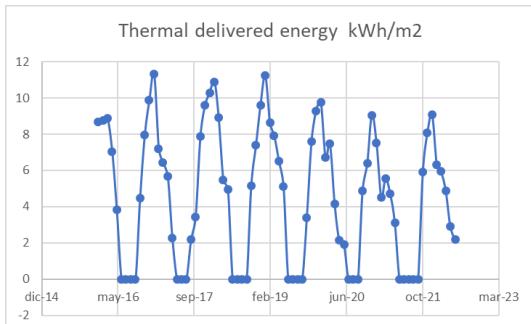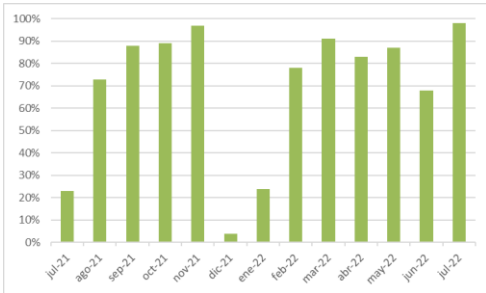
KPI	Value
Peak load and load profile of electricity demand	The peak load for electrical energy carrier is 2.20 kWh/m^2 corresponding to March 2021 *kWh/m2*
Peak load and load profile of thermal (heating/cooling) energy demand	The peak load of thermal (heating/cooling) energy carriers is 11.04 kWh/m^2, corresponding to January'2017 *Thermal delivered energy kWh/m2*
Degree of energetic self-supply	69% on average (see KPI "Share of renewable energy" below) Considered here the biomass percentage, from the moment the DH is working on.
Share of renewable energy	This indicator is applicable once the DH network is working. Average value of 69% taking all values into account. Filtering the months with works on the DH chimney we obtain 85% which could be more accurate at long term. This indicator is applicable once the DH network is working.

Table 5. Energy protocol KPIs for Vitoria-Gasteiz

It is important to notice that, as gas consumption values where available yearly, a calculation based on HDD has been done in order to estimate monthly gas consumption values.

Besides, it is worth mentioning that there are years with just gas carrier (2016-2020), one year with both gas and biomass (2021: Jan-May with gas, and Jun/Dec with biomass), and

one semester (1st semester of 2022) just with biomass. Considering this issue, and with regard to the two first graphs included on Table 5, the blue part of the bars is related to gas, and the grey one is devoted to biomass. Mention also that the renovation activities on the buildings have been carried out in stages starting the initial phase in July 2018 and finishing the last one by June 2021.

Comfort indicators evaluation

This part of the section presents Comfort KPI objectives, calculations, results and their evaluation in the form of conclusions.

Objectives: In relation to comfort, the project objectives are:

- Calculate the comfort of each dwelling according to a standard using the input measurements obtained from sensors.
- Compare between buildings with isolation and those without, or the same building before and after isolation.
- Find statistical justifications for comfort improvement in buildings with isolation (lower deviation of measurements, comfort improvement).

Indicators and calculation: To achieve those objectives, the following indicators were identified in previous deliverables:

Internal air temperature: This parameter is directly involved in the determination of internal comfort condition, but it also allows to investigate (with another parameter as the heat quantity for set point achievement) how much energy is necessary to reach a particular desired condition known as set point. Use both this parameter (before and after an Energy Conservation Measure (ECM) considering the same set point condition) allows to know how much heating energy has been saved thanks to the ECM's interventions.

In this project this indicator has been calculated from the measurements given by the sensors installed in the dwellings. It is measured in ºC. We calculate the temperature in each building every hour. This value is the average temperature in all the dwellings in that building. We also calculate the standard deviation of those values. These indicators are presented in the KPI application available at https://vitoria-gasteiz.smartencity.eu/kpiservice/.

Internal humidity: This parameter is directly involved in the determination of internal comfort condition. In this project this indicator has been calculated from the measurements given by the sensors installed in the dwellings. It is measured in %. We calculate the humidity in each building every hour. This value is the average humidity in all the dwellings in that building. We also calculate the standard deviation of those values. Those indicators are presented in the KPI application available at https://vitoria-gasteiz.smartencity.eu/kpiservice/.

Heat quantity for set point achievement: This parameter allows to collect information about the quantity of energy that is needed to reach a particular temperature condition known as set point. Using this data before and after an ECM (considering the same set point condition) allows to know how much heating energy has been saved thanks to the ECM's interventions. There are no means to calculate this indicator since the setpoint inside the dwellings is not collected by our sensors and devices.

Thermal comfort: This indicator represents the level of thermal comfort measured as the number of hours that the indoor temperature and relative humidity conditions are within

range of values defined. The range of comfort values varies with the seasons, inhabitants (as it depends on the metabolic rate and clothing of the building users) and the climatology of each city (average monthly temperatures (max & min) and average monthly relative humidity).

To evaluate this indicator, we have used the calculations proposed by the standard ASHRAE 55[8]. The official website of ASHRAE 55 states that the standard "specifies conditions for acceptable thermal environments and is intended for use in design, operation, and commissioning of buildings and other occupied spaces". ASHRAE 55 defines thermal comfort as "that condition of mind that expresses satisfaction with the thermal environment" and is used primarily in the USA but is well known around the world as the standard for designing, commissioning and testing indoor spaces. This standard does not take into consideration factors including air quality, acoustics, illumination, or contamination. The thermal conditions that ASHRAE aims to achieve are applicable to healthy adult occupants, up to an altitude of 3K meters, where occupancy time must surpass 15 minutes.

The algorithm used by the ASHRAE standard considers the following environmental and personal factors as input parameters:

- **Temperature**: The temperature measured inside the building. For our calculations we have used the temperature collected by the sensors in the dwellings.
- **Humidity**: The humidity measured inside the building. For our calculations we have used the humidity collected by the sensors in the dwellings.
- **Airspeed**: The rate of air movement at a given point in time regardless of the direction. For all our calculations we have used a fixed value 0.1m/s
- **Clothing**: The unit used to represent the thermal insulation from clothing, where 1clo = winter clothing and 0.5 clo = summer clothing. For our calculations we have used a fixed value of 0.6 clo = winter and 0.5 clo = summer.
- **Metabolic Rate**: The rate of transformation of chemical energy into heat and mechanical work by metabolic activities within an organism, usually expressed in terms of unit area of the total body surface. In this standard, the metabolic rate is expressed in met units. This unit is accounted for as the personal activity of occupants, where 1 met is a person at rest. For our calculations we have used a fixed value of 1 met.
- **Mean Radiant Temperature** (tr): The uniform surface temperature of an enclosure where an occupant would exchange the same amount of heat as in the actual non-uniform space, calculated from the weighted temperature average of each surface divided by the total area of the space

The indicators obtained from the ASHRAE calculations are the following:

- **Predicted Mean Vote (PMV)**: An index that predicts the mean value of votes of a group of occupants on a seven-point thermal sensation scale that is based on the balance of heat within the human body. This balance, much like thermal neutrality, is obtained when an occupant's internal heat production is the same as its heat loss. The PMV scale is shown in Figure 21.

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[8] [Ashrae, 2021] Ashrae (2021). STANDARD 55 – THERMAL ENVIRONMENTAL CONDITIONS FOR HUMAN OCCUPANCY. ://www.ashrae.org/technicalresources/bookstore/standard-55-thermal-environmental-conditions-for-human-occupancy.

- **Predicted Percentage of Dissatisfied (PPD)**: An index that establishes a quantitative prediction of the percentage of thermally dissatisfied occupants (i.e., too warm or too cold). The PPD is calculated from the PMV, as it can be found from the distribution of individual thermal sensation votes compiled collectively. It indicates the percentage of people in discomfort considering a given PMV.

Thermal sensation	vote
+3	Hot
+2	Warm
+1	Slightly warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold

Figure 21: PMV Scale

These indicators along with their standard deviation are presented in the KPI application available at https://vitoria-gasteiz.smartencity.eu/kpiservice/.

Results: The results obtained for each indicator are the following:

Internal air Temperature Results: Figure 22 and Figure 23 present the mean internal air temperature in the district and the buildings. The values for all the buildings with sensors in at least one dwelling are shown in the figures. Data from each building started to be collected at a different time (when equipment was installed). Consequently years 2019 and 2020 present average values only considering few dwellings. The graph shows mean values calculated every hour from the dwellings in each building. As can be seen in the plot values range between 17 and 24 after year 2020 when a considerable amount of dwellings started providing data. These values fall close to the ideal temperature for a home (according to Endesa[9] between 20 and 21ºC during the day, and between 15 and 17ºC at night). The standard deviation from all the values used in the average calculation (every hour) has been also calculated.

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[9] https://www.endesa.com/en/blogs/endesa-s-blog/air-conditioning/home-recommended-temperature
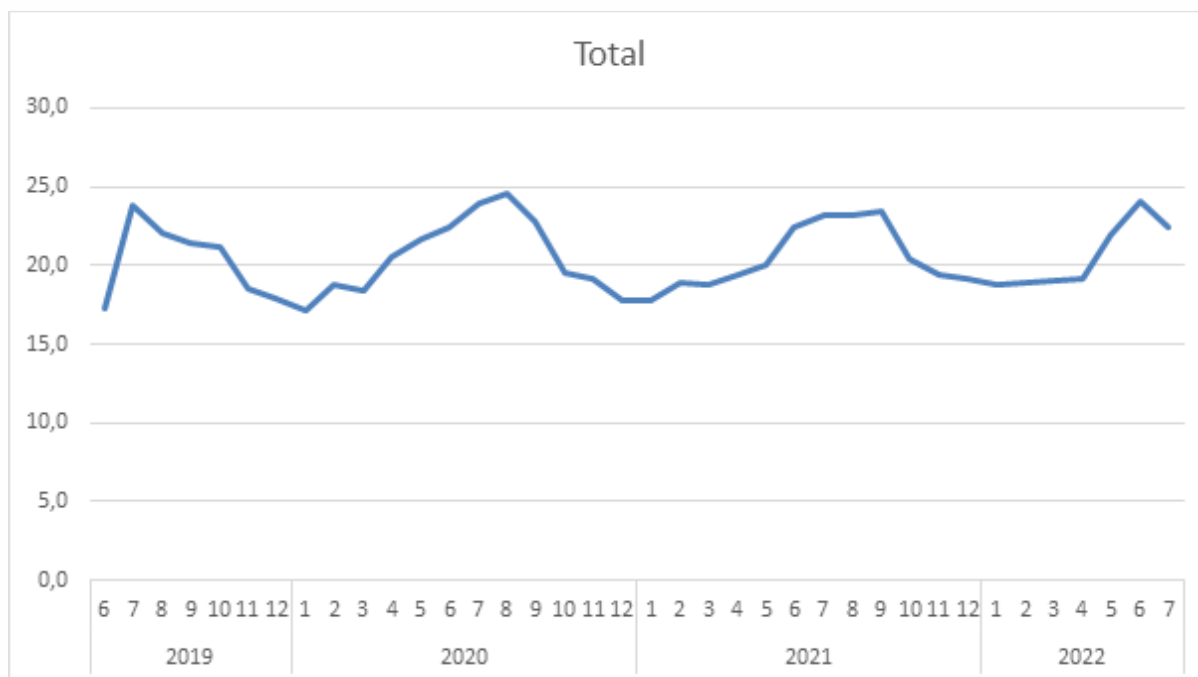
Figure 22: Mean Internal Air Temperature [ºC] (District)
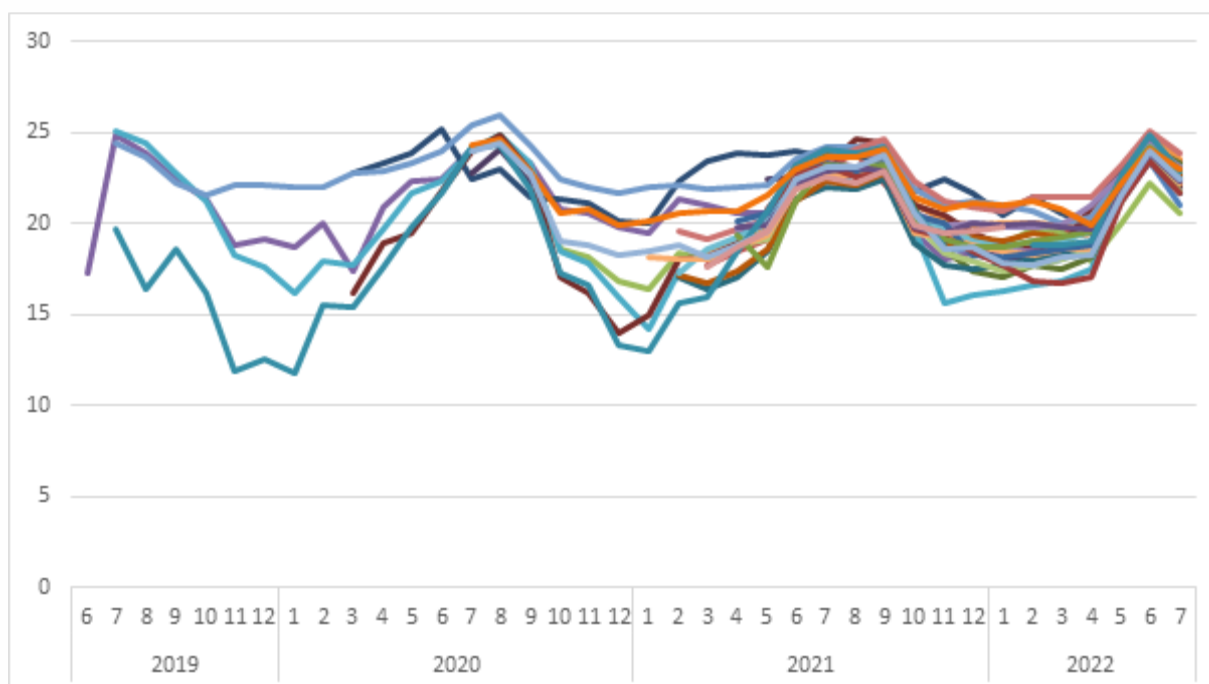
Figure 23: Mean Internal Air Temperature [ºC] (Building)

Figure 24 presents the mean internal air temperature for one of the buildings during 2 days. The standard deviation of the temperatures used for the calculations is added to the graph. With this representation we present the capacity of determine the temperature ranges in buildings. The calculations are done considering all the dwellings in that building. It is worth mentioning that the conditions in those dwellings (ventilation, number of inhabitants, setpoints …) might be different. In addition, we have created 2 applications: one for the residents to monitor the comfort conditions inside their home and another for the ESCOs to monitor dwelling and building comfort conditions. Details on these applications is presented

in Deliverable 3.8 or can be accessed by the web portal at https://vitoria-gasteiz.smartencity.eu/#/.

Internal Air Temp Avg and stddev (2 days)
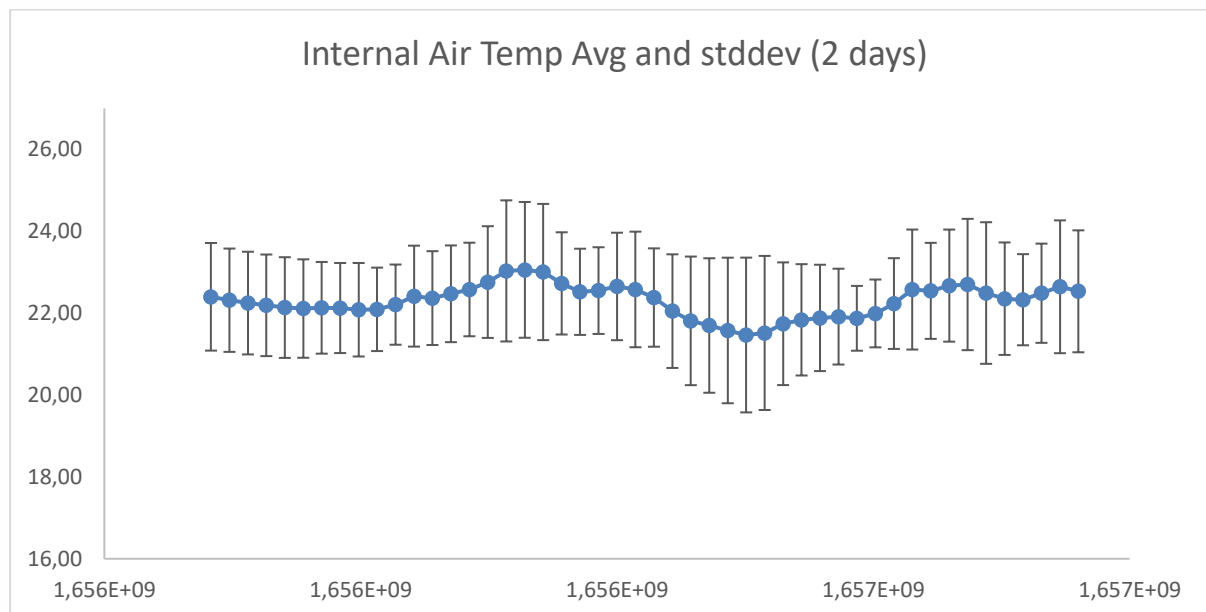
Figure 24: Internal Air Temperature [ºC] (Scatter Plot Graph)

Internal Humidity Results: Figure 25 and Figure 26 present the mean internal humidity in the district and each building calculated from sensor data computed every hour. The values for all the buildings with sensors in at least one dwelling are shown in the figures. As for the previous case data starts to be consistent from 2021 onwards (more dwellings in more buildings monitored). Data from each building started to be collected at a different time (when equipment was installed). The graph shows mean values calculated from sensor information computed every hour from the dwellings in each building. As can be seen in the plot values range between 40 and 70 which falls close to the ideal humidity for a home (according to Endesa[10] and IDEA[11] a relative humidity level of 40-60%). The standard deviation from all the values used in the average calculation has been also calculated.

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[10] https://www.endesa.com/en/blogs/endesa-s-blog/air-conditioning/home-recommended-temperature
[11] https://www.idae.es/en/node/283
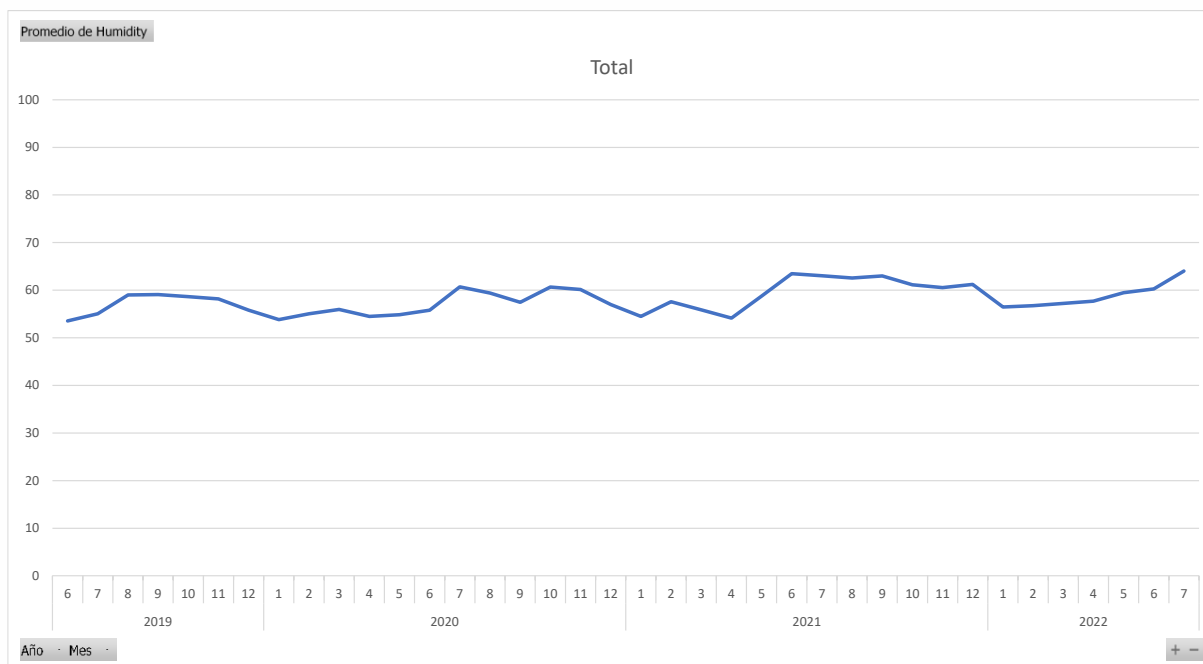
Figure 25: Mean Internal Humidity [%] (District)
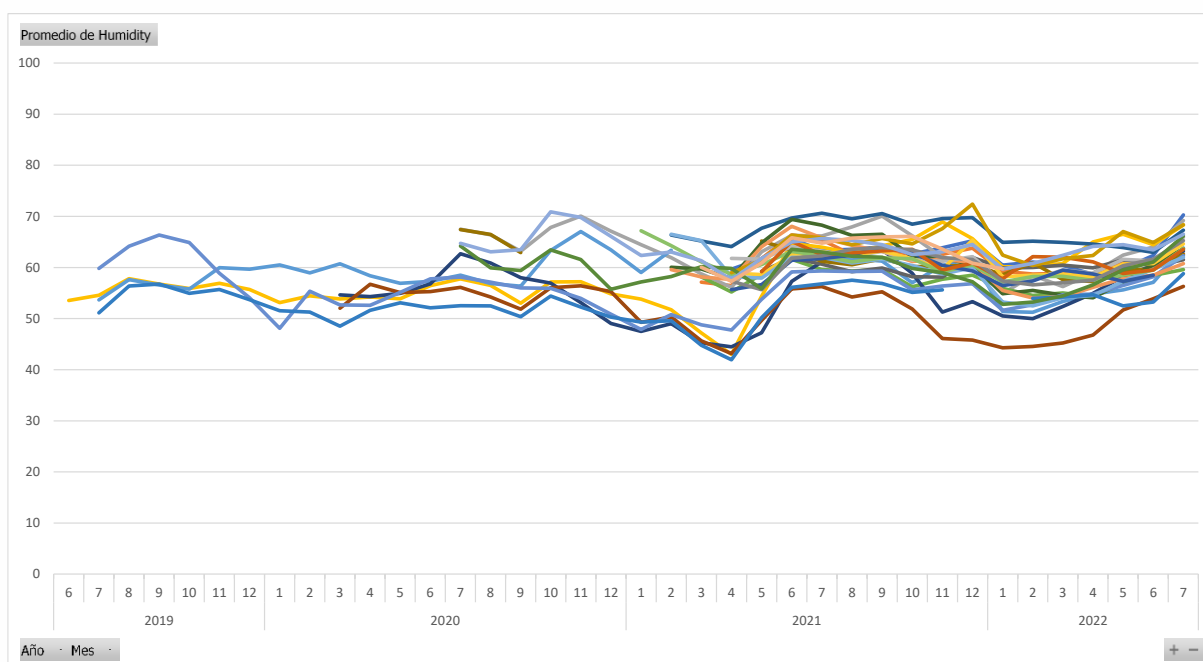
Figure 26: Mean Internal Humidity [%] (Buildings)

Figure 27 presents the mean internal humidity for one of the buildings calculated during 2 days. The standard deviation of the humidity used for the calculations is added to the graph. With this representation we present the capacity of determining the humidity ranges in buildings. The calculations are done considering all the dwellings in that building. It is worth mentioning that the conditions in those dwellings (ventilation, number of inhabitants, setpoints …) might be different. As for the previous case there are applications to support stakeholders with this indicator. Those applications are presented in Deliverable 3.8 or can be accessed by the web portal at https://vitoria-gasteiz.smartencity.eu/#/.
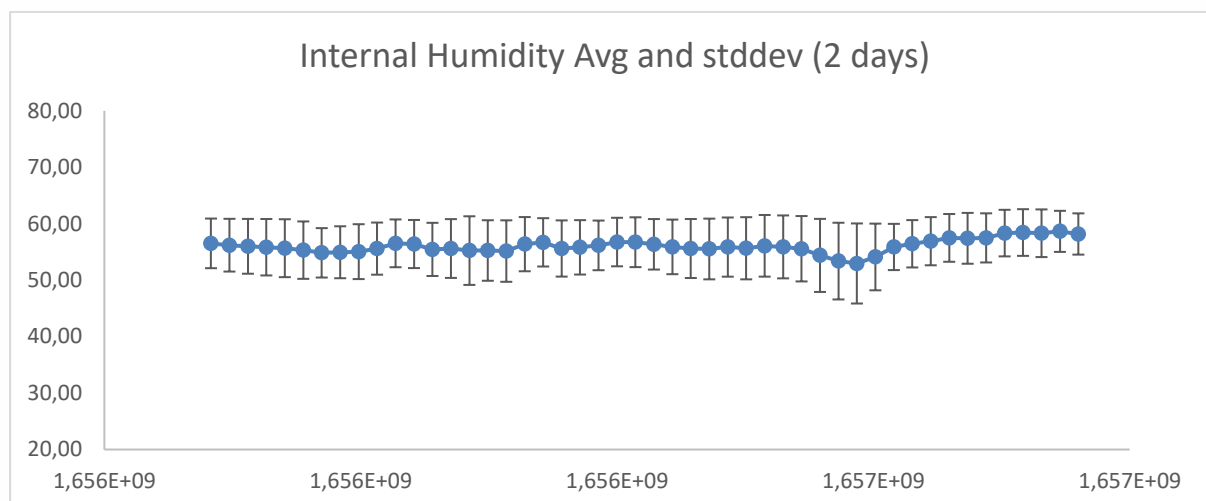
Figure 27: Internal Humidity [%] (Scatter Plot Graph)

Thermal Comfort Results: Figure 28 and Figure 29 present the average PMV in the district and in the buildings calculated from data collected every hour. The values for all the buildings with sensors in at least one dwelling are shown in the figure. Data from each building started to be collected at a different time (when equipment was installed). This has an impact in the calculations as in the previous cases. The graph shows mean values calculated every hour from the dwellings in each building after applying the ASHRAE 55 algorithm for each calculation within the hour. As can be seen in the plot values range between 0 to -1.5 for most buildings which falls within the slightly cold range identified in ASHRAE. Additionally, we have calculated the average PPD values. The standard deviation from all the values used in the average calculation has been also calculated.
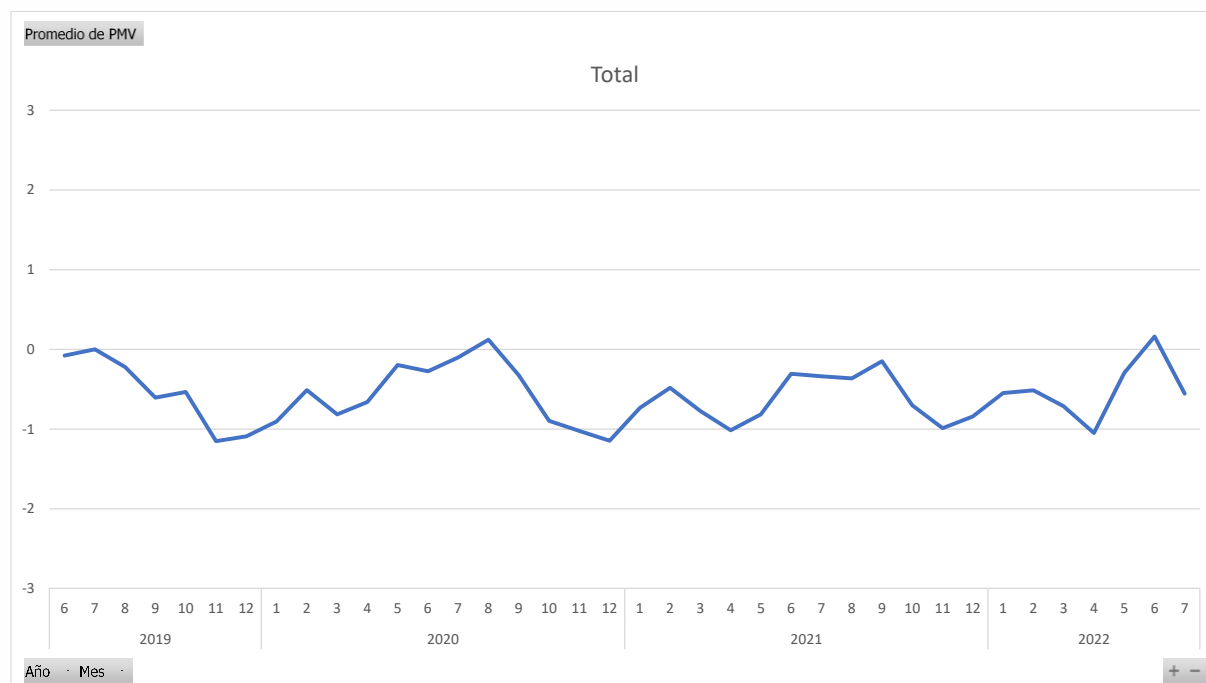
Figure 28: Mean PMV (District)
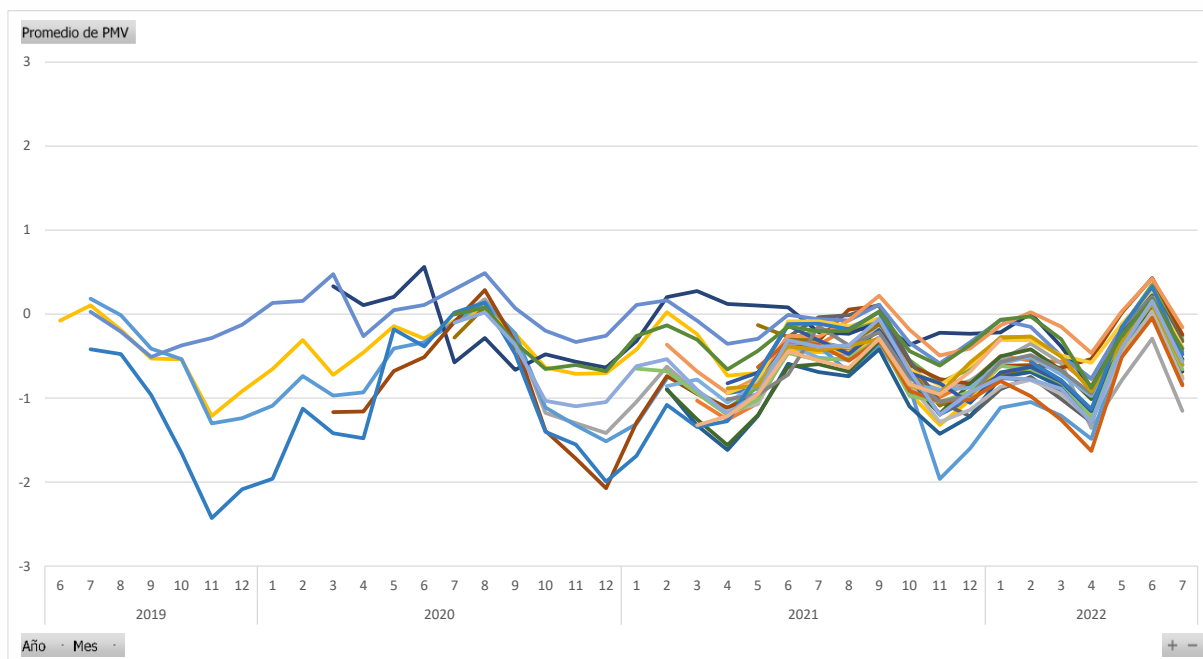
Figure 29: Mean PMV (Buildings)

Figure 30 presents the mean PMV for one of the buildings for 2 days. The standard deviation of the PMV used for the calculations is added to the graph. With this representation we present the capacity of determining the PMV ranges in buildings. The calculations are done considering all the dwellings in that building. It is worth mentioning that the conditions in those dwellings (ventilation, number of inhabitants, setpoints …) might be different. As for the previous case there are applications to support stakeholders with this indicator. Those applications are presented in Deliverable 3.8 or can be accessed by the web portal at https://vitoria-gasteiz.smartencity.eu/#/.
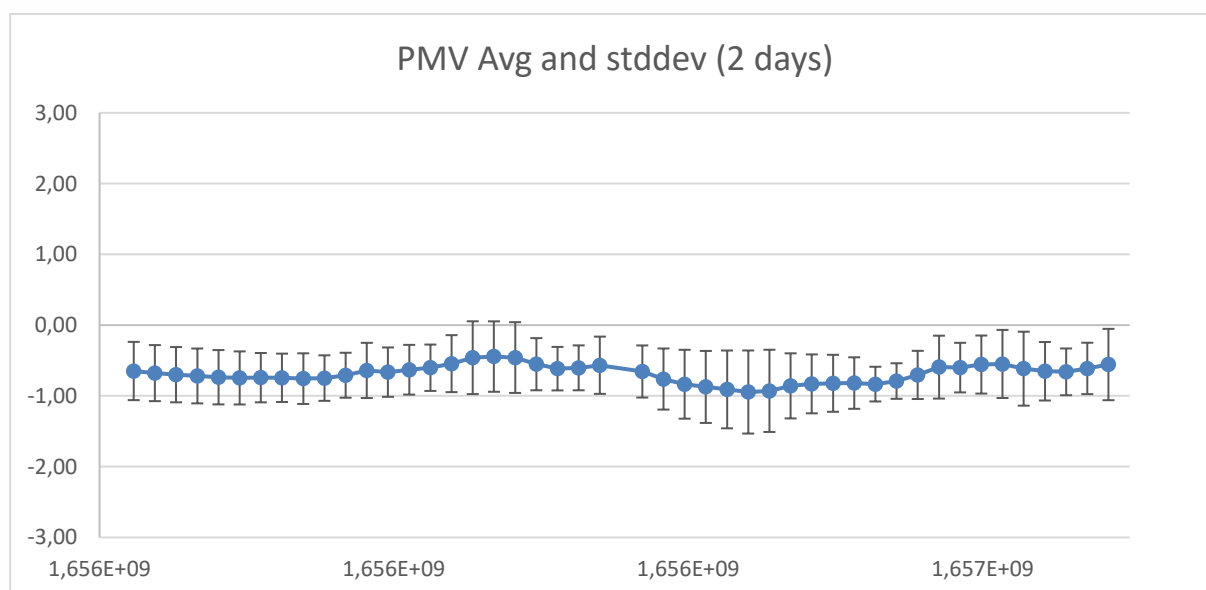
Figure 30: PMV (Scatter Plot Graph)
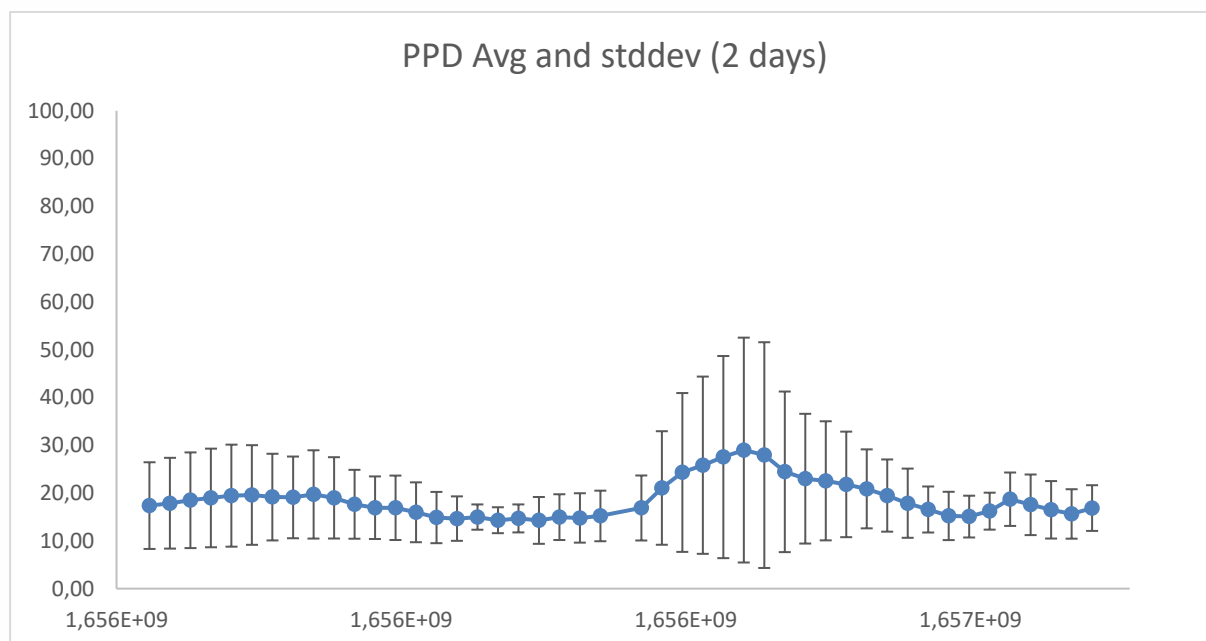
Figure 31: PPD (Scatter Plot Graph)

In addition to the statistical calculations, we conducted two experiments to compare comfort before and after isolation of buildings. It is worth mentioning that the amount of data available before façade renovation is scarce. These experiments were oriented to a preliminary analysis since they lacked statistical value. For the test results to have mathematical significance the extracts without isolation and with isolation should be given the same human factors (# of inhabitants, heating and ventilation), since the buildings were located within a kilometre of each other and we assumed that the climate was identical.

In the first experiment, we compared ASHRAE comfort, temperature and humidity data for a building before and after isolation. For this purpose, we selected two buildings for which we have data available. The following steps were carried out for this study:

- Extract from the dataset the columns needed for the test (temperature, humidity, comfort, building id, day of the year).
- Group the data into two different groups. Before isolation and after isolation.
- Calculate the mean, median and standard deviation of temperature, humidity and comfort for each of the groups.
- Compare the results of the two groups.

The results obtained are shown in Figure 32:

	Before Isolation	After Isolation
Temp mean	21.7	18,34
Temp std	3	0,9
Hum mean	64.44	60
Hum std	6.76	5,25
Comfort mean	-0,53	-0,94
Comfort std	0,62	0,39

Figure 32: Before and after Isolation Comparison (same building)

These results lack statistical accuracy because first, the amount of data before and after isolation is not the same, the weather conditions are not the same in the two samples and we lack relevant information such as the use of heating and ventilation.

In a second experiment, we compared ASHRAE comfort, temperature and humidity data for a group of buildings before and after isolation. For this experiment we followed the same philosophy as for the previous experiment. In this case we created two groups of isolated houses and others that were not isolated at that time. We conducted the following steps:

- Extract from the dataset the columns needed for the test (temperature, humidity, comfort, building_id, dayoftheyear).
- Filter the data for a given period.
- Group the data into two different groups. Group of buildings with and with no isolation.
- Calculate the mean, median and standard deviation of temperature, humidity and ASHRAE comfort for each of the groups.
- Compare the results of the two groups.

We can see the results obtained in Figure 33

	Isolation	No Isolation
Temp mean	18,41	18
Temp std	2,14	2,09
Hum mean	64	58
Hum std	8,63	9,85
Comfort mean	-0,86	-1,09
Comfort std	0,54	0,57

Figure 33: Before and after Isolation Comparison (groups of buildings)

In these results humidity is higher in those houses with isolation, which is an expected behaviour. Houses with isolation tend to have higher humidity values and need more ventilation. On the other hand, we see an improvement in comfort values, being the houses with isolation between slightly cold and neutral values, while those without isolation are directly in the cold range. However, as in the first experiment, these results lack statistical background for the reasons already stated; lack of information on the indoor conditions of the houses (occupancy, heating and ventilation). In this case, since we compared the same dates in the two groups and given that these houses were located within a perimeter of less than 1 km, we can say that the meteorological conditions were identical for all the blocks.

Conclusions:

Considering the first comfort objective defined in this section ("Calculate the comfort of each dwelling according to a standard using the input measurements obtained from sensors"), we have calculated indicators according to the ASHRAE standard. This standard classifies values at different comfort levels supported by the surveys on resident satisfaction behind the study. The calculations have been performed for all dwellings where sensor data was available obtaining this way a normalized comfort criterion.

All these calculations and indicators have been included in three tools for the stakeholders in the project:

Monitoring of energy consumption and home comfort[12]: Application that monitors energy consumption and comfort conditions in the home from sensors installed in the home (see Figure 34). The main objective is to empower residents in the knowledge of comfort conditions and energy consumption.

ESCO Comfort Tool[13]: Tool for monitoring comfort conditions in buildings to support energy service companies. Building comfort information is presented on dashboards that allow energy service companies to monitor comfort, know the impact of energy saving and retrofit measures or identify anomalous situations. Figure 35 shows the comfort information provided for one building including the average PMV and PPD.

KPI Evaluation tool KPI Evaluation tool[14]: Dashboard for decision-making support and visualization of the KPIs (Key Performance Indicators) defined in SmartEnCity in order to evaluate the performance of the project interventions.
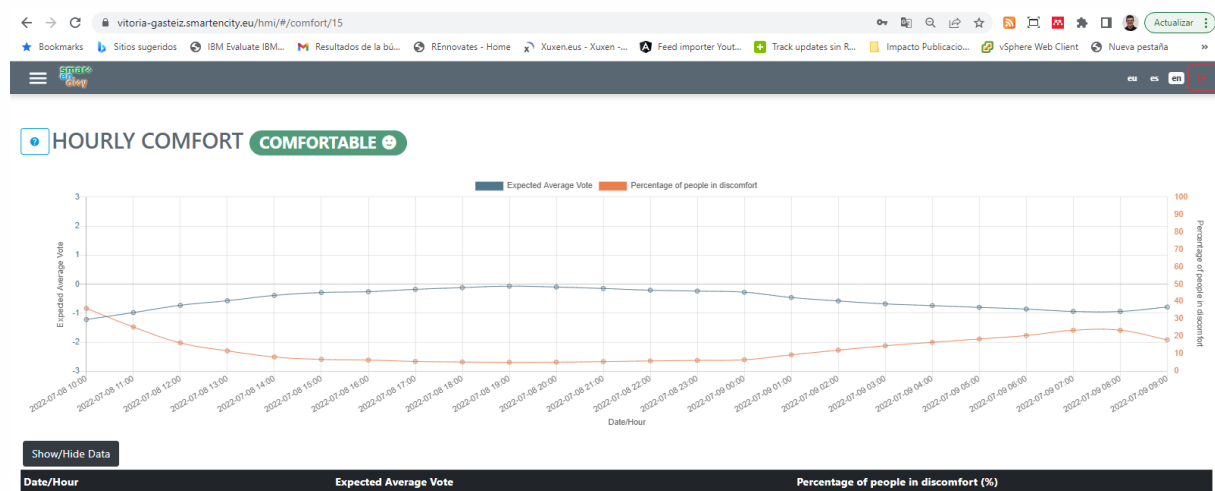
Figure 34: Monitoring of Energy and Comfort Home

Figure 35: ESCO Comfort Tool (ASHRAE information building)

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[12] https://vitoria-gasteiz.smartencity.eu/hmi
[13] https://vitoria-gasteiz.smartencity.eu/grafana
[14] https://vitoria-gasteiz.smartencity.eu/kpiservice/

The statistical calculations from the different indicators have been performed at district and building level. The mean calculations per groups distorts the specific conditions of the dwellings but overall, those comfort conditions seem to be good. It is important to observe that conditions inside the dwellings vary. Some dwellings might be empty, in others the number of inhabitants can be large and other conditions such as ventilation, heating devices or setpoints might be different. Consequently, determining a general state of comfort for the district from the statistical calculations is daring. The web applications developed in the project allow a personalised monitoring of each of the dwellings.

Another objective was to compare the impact of isolation on the comfort data of the houses. Throughout the different experiments that we conducted; it has been proved that we have not been able to demonstrate statistically this improvement in comfort thanks to the isolation of the facades. This is due to several factors that we have deduced from our experiments, which are the following:

- The amount of data collected previous to the interventions is not sufficient for an effective analysis. With the exception of few cases, there is no comfort monitoring data available prior to isolation, so it is not possible to make a comparison of the improvement of the comfort status in those blocks. We could try to make a comparison between different blocks, but to do so we would have to ensure that most of the characteristics shared by these houses were identical.
- Key information is missing to analyse the status of specific houses. This refers to information such as occupancy, heating, ventilation and air conditioning. Factors that clearly impact on the temperature and humidity measurements and therefore the comfort itself.

To make a comparison of two different moments and to be able to draw true conclusions about the results, it would be necessary to compare two moments of the same house, being the human factors and meteorological conditions identical. This is impossible for all the reasons we have identified above. To get relevant data from these experiments we would need data from before and after the isolation of meteorologically identical days and same human factors inside the houses.

5.1.2 ICT Protocol

The main objective of the ICT protocol is to evaluate the final deployed ICT tools in the cities. Thus, a common evaluation framework based on indicators was set up in D7.3 (SmartEnCity evaluation protocols) in order to evaluate the effectiveness of the aforementioned ICT tools.

ICT tools are the main enablers for the cities, as well as one of the main contributors to urban transformation. In this case, the main objective concerning ICT tools in the scope of the SmartEnCity project is the improvement of the existing urban platforms.

It is important to notice that, in the case of Vitoria-Gasteiz, there were no ICT systems in place directly linked to the ICT interventions specified in the project apart from the CIOP. The main interventions in this city are related to energy efficiency, mobility and citizen engagement. Taking into account the previous information, understandably there is no place for an initial measurement of a baseline for the city in ICT terms (see D7.3 for more information). As a result, the focus now is to measure the results of the ICT interventions in the neighbourhood through the new developments under SmartENCity, focusing on the CIOP.

As explained in D3.10, the CIOP Portal and different Added Value Services have been developed and deployed.

First of all, the CIOP landing application and access page is a web application who acts as the landing page for the CIOP portal. It provides general information about the project, and connects with the different utilities that the portal offers.

The different added value services which are accessible through the aforementioned web application are the following ones:

- Home monitoring APP, which provides information about consumption and comfort conditions in each dwelling, empowering residents in the knowledge of comfort conditions and energy consumption.
- Installation and management support tools: On the one hand, this tool enables data commissioning for installations showing the status of each installation and its sensors and assuring that data is being acquired. On the other hand, it provides alarms for malfunctioning devices.
- Data analysis of comfort conditions for ESCO support app, which comprises tools for monitoring conditions in buildings to support energy services companies.
- Local news channel (TV), which is a portal offering a local news channel based on RSS from websites about Vitoria that can be consumed through building infrastructure (TV).
- Municipal buildings energy usage monitoring: This application provides information on the different municipal consumption on the city, including municipal buildings or facilities, water used in parks and gardens, public lighting and mobility of vehicles used by the city council.
- Intelligent Electric Bus – BEI – Monitoring, which provides KPIs and the positioning of the electric buses in Vitoria-Gasteiz.
- KPI evaluation tool: This is an application devoted to the calculation, storage and visualization of KPIs (not for all the pillars, where external calculations are used (e.g. comfort). The main objective of this tool is to provide a dashboard for decision-making and self-assessment of the interventions carried out in the city of Vitoria-Gasteiz (in the Coronación district).
- Thermal energy demand prediction tool for energy planning, whose main aim is to provide an energy demand forecasting at multiple time spans in order to plan the energy generation and distribution according to this expected demand.
- GIS3D Viewer for KPI visualization, to see different parameters at building scale using a GIS3D viewer.

In order to evaluate the aforementioned ICT tools, an online questionnaire has been distributed among the partners in charge of these developments, and, then, the different KPIs (stated in D7.3) have been calculated. For most of the indicators, the value of the KPI has been directly asked in the questionnaire, so the final calculation of the KPIs has been just an average of the values received for the different ICT services to be assessed.

First of all, Table 6 contains the calculations for the indicators related to the development, integration and deployment of the CIOP landing application and the different added value services explained before.

KPI	Description	Measure	Average value[15]	Min	Max
Response time	Measure the time the requests take to provide the information to the user (citizen or other system). Data may be taken from database engine or framework	time	8.6	0.1	30
Scalability	This indicator will give information on the how well the ICT systems will be replicated. The data will be obtained by counting the times each class is instantiated	Number of instances per service/class	3.8	3	5
Extensibility	Increase of sensors managed (note that currently this number is 0). Number of services implemented. This data will be a count of services and classes in the system	Number of newer services or classes implemented	3.9	2	5
Storage Capacity	As ICTs are deployed and host the data captured from sensors and operations, the storage needs will be incremented. The increase in storage need will provide information on how much the system is connected and integrated to the physical world. Calculated from the storage needs.	disk/cloud storage space	1347.8	0	4000
Hours of maintenance	Expressed as the time needed to upgrade the system, this information provides an insight on how much the system needs to provide newer services (demanded by users) or increase the functionality by connecting to other existing or newer systems. The data is related to the number of additional developing hours for new services	time	11.3	1	40
Non-expected hours off-line	This is a measure of the down time of the system, which should be kept closest to zero. The data is the number of hours the system is not operative	time	3.6	0	8

Table 6. KPI values concerning the development, integration and deployment of the different ICT services in Vitoria-Gasteiz

Table 7 shows the average values of the KPIs concerning the number of elements managed by the ICT systems developed and deployed in Vitoria-Gasteiz.

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[15] Average of the value of the KPI for the different ICT services

KPI	Description	Measure	Average value	Min	Max
# of HEMS connected	This is related to the number of sensing systems installed in the dwellings and integrated into the urban platform.\n\nIt can be easily obtained from the instances declaration in the Platform	Units	595	0	2741
# of BEMS connected	Number of systems installed per building, related to common operations (not dwellings), integrated in the platform.\n\nIt can be easily obtained from the instances declaration in the Platform	Units	356,9	0	1946
# of EV connected	Electric vehicles integrated the platform. Could be further enhanced with vehicle class definition (cars, bikes, etc.)\n\nMeasure the number of classes and number of instances of each in the platform declarations	Units (per class)	1,7 [16]	0	15
# of mobility equipment connected	Other equipment integrated to the platform and also related to mobility.\n\nMeasure the number of classes and number of instances of each in the platform declarations	Units (per class)	0	0	0
Total amount of data generated	This will measure the amount of data generated.\n\nObtained from the storage used.	Disk/cloud storage space	71,6	0	500
Types of measurements	This relates to the magnitude definition of the data (temperature, energy, speed, etc.)\n\nIt will be obtained from the magnitudes of the data definitions in the city data model	Units	See below	-	-
Percentage of equipment connected	This relates to the degree of achievement of the intervention to existing system.\n\nThis data will be obtained from the number of elements managed with the platform comparing to the total number of candidate elements.	Percentage	66,7	0	100
Recharging points equipment connected	This relates to the number of EV post installed in the City.\n\nCount of instances of this class.	Units	0,2[17]	0	2

Table 7. KPI values concerning the elements managed by the ICT systems in Vitoria-Gasteiz

As the "types of measurements" KPI is non-numerical KPI, Figure 36 shows the percentage of use of the different types of measurements.

[16] Just one service is connected with EV (the one devoted to BEI), and it manages 15 vehicles.
[17] 2 units from the services related to BEI.
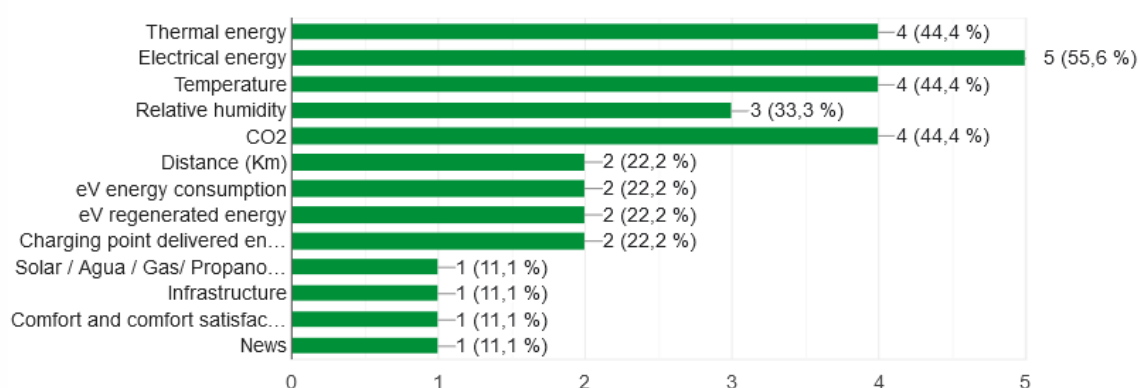
Figure 36 Percentage of use of the different types of measurements

Finally, Table 8 shows the average values of the KPIs devoted to the evaluation of the application of ICTs for the citizen in Vitoria-Gasteiz.

KPI	Description	Measure	Value	Min	Max
Number of services developed	Relates to the amount of services based on ICTs to offered citizens and third parties. The KPI will be the count of services implemented	Units	9	-	-
Types of services	The services will be classified by area (mobility, engagement, energy efficiency, management, etc.). The count of services deployed for each area will be measured.	Classification/ units	Energy, mobility, social	-	-
Percentage of dwellings connected	This relates to the success of the system deployment throughout the project implementations. The KPI will be calculated considering how many are on-line out of the number considered in the actions	Percentage	84,4 (average value)		
Percentage of Buildings connected	This relates to the number of buildings with common systems connected. The KPI will be calculated considering how many are on-line out of the number considered in the actions	Percentage	45,6 (average value)	25	100
APIs integrated	This will measure the ease of connectivity for third parties to provide services through the ICT system. The measure will be the number of APIs developed for interoperability	Units	1,8 (average value)	1	7
Open-Data sets available	This indicates the availability of data for citizens and third parties for evaluation and service building. The sets considered will be related to the services defined before.	Units	2.2 (average value)	0	7

Table 8. Average values for the KPIs devoted to the evaluation of the application of ICTs for the citizen in Vitoria-Gasteiz

Concerning "types of services" information (and as shown in Figure 37), the most common ones are the energy services.
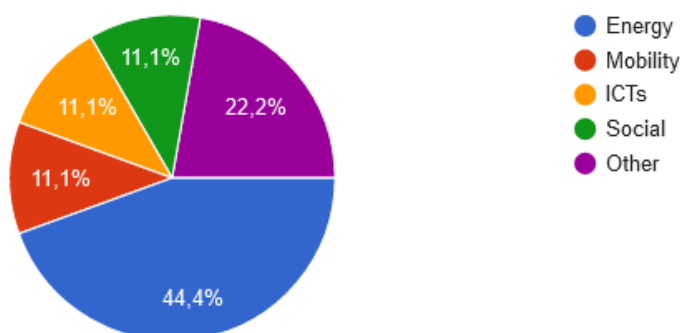
Figure 37 Types of services (related to society)

5.1.3 Life Cycle Analysis Protocol

a) Identification of the purpose

The goal and the purpose of this protocol has been to **characterize the environmental impact through the LCA methodology for the retrofitting and energy measures taken in the demonstrator of Vitoria-Gasteiz (Spain**) to reveal the environmental impacts from different life cycle stages. The **objective**, then, is **to compare the LCA results with and without the retrofitting process and the district heating installed** and such comparison allows interpreting its environmental footprint showing on the impacts caused by the retrofitting and its influence for the operation phase. This means that the reduction of the operational energy achieved due to SmartEnCity actions, in comparison with no intervention, and considering a life cycle approach, has been assessed.

b) Functional unit and district characterisation

It is important to note that the conditioned area of Vitoria-Gasteiz district finally reaches the amount of 22,461 m^2.

The functional unit (F.U.) is the reference unit through which the system performance for the compared scenarios is quantified. In this case, as mentioned in deliverable D3.2, the F.U. is defined as 1 m^2 of conditioned area considered for a time period of 1 year. The results for the LCA are expressed by m^2*year then.

Reference study period

Although the F.U. is expressed considering a time period of 1 year, the gross values are obtained from a **50 years** reference study period.

System boundaries

A **"cradle to grave" approach** is followed in this study, including all life cycle stages of the building proposed by the European standard EN 15978[18].

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[18] UNE EN 15978:2012 Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method

It is important to state here that the improvements in the energy system to be considered for the assessment have included the **external façade and the roof insulation**, as well as the multisource (biomass and natural gas) **district heating system**.

Within the system boundaries, the activities concerning replacement have been included, only regarding to the windows and the heating systems (boilers) replacement after their life time ends.

Thermal and electricity energy consumption, as well as the end of life of the elements involved, have been also included

c) Scenarios for defining the building life cycle

Two scenarios from an environmental point of view have been quantified within SmartEnCity project development. A simplified LCA for the two scenarios has been used because of the complexity of the retrofitting actions.

1. **Baseline** scenario: The first scenario evaluated comprised the normal behaviour of the Coronación neighbourhood district functioning **before SmartEnCity project** and their resources and energy consumptions were quantified and analysed for 50 years. The details were included in the deliverable D3.2.
2. **SmartEnCity** scenario: This scenario involves the behaviour of the Coronación neighbourhood functioning **after SmartEnCity demo site interventions**, that is, all energy conservation measures developed during the project in the Spanish demo case.

A simplified LCA for the two scenarios has been used because of the complexity of the retrofitting actions.

More details about SmartEnCity demo site interventions scenario in Spain

The overall target for the retrofitting action in Vitoria-Gasteiz's demo has been focused on energy reduction measures and complementing the heating supply with a biomass based efficient heating network. Therefore it has included:

- **Retrofitting**. Part of the residential buildings of the Coronación district have been fully renovated, including the intervention in the façade and cover, improving insulation and installing new low energy windows.

- **Biomass district heating system**. In addition to the retrofitting activities, a biomass heating network was deployed in Vitoria-Gasteiz.

The simplified LCA here developed has been carried out once the implementation phase ended, focused on the evaluation of the system to carry out the insulation (A1-5 stages), replacement (B5) and operational energy use phase (B6) together with the C stages.

Considering the life cycle stages according to UNE EN 15978:2012 (Figure 38):
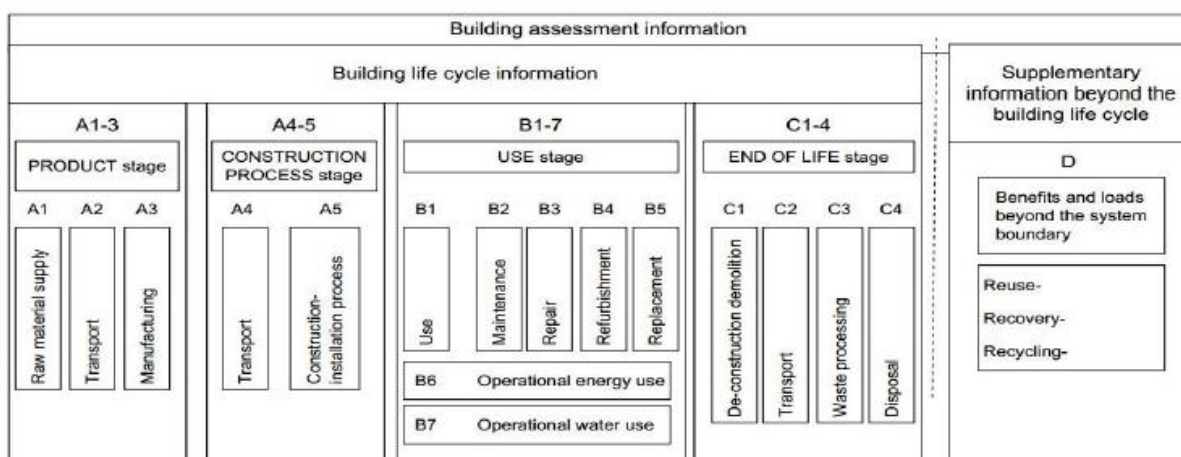
Figure 38. Building assessment information. Life cycle stages according to EN 15978:2012

Next stages have been included for the LCA evaluation in this scenario

A1 – A3 Production stage. The product stage A1-A3 refers to the extraction of materials and the manufacturing of the construction products used within the **façade** and the **roof insulation** strategy, from production line to the demo site where they were installed as a part of the finished building. Several commercial systems have been installed (data from VIS). In general terms, they are exterior insulation finishing systems consisting of an insulating panel adhered to a wall, usually with adhesive and mechanical fixation.

Because of the lack of information about all the commercial systems used, it was a CARTIF decision to assume that all the installed insulation was *StoTherm Classic* because its appropriate market life cycle data is reported as an Environmental Product Declaration (EPD-WDV-20170080-IBG1-DE[19]). Therefore, the aggregated impact from module A1-A3 declared in its EPD has been here considered.

A4 Transportation. The emissions occurring from transporting the material for the insulation from the production site to the application site have been here evaluated, based on the assumption mentioned in the production stage (all the installed insulation was *StoTherm Classic*). The transport has been calculated based on a scenario including an intermediate storage in Gijón (Spain) (330 km).

A5 Construction process. The origin emissions from the energy used during construction and waste management processes of the waste generated, both from the replaced materials and rest of materials for the new products included, should be here evaluated according to EN 15804. However, **the construction process (A5) was neglected in this scenario** as was done in the baseline because no data has been recorded and several studios estimate that these phases account for less than one percent of the total life cycle (Vilches, Garcia-Martinez, & Sanchez-Montañes, 2017)[20].

B5 Replacement. Regarding this stage, it is important to state here that **retrofitting in the project scenario** has included the **necessary material** for the **windows** and the **insulation**

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[19] https://www.de.weber/files/de/2020-06/fvwdvs-epd-wdvs-mit-schienenbefestigung.pdf

[20] Vilches, A., Garcia-Martinez, A. & Sanchez-Montañes, B., 2017. *Life cycle assessment (LCA) of building refurbishment: A literature review*. Energy and Buildings (135), pp. 286-301.

replacement (if necessary) as well as the **biomass and new gas boilers installed.** The removal of the existing boilers was already evaluated within the baseline framework.

Windows: The windows replacement has been carried out only when needed, just in those cases where windows were in poor conditions. In total, 889 windows were replaced with a new frame and glazing (data from VIS), that is, a 46 percent of the total number of windows. Life time for the PVC frame window is 30 years. Considering that the windows surface renovated in the district has been 1,446 m^2 of PVC frame, the theoretical replacement scheme modelled (due to the reference study period is 50 years) has been:

☆PVC frame windows **into the system:**
Year #0: 1,446 m^2 *30/30 = 1,446 m^2
Year #30: 1,446 m^2 *20/30 = 964 m^2
☆PVC frame windows **out of the system:**
Year #30: 1,446 m^2 *30/30 = 1,446 m^2

Total PVC frame windows **into** the system = **2,410 m^2 of PVC frame windows.**

Total PVC frame windows **out** of the system due to replacement operations = **1,446 m^2 of PVC frame windows.**

For the project scenario, it has been considered that there is no change in the windows frame type during the replacement operations, maintaining the same proportion for the PVC - glass percentage during the 50 years of the reference study period.

The environmental impacts from windows **transports** (into and out of the system) due to this replacement operations have been calculated within this stage, following EN 15804 standard. It has been assumed that the windows were transported 65 kilometres away from the factory gate to Vitoria-Gasteiz demo site and 250 km away from the demo site to the waste facilities (waste from the replacement process).

Insulation. The reference service life of the insulation has not been provided neither in the EPD that applies to the system installed nor by the manufacturer. Therefore, the performance of the product under consideration leads to the conclusion that its service life equals the reference study period. This implies that once applied, the system components do not require technical actions or replacement operations until the end-of-life stage, so it is considered that the product does not generate environmental loads at this B5 stage.

Boilers: The assessment of this stage in the project scenario has been carried out based on the same assumption used in the baseline, that is, boilers installed during SmartEnCity project will need maintenance (theoretical impacts included in the assessment) and should be replaced and substituted (theoretical impacts included in the assessment too) after their life time period, defined as 25 years.

Therefore, during the 50 years analysed, the number of replacements rate are calculated according to the following scheme:

Substitution of the boilers 25 years after their installation in year #0 together with the incorporation of new boilers in this year #25.

The environmental impacts during the use phase regarding the boilers **transport** to the district and their **replacement wastes** (in year #25) were calculated within this

stage . Transport step was involved in the model with assuming that new boilers were transported 1,950 and 1,300 kilometres away from manufacturer to Vitoria-Gasteiz demo site for biomass and new gas boilers respectively, and 50 km away from the demo site to the waste facilities (waste from the replacement process).

B6 Operational energy use. The impact from the operational energy use has been based on the energy consumption measured for the buildings once all energy conservation measures have been implemented and during one year of operation (from July 2021 to June 2022). The new district heating network installed is composed by two biomass boilers and two gas boilers, the heating network and a set of substations. Electricity consumption has been here assessed too.

C1-C4 End of life stage. Due to the fact that the simplified LCA here developed is focused on assessing the building retrofitting, the environmental impact at the end-of-life of the new materials installed has been included in these stages once the useful life considered for the building ends.

> **C1 De-construction, demolition:** According to several studies, the construction and demolition processes for the building do not significantly impact the global life cycle (Cabeza, Rincón, Vilariño, Pérez, & Castell, 2014)[21] and as it has been explained in the baseline scenario, demolition of the building after 50 years is not expected in Vitoria-Gasteiz demo site. The buildings are of enough quality to have a longer life service and, for that reason, the demolition of the whole building is not assessed at the end of the life phase.
>
> **C2 Transport:** The environmental impacts generated for transporting the products to the waste treatment facilities have been calculated within this stage. It includes the transfer of construction waste from the construction site to the waste treatment point.
>
> o The environmental impact from **windows** transports out of the system, once ended the reference study period, have been considered assuming that the windows were transported 250 km away from the demo site to the waste facilities.
>
> o Regarding the **insulation**, for the final scenarios it has been selected three different theoretical distances (Oregi, et al., 2017[22]): 50 kilometres (distribution within the province), 120 kilometres (distribution within the region) and 300 kilometres (distribution within the same member state) depending on the type of waste.
>
> o Referred to the **boilers**, it has been considered 50 km away from the demo site to the waste facilities (data from VIS).
>
> **C3 Waste treatment:** Considered for the windows and the boilers at year #50. It includes the recycling of wastes.

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[21] Cabeza, L. F. et al., 2014. *Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review. Renewable and Sustainable Energy Reviews (29),* pp. 394-416.

[22] Oregi, X., Hernandez, P. & Hernandez, R., 2017. Analysis of life-cycle boundaries for environmental and economic assessment of building energy refurbishment projects. *Energy and Buildings (136),* pp. 12-25.

Windows. The following allocation factor has been used:

30-50 years: 1,446 m^2 *20/30 = 964 m^2

Total PVC frame windows out of the system for this stage = 964 m^2 of PVC frame windows.

Boilers. Their total removal will occur at year #50 and so it has been considered.

C4 Waste disposal: As explained in B5 stage, the life time of the **insulation** has been assumed as the same as the reference study period, that is, 50 years. It is assumed that 100% of the waste is disposed of in a landfill and the environmental impacts generated for the waste management have been calculated under this premise. The final scenarios have been selected considering the current destination in building demolition/deconstruction, with a good recovery rate. The aggregated impact from module C4 from the EPD have been used here.

d) Life Cycle Assessment results for the Vitoria-Gasteiz demo case. Comparison between scenarios.

LCA has been carried out with the aid of SimaPro 8® software according to ISO 14040 and 14044 standards. The software has provided the environmental impacts and the LCA indicators calculated are the same as in the baseline assessment to allow the comparison, that is:

Abiotic depletion (elements) (ADE); abiotic depletion (fossil fuels) (AD); climate change (GWP); ozone layer depletion (OLD); photochemical oxidation (PO); acidification (A); eutrophication (E); use of renewable primary energy excluding energy resources used as raw material (RE1); use of renewable primary energy used as raw material (RE2); use of non-renewable primary energy excluding energy resources used as raw material (NRE1); use of non-renewable primary energy used as raw material (NRE2); hazardous wastes disposed (HW); non-hazardous wastes disposed (N-HW); exported energy (EE) and ecological footprint (EF).

The project scenario calculation method for the environmental impact in this demo includes the calculation of maintaining the renovated buildings in their current state and with retrofitting-interventions implemented. The scheme followed is:

αʃ Environmental assessment for 50 years

αʃ Normalization to the functional unit of each area (1 m^2 * 1 yr)

By this way, the results are referred to the entire district of Vitoria-Gasteiz (22,461 m^2 and 50 years) normalized to the functional unit (1 m^2 and 1 year).

The comparison between the results of the selected Key Performance Indicators calculated for both scenarios is shown in Table 27 and the total environmental results are presented in Table 28, for all the environmental categories selected for the baseline scenario (D3.2) and updated with the project scenario results.

List of indicators	Definition	Value/Unit (Baseline)	Value/Unit (Final)	Data source
Global Warming Potential (GWP)	Index that attempts to integrate the overall climate impacts of a specific action. It relates the impact of emissions	54.7 kg CO$_2$ eq/m^2/year	16.4 kg CO$_2$ eq/m^2/year	Ecoinvent database

List of indicators	Definition	Value/Unit (Baseline)	Value/Unit (Final)	Data source
	of a gas to that of emission of an equivalent mass of CO_2. The duration of the perturbation is included by integrating radiative forcing over a time horizon (e.g., standard horizons for IPCC have been 20, 100, and 500 years). The time horizon thus includes the cumulative climate change and the decay of the perturbation. 100 years has been chosen for the LCA study.			
Ecological footprint	The Ecological Footprint is defined as the area of productive land and water ecosystems required to produce the resources that the system needs and assimilate the wastes generated.	179 m^2/m^2/year	51.0 m^2/m^2/year	Ecoinvent database
Use of renewable primary energy excluding energy resources used as raw material (RE1)	For these four indicators, using the environmental indicator Cumulative energy demand, it will be able to separate the primary energy in renewable and non-renewable, as well as energy used for raw material and other uses	94.3 MJ/m^2/year	78.7 MJ/m^2/year	Ecoinvent database
Use of renewable primary energy resources used as raw material (RE2)		17.3 MJ/m^2/year	0.852 MJ/m^2/year	
Use of non-renewable primary energy excluding energy resources used as raw material (NRE1)		933 MJ/m^2/year	311 MJ/m^2/year	Ecoinvent database
Use of non-renewable primary energy resources used as raw material (NRE2)		33.2 MJ/m^2/year	12.6 MJ/m^2/year	
Hazardous wastes disposed	Amount of hazardous and non-hazardous wastes disposed during the life cycle of the district intervention according to the current European legislation. Directive 2008/98/EC and Annex III to Directive 2008/98/EC.	0 kg/m^2/year	0 kg/m^2/year	Ecoinvent database
Non-hazardous wastes disposed		0.394 kg/m^2/year	0.158 kg/m^2/year	Ecoinvent database
Exported energy	Energy that is produced in the context of the district studied that can be exported from the system to other use out of the systems boundaries.	0 MJ/m^2/year	0 MJ/m^2/year	

Table 9: Vitoria-Gasteiz baseline and final monitoring KPIs comparison

	AD(E)	AD (FF)	GWP	OLD	PO	A	E	RE1	RE2	NRE1	NRE2	N-HW	EF
	kg Sb$_{eq}$/m^2/year	MJ/m^2/year	kg CO$_2$eq/ m^2/year	kg CFC^{-11}eq/m^2/year	kg C$_2$H$_4$eq/m^2/year	kg SO$_2$eq/m^2/year	kg PO$_4$$^{3-}$ eq/m^2/year	MJ/m^2/year	MJ/m^2/year	MJ/m^2/year	MJ/m^2/year	kg/m^2/year	kg/m^2/year
A1 – A3 Production stage	1.17E-06	8.06E+00	3.75E-01	8.53E-10	1.28E-03	1.43E-03	9.82E-05	6.12E-01	0.00E+00	8.55E+00	0.00E+00	0.00E+00	4.16E+02
A4 Transport	1.40E-08	6.44E-02	4.32E-03	8.00E-10	5.06E-07	1.01E-05	2.12E-06	9.66E-04	0.00E+00	6.99E-02	0.00E+00	0.00E+00	1.20E-02
B5 Replacement	1.15E-05	4.43E+00	4.01E-01	2.94E-08	1.20E-04	2.65E-03	8.88E-04	-3.37E-01	8.52E-01	-7.38E+00	1.26E+01	0.00E+00	1.13E+00
B6 Energy	7.65E-05	2.21E+02	1.59E+01	1.36E-06	3.90E-03	6.78E-02	1.69E-02	7.86E+01	0.00E+00	3.14E+02	0.00E+00	0.00E+00	9.38E+01
C2 End of life transportation	1.75E-08	8.18E-02	5.49E-03	1.02E-09	7.08E-07	1.75E-05	3.88E-06	1.21E-03	0.00E+00	8.88E-02	0.00E+00	0.00E+00	1.53E-02
C3 Waste processing	-2.98E-06	-4.26E+00	-2.15E-01	-9.68E-08	-5.94E-05	-9.03E-04	-3.05E-04	-2.29E-01	0.00E+00	-5.11E+00	0.00E+00	0.00E+00	-6.26E-01
C4 Final disposal	5.03E-09	2.77E-02	1.24E-03	3.07E-10	3.63E-07	8.22E-06	2.25E-06	8.31E-04	0.00E+00	3.48E-02	0.00E+00	1.58E-01	4.55E-03
Project scenario	**8.62E-05**	**2.30E+02**	**1.64E+01**	**1.30E-06**	**5.24E-03**	**7.10E-02**	**1.76E-02**	**7.87E+01**	**8.52E-01**	**3.11E+02**	**1.26E+01**	**1.58E-01**	**5.10E+02**
Baseline	**1.20E-04**	**7.60E+02**	**5.47E+01**	**6.34E-06**	**1.32E-02**	**2.75E-01**	**4.91E-02**	**9.43E+01**	**1.73E+01**	**9.33E+02**	**3.32E+01**	**3.94E-01**	**1.79E+02**

Table 10: Environmental results comparison between scenarios. Vitoria-Gasteiz functional unit (1 m^2 and 1 year)

e) Interpretation

Environmental impacts for the project scenario from Vitoria-Gasteiz have been calculated throughout the LCA methodology. In Figure 39 Figure 52it can be seen the percentage scheme of responsibility of each stage in the final result of each impact category.

Graphically the comparison is shown in Figure 39 evaluating them as the percentage contribution of each stage in the impact category.

Life Cycle Assessment results for Vitoria-Gasteiz demo case. Impact comparison between stages

Figure 39: Characterization of the environmental impacts of Vitoria-Gasteiz project scenario

In this figure, it can be observed that the most impacting life cycle stage in Vitoria-Gasteiz demo case is the **B6 Operational energy use** stage in the following impact categories:

◎ Abiotic depletion

◎ Abiotic depletion (fossil fuels)

◎ Global Warming Potential

◎ Ozone layer depletion

◎ Photochemical oxidation

◎ Acidification

◎ Eutrophication

◎ Use of renewable primary energy excluding energy resources used as raw material (RE1)

◎ Use of non-renewable primary energy excluding energy resources used as raw material (NRE1)

Only in two impact categories, the **B5 Replacement** is the most impacting one:

◎ Use of renewable primary energy used as raw material (RE2)

◎ Use of non-renewable primary energy used as raw material (NRE2)

Both stages are the phases of the building that affect most the Life Cycle Assessment.

Moreover the **C4 Waste disposal** stage is the most impacting phase in the category of non-hazardous wastes while in ecological footprint category the A1-A3 Production stage is the most impacting, and this stage is specifically referred to the extraction of new materials and the manufacturing of the construction products used within SmartEnCity insulation strategy.

Figure 53 shows the results for all the impact categories studied compared to the baseline scenario, evaluating them as the percentage contribution of each stage in the total impact category for each scenario.

Figure 40: Environmental impact comparison between scenarios in Vitoria-Gasteiz demo case

In 11 of the 12 categories evaluated the environmental impacts from the baseline are higher than in the project scenario, only in the ecological footprint category the environmental impact is higher for the SmartEnCity intervention.

5.1.4 Mobility Protocol

In Vitoria, one of the main actions concerning mobility has been the evolution of the circular bus-line with the highest number of passengers in the city into a modern and clean electric bus rapid transit line (BEI ("Bus Eléctrico Inteligente" – Smart Electric Bus) intervention). This **BEI intervention** represents a significant technical challenge, and one of the main activities within SmartEnCity in Vitoria. Table 11. contains the values for the KPIs related to BEI.

KPI	April	May	June	Annual Value[23]	Units
CO_2 Emissions (avoided)	65517	68144	70080	817728	$kgCO_2eq$
Travelled distance	37433	39028	40226	466748	km
CO_2 Emissions (avoided) by travelled distance	1.750	1.746	1.742	1.746	$kgCO_2eq/km$
Average vehicle speed (peak / off-peak)	13.44	13.90	14.53	13.90	kmh
Energy consumption	51917	44838	57985	623.004	kWh
Total number of recharges	4107	3748	4378	48932	#
Average charging time	2.21	2.02	2.15	2.1	min
Total kWh recharged in the EV charging stations	50939	43572	55708	611268	kWh

Table 11. KPI values concerning BEI intervention in Vitoria

It has been foreseen to also calculate the four following KPIs: average occupancy, number of trips per month/year, accuracy of timekeeping for public bus and occupancy hours, but it has not been possible to calculate them accurately due to lack of data.

Apart from the calculation of the previous KPIs (the KPIs defined in the scope of the project), the mobility application obtains BEI information provided through an API offered by DATIK. The DATIK platform offers data from the systems on board of the different BEI vehicles and from the charging points that the vehicles use.

In addition, DATIK, being an integral system or platform, has data from ticketing, CCTV (video surveillance), among others, to which we do not have access.

In addition to the previous KPIs, the developed mobility application offers the following KPIs (collected from the data offered by DATIK's API) for the BEI (electric vehicles):

- Amount of vehicles and total mileage by vehicle (Figure 41).
- Speed (Figure 42)
- Consumption (Figure 43)
- The mobility application also offers the possibility of generating a summary table per vehicle and aggregated data (per month and year), with the following information: vehicle identifier, total mileage, average speed and average consumption.
- Concerning CO2 emissions, the application can show a table, per vehicle, with the following information: vehicle identifier, total kilometres, CO2 emissions diesel, CO2 emissions electricity.
- Real-time data: amount of vehicles in motion, amount of vehicles connected to the charger and number of vehicles stopped.

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[23] Annual estimated data based on the consolidated values from the months of April, May and June.

Figure 41. Mileage travelled + average value data chart. Vitoria mobility application

Figure 42. Speed (+average value) data chart. Vitoria mobility application

Figure 43. Consumption data chart. Vitoria mobility application

The application provides also information about the charging stations and charges done. Following some examples on the information that can be displayed are shown.

- Amount of chargers
- Total duration of loads (Figure 44)
- Average load duration (Figure 45)
- Total energy supplied (Figure 46)
- Average energy supplied (Figure 47)

Figure 44. BEI chargers - total duration of loads data chart. Vitoria mobility application

Figure 45. BEI chargers - average load duration. Vitoria mobility application

Figure 46. BEI chargers - total energy supplied. Vitoria mobility application

Figure 47. BEI chargers - average energy supplied. Vitoria mobility application[24]

- Real time data: amount of available chargers, amount of chargers in use
- There is also de possibility of generating a summary table per charger (per month and year) with the following information: charger identifier, charger name, total charging time and total energy supplied.

Other KPIs that can be displayed are:

- CO2 emissions diesel.
- CO2 emissions electricity.

As the BEI has been deployed in the first quarter of 2022, a full year of exploitation data is not available at the moment but, in any case, all the aforementioned information is available through the mobility application despite the fact that it is not related to one year of data.

As mentioned before, and in accordance to the deliverable (D7.3) the occupancy information (4 KPIs) could not be obtained because this information is not available at the moment.

Apart from this, and despite the fact that the city of Vitoria-Gasteiz is not looking for an increase in the number of vehicles on the streets but the opposite (following the city Sustainable Mobility and Public Space Plan (SUMPSP)), it does support the **electrification of the demand for motorized transport**, starting a progressive replacement of the current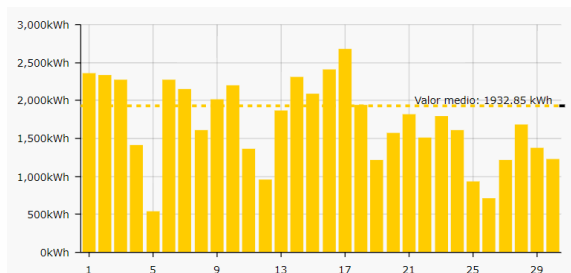 combustion vehicles. Concerning this, the promotion of electro-mobility both for public (administration and other public entities) and private entities is a key aspect, and this action along with the **e-bike sharing station** initiative from the municipality (together with the BEI) conforms the bulk of sustainable mobility actions within the SmartEnCity project.

Table 12 shows the available KPIs and information concerning the electric vehicles of VISESA, GIROA and Vitoria-Gasteiz Municipality. As the data available does not correspond to the same slots of time in the different cases, multiple comments have been added to the table in order to explain it and make the table as clear (and useful) as possible. As electric vehicles do not generate any CO2 emissions while operating, the equivalent kg CO2 avoided has been calculated using the formula stated in D7.3 (see Figure 48), assuming a combustion engine vehicle travelling the same number of kilometres than the electric ones deployed within SmartEnCity.

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[24] This data chart can be generated per vehicle or fleet as a whole *(per day or month)*

$$\text{Baseline for CO2 emissions}$$

$$= \text{Total km travelled by buses} \cdot 0.6762 \, \frac{l \, diesel}{km} \cdot \frac{2.68 \, Kg \, CO2}{l \, diesel}$$

$$+ \text{Total km travelled by electric cars} \cdot (0.47 \, \text{gasoline car ratio} \cdot \frac{2.35 \, Kg \, CO2}{l \, gasoline}$$

$$\cdot 0.055 \, \frac{l \, gasoline}{km} + 0.51 \, \text{diesel car ratio} \cdot \frac{2.68 \, Kg \, CO2}{l \, diesel} \cdot \frac{0.047 \, l \, diesel}{km})$$

Figure 48 Baseline for CO$_2$ emissions formula

	kWh	Bookings	Charges	Km	Equivalent Kg CO$_2$ avoided
VISESA 2021	936.22	253	205	9690	1211.12
VISESA Jan-Jun 2022	599.60	145	115	7347	918.28
GIROA 2021	---	---	199[25]	5361[26]	670.06
GIROA 2022 Jan-Jun 2022	---	---	---	985	123.11
AVG 2021	---	---	---	12700[27]	1587.34
AVG 2022 Jan-Jun 2022	---	---	---	5822	727.67
TOTAL				**41905,7**	**5237.58**

Table 12. Different KPIs for the VISESA, GIROA and AVG eVehicles

For the case of the e-bike sharing station, the only data available are the kilometres travelled by the 6 e-bikes (see Table 13 below). Based on this, the equivalent kg CO$_2$ emissions avoided have been calculated following the same approach as used before.

	Km	Equivalent kWh consumption avoided	Equivalent Kg CO$_2$ avoided
2020	3031.9	1414.21	378.95
2021	5454.8	2544.35	681.78
2022	4371.5	2039.05	546.38
TOTAL	**12858,2**		**1607.11**

Table 13. Indicators for the e-bike sharing station.

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[25] Annual value estimated from real value of 140 charges from 04/01/2021 to 17/09/2021
[26] Annual value estimated from real value of 4021 Km covering 9 months from April to December
[27] Annual value estimated from real value of 11642 Km covering 11 months from February to December

5.1.5 Social Acceptance Protocol

Social acceptance data were retrieved through a phone survey among the beneficiaries of the project. The questionnaire was prepared by an iterative process with involved partners during last reporting period.

The questionnaire was announced in advance through posters (in Basque and Spanish) in each building entrance to maximize the results.

Dear neighbours:

Over the next few days, as part of the accompaniment process that VISESA is carrying out with the consultancy firm ATARI, you will receive a telephone call to carry out a brief satisfaction survey on the SmartEnCity project in which you have participated over the last few years.

We encourage you to participate and share your impressions with us. We want to collect constructive opinions that will help us to improve in the future and that will allow us to draw conclusions from the work carried out since February 2017.

Over the next few days, we will contact you, but if you have any question, you can contact Maite XXXX* from ATARI CONSULTORA SOSTENIBLE on XXX XXX XXX*.

To close the Accompaniment Process, ATARI will be at your disposal in the Aldabe Civic Centre to help you personally to solve any pending doubts during June 1st (from 10:30h to 13:30h) and June 2nd (from 16:30h to 19:30h).

Thank you very much for your kindness and collaboration over the years!

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*Hidden because of privacy issues

The questionnaire includes a series of (maximum) 57 questions related with social acceptance, citizen engagement, general satisfaction and personal data.

- The questionnaire was carried out during May 2022, from 18th to 25th.
- 170 questionnaires form 268 possible answers were retrieved (63,4%)
  - o Main reported reasons for not answering the questionnaire were:
    - ▪ Rejection to answer
    - ▪ Erroneous contact data
    - ▪ Not the owner anymore, the dwelling was sold during the project.
    - ▪ Impossible to reach
- Trust level: 95%, p=q=0,5 for total data
- 2,9% of the questionnaires were carried out in Basque and 97,1% in Spanish
- Average length of the questionnaire was of 11'02''. Longer one took 23' and shorter one 6'.

Dimensions	Elements (KPIs)	Result
Social background	Characteristics of the resident: age, education level, nationality and income	See below
	Characteristics of the dwelling: type of building, dwelling size, ownership, accommodation time	See below

Age

	Value
Less than 18	0
18 to 24	0
25 to 34	3
35 to 44	16
45 to 54	39
More than 54	112

Monthly average income

	Value
Less than 1.000 €	16
1.000 to 2.000 €	61
More than 2.000 €	65
NR/DK	29

Education level

	Value
None	0
Basic education	32
Secondary education	76
University or high education	58
Postgraduate degree	1
NR/DK	4

Birth place

	Value
Vitoria Gasteiz	95
Any other place in Basque Country	27
Any other place in Spain	37
Other country	9
NR/DK	3
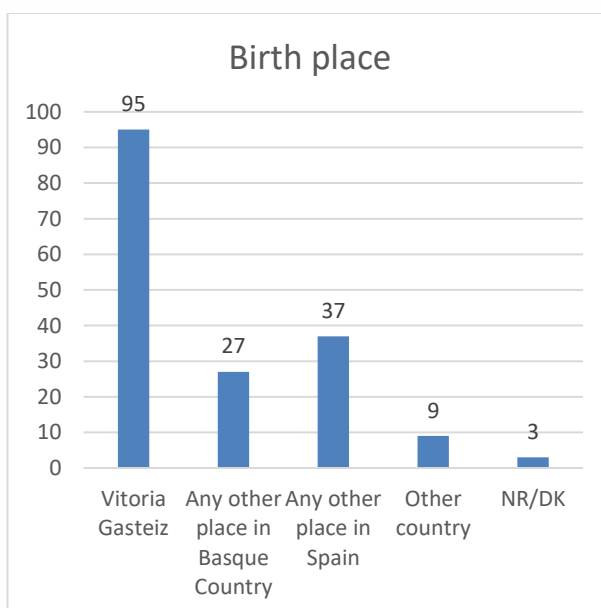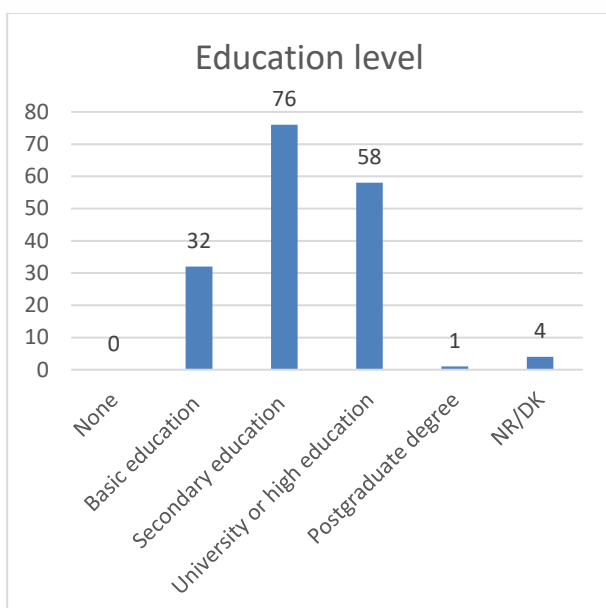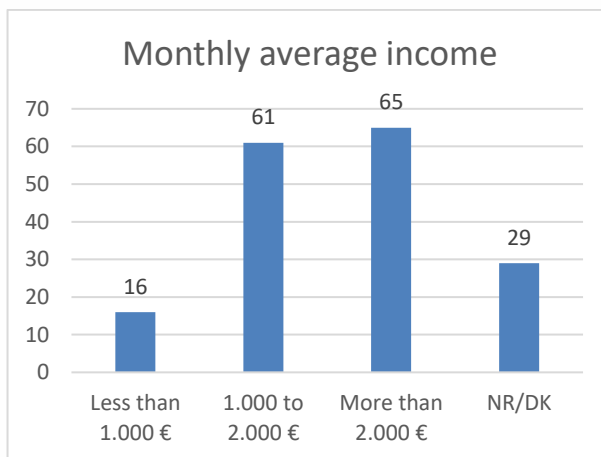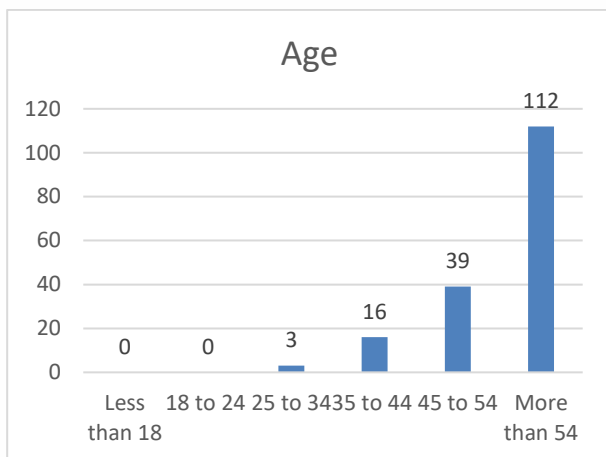
Ownership:
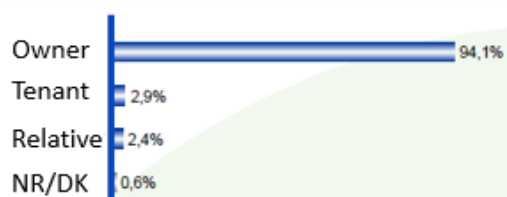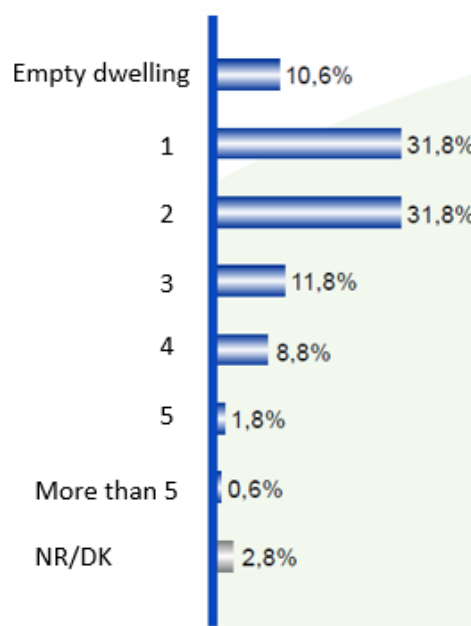
Years living in the dwelling:

Dwelling area:

People living in the dwelling:
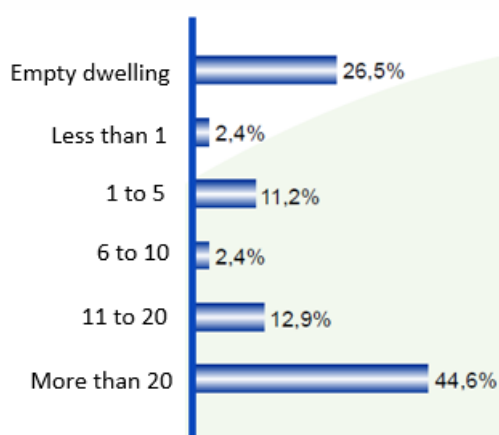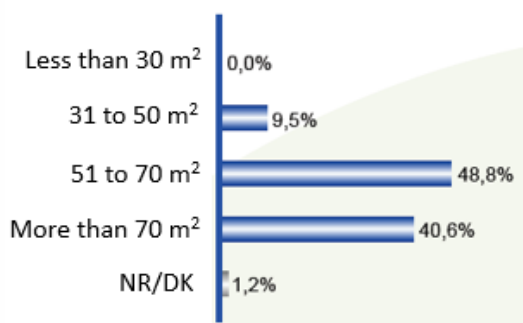
Dimensions	Elements (KPIs) & Questionnaire question	Result
Environmental background	Knowledge and environmental awareness on environmental problems: "How aware are you of different environmental problems such as climate change or environmental pollution?"	7,06
	Knowledge and benefits of the solutions implemented in energy efficient retrofit projects	--
	Satisfaction from the energy perspective (comfort): "What is your level of satisfaction with the current comfort of your home? How much would you say the comfort of your home has improved compared to the situation before the renovation?"	7,46

	Satisfaction from the energy perspective (energy savings satisfaction) "How satisfied are you with the reduction of energy consumption in your home?"	6,43
	Satisfaction from aesthetic perception: "How satisfied are you with the current aesthetics of your building? How much would you say the aesthetics of your building have improved compared to the situation before the renovation?"	7,72

Dimensions	Elements (KPIs)	Result
Individual perception of residents	Fairness and inclusiveness in the decision-making process: satisfaction with the project, with the level of information received, with the involvement degree. "To what extent do you feel that your views and opinions during the decision-making process regarding the performance of your building have been heard?"	5,86
	Trust in decision makers in terms of suitable time plan for the execution of actions and the communication and dialogue with decision makers:	--

Other questions about individual perception of the residents:

- Overall satisfaction with the project: 6,90
- Satisfaction with the level of information received in…:
  - District office: 7,82
  - General meetings in Aldabe Civic Centre: 7,42
  - Visesa's HQ office: 6,86
- Overall level of satisfaction with the implemented measures in the building: 6,72
- Level of satisfaction with the duration of the works: 5,47
- Level of satisfaction with the workers who carried out the works: 6,07
- Level of satisfaction with the post-retrofitting accompaniment process: 5,72
- After your experience, do you think you would make the decision to renovate your home again if you had to make the decision now?
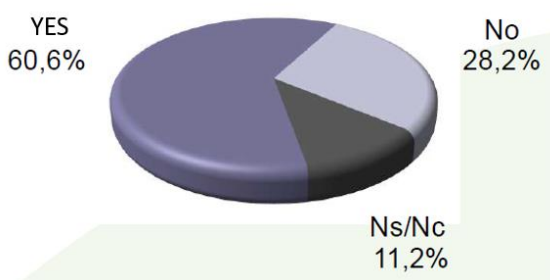
Dimensions	Elements (KPIs)	Result
Economic value of the solutions	Satisfaction with the investment costs: "How satisfied are you with the cost of the works?"	5,69
	Satisfaction with the access to financing	6,78

	"Have you approached a bank to finance the cost of the action? If you have needed funding, how easy was it to access it?"	
	Satisfaction with the payback period See below.	--
	Satisfaction level with the reduction in the energy bill "How satisfied are you with the amount of your energy bills compared to what you would be paying if you had not refurbished your home?"	4,86
	Willingness to invest in further energy projects "If you had the option in the future to invest in other projects related to energy efficiency in your home or in other areas, would you be willing to participate?"	6,29

Regarding the payback:

Payback concept is not familiar to the average demo site citizen. Because of that, a question about payback period was not suitable and it was substituted by a more open question about how it influenced the decision that could be more easily understood by neighbours.

Have you at any time assessed the payback period for the investment made in your home with the construction work?

No — 64,7%

Yes — 12,4%

Yes, but the decision was finally made for other reasons — 22,9%
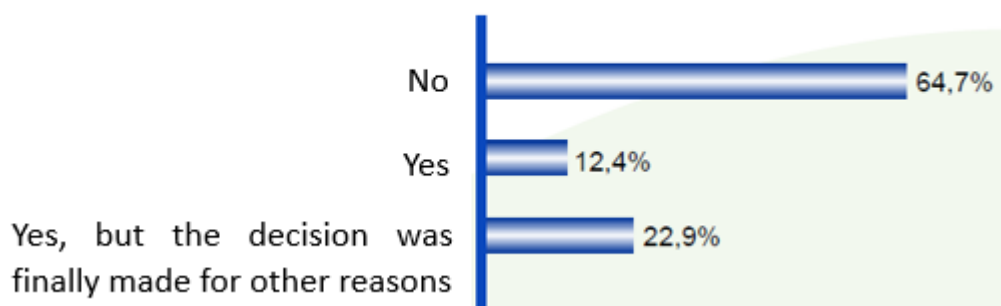
Dimensions	Elements (KPIs)	Result
Technical value of the solutions	Satisfaction with the solution implemented as a whole "How beneficial do you think the rehabilitation action has been for you?"	7,74

Other questions related to technical solutions and performance:

- Level of satisfaction with the connection to the heating network: 6,96
- Level of satisfaction with the current (retrofitted) aesthetics of respondent's building: 7,65
- Level of satisfaction with aesthetics improvement of respondent's building compared to the situation before the renovation: 7,72
- Level of satisfaction with the operation of the district heating and hot water system: 7,02
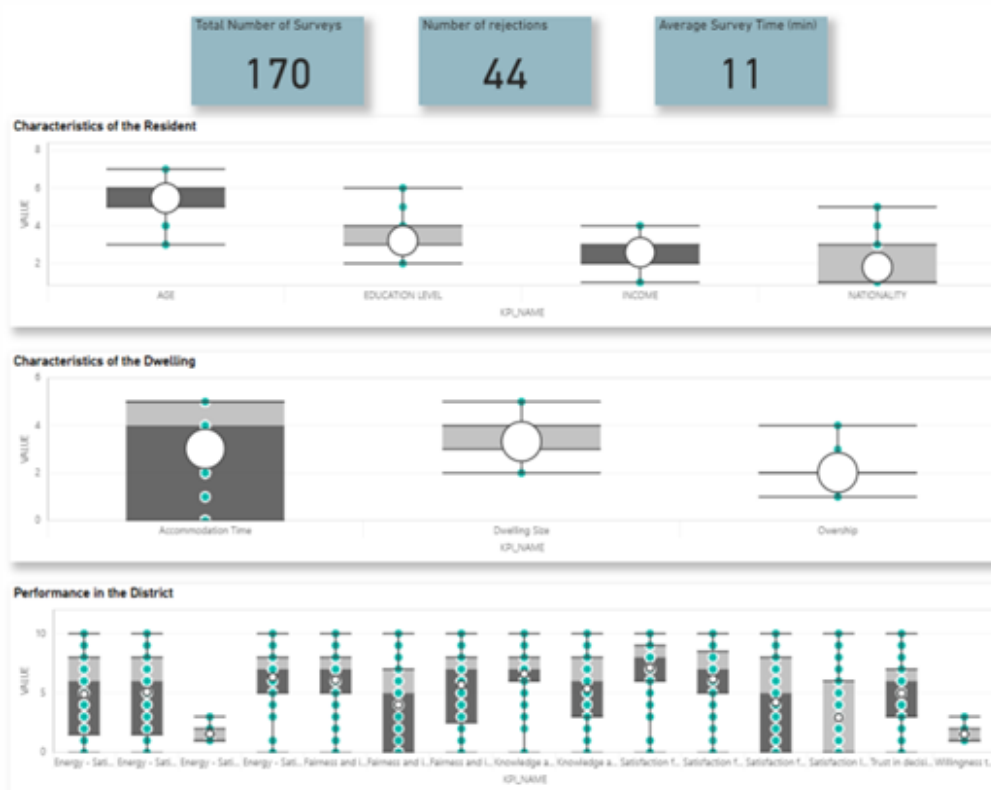
Figure 49. Summary of the answers from the questionnaire as they are shown in the KPIs visualization

Log books:

In the case of Vitoria Gasteiz, there are no log books to collect the complains but VISESA has acted as Delegated Promoter or One-Stop shop, which includes managing any comment, suggestion or complain that citizens may have about the deployment of the project in general or about any other specific issue related with the retrofitting works.

All the comments, suggestions or complains have been filed but they are not categorized in the same terms or dimensions aforementioned in the table.

Mobility:

Type of questions to be included in mobility questionnaires for Vitoria-Gasteiz:

Regarding Mobility KPIs, some questions were initially foreseen to retrieve information from some activities that, unfortunately, couldn't be carried out due to several reasons. For instance, last mile electric vehicles mobility action was finally not deployed and was substituted in latter amendment by other alternative mobility actions that fulfilled the project objectives. Additionally, main mobility action, the Smart Electric Bus (BEI), was deployed with some delay that made impossible to get this information through the surveys. Beside of that, this mobility action (BEI), would have required to extend the questionnaire to the whole city as this bus line serves all the city and not only the demo site, which was directly unfeasible.

Conclusions

The most suitable method to obtain the information is the phone questionnaire, but, despite of being the best method in terms of efficiency and cost, it is not possible to reach all the participants through this method because of multiple reasons: mistrust with unknown phone calls, reluctancy to answer, erroneous contact data, timetable incompatibility, etc.

Still, the questionnaire reached two thirds of the total participant population and results are good enough to have an overall view of the opinion of the participants.

Regarding the obtained results, main conclusion is that overall project satisfaction seems to be quite high among the questionnaire respondents, especially when asked about comfort, functionality and aesthetic. Some doubts and complains appeared when referring to district heating cost. This is logical taking into account that many of the dwellings have pass from individual gas boilers to a district heating network. This change brings to the invoices some concepts that are not well understood like "availability charge" which is inherent to any centralised installation like the one deployed in Coronación District. To minimize this, local partners have carried out an Accompanying Process after the retrofitting works where District Heating experts from Giroa Veolia explained to the owners the new invoices and the concepts that people perceived as unclear or messy.

5.1.6 Citizen Engagement Protocol

In Vitoria-Gasteiz, the data gathering process to fulfil this protocol was treated jointly with the social acceptance aspects, among others, in a comprehensive dedicated survey. This means data were, as well, retrieved through a phone survey among the beneficiaries.

Actions	Objectives of evaluation	KPIs	Results
Citizen engagement strategy	Evaluate the citizen engagement strategy_ through the perception of residents	Number of residents who considered to be **well-informed** during the information campaigns that were carried out as part of citizen engagement actions / Number of residents who answered this question	69%
		Number of residents who considered to be **well-consulted** during the information campaigns that were carried out as part of citizen engagement actions / Number of residents who answered this question	--
		Number of residents who **felt involved** in the decisions taken in the district / Number of residents who answered this question	58,6%
		Number of surveys fulfilled by residents/ Number of residents involved in the citizen engagement actions	63,4%
	Evaluate the citizen engagement strategy_ through the perception of responsible of their design	Perception of success or failure by actors involved about citizen engagement activities performed	--
Citizen engagement plan	Evaluate the level of attendance of residents to	Number of activities carried out for informing residents about the project to implement the district renovation	See below

	information campaigns and events held in the city as part of the citizen engagement strategy	Number of residents involved in the citizen engagement actions carried out to implement the district renovation	--
		Number of active residents involved in the citizen engagement actions carried out to implement the district renovation	--
	Evaluate the use of urban platform (apps, added value services, social media and website) as part of the citizen engagement strategy by residents from district, mobility actors and citizens	Number of citizens using web comfort application	12,4%
		Number of citizens (registered users) using comfort web application	12,4%
		Number of visits (daily/monthly) to the web comfort application	See below
		Increase of new visitors in the web comfort application	263 unique visits
		Maximum concurrent users/requests in the comfort web application	**Maximum number of active users in…**
			1 day 7
			7 days 21
			14 days 33
			28 days 42
		Time spent of the web	38'' in average
		Number of Apps developed in the framework of SmartEnCity	8
		Number of Apps developed in the framework of SmartEnCity focused in residents from district	4
		Number of Apps developed in the framework of SmartEnCity focused in mobility actors	1
		Number of Apps developed in the framework of SmartEnCity focused in citizens	4
		Number of mobile app downloads in the framework of SmartEnCity	N/A
		Number of mobile app downloaded by residents from district	N/A
		Number of mobile app downloaded by mobility actors	
		Number of mobile app downloaded by residents from district	
		Number of active users of Apps	21
		Number of active users of Apps in the category of residents	N/A
Citizen engagement plan		Number of active users of Apps in the category of mobility actors	
		Number of active users of Apps in the category of citizens	
		Quality of services/added value services	N/A
Citizen	To evaluate the	Number of dwellings retrofitted	302

engagement strategy + plan	success of project objectives_ building refurbishment action and district heating with RES	Number of buildings connected to the District Heating	26
		Number of residents benefited by the intervention	--
		Number of residents who were against project	--
		Number of doubts solved face to face	+ 2000
		Number of doubts solved through citizen inbox	N/A

Regarding "Number of activities carried out for informing residents about the project to implement the district renovation":

- Public informative events 10
- Meetings with Communities of homeowners > 400
- Phone calls to homeowners > 400
- Visits attended in the Information Office > 1600
- "Door to door" campaign visits 650
- Advertising cards in mail campaigns 1650

Regarding frequency of use of the comfort app:

How many times have you used the comfort app since it was released?

Times used	Percentage
1	38,1%
2	33,3%
3	9,5%
4	9,5%
5 or more	9,5%
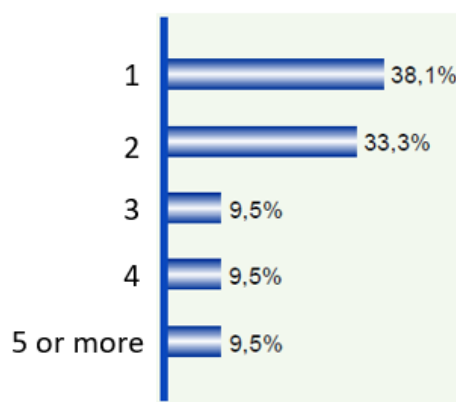
Conclusions:

During the first phase of the project a lot of effort was focused on Citizen Engagement strategy and many actions for information dissemination and project communication were carried out. As a result of that, the participants seem to feel well-informed and give a high value to the clarity and completeness of the information delivered and to the kindness and courtesy of the people in charge of this task.

During the commercialization phase of the project, before deadline arrival, "Door to door" campaign revealed to be key in the dissemination of the project. This was one of the main learned lessons extracted from the citizen engagement point of view.

After the retrofitting project, the same effort was made with an Accompanying Campaign offered to the participants so they could learn how to use the comfort app and which are the recommendations to achieve the full potential of their new retrofitted dwellings. Despite of this, neighbours seemed to be tired after more than 5 years of project involvement and the success of the campaign was not the best. Many of the neighbours didn't show interest on the application. This can be explained, as well, because of the high percentage of elderly people living in the demo district. The technological gap has been a major handicap on communicating the benefits of this app and the CIOP services targeted on citizens.

5.1.7 Economic performance Protocol

According to the final actions done in Vitoria-Gasteiz, the economic performance protocol will assess here those related to the buildings' refurbishment and connection to the district heating. The initially foreseen indicators devoted to measure the last mile eV vehicles have not been thus evaluated as this action was not finally launched.

Methodology

Different partners working on the actions in Vitoria-Gasteiz have provided all the data necessary to realize the economic analysis and calculate the KPIs of Economic Performance protocol: project consumption, cost of works, energy prices, dwelling areas. Once those KPIs are estimated, the economic performance is analysed according to the established protocol.

Among all data we received, those integrated in the analysis are introduced below.

Considered data

Area of the dwellings retrofitted by the project.

Building	Nº dwellings retrofitted	Heating surface (m2)
PHASE 1: EARLY ADOPTERS. 2 Buildings	24	1775,98
PHASE 2. 9 buildings	98	6669,23
PHASE 3. 8 buildings	92	6855,72
PHASE 4. 7 Buildings	88	6769,19
TOTAL BUILDINGS	**302**	**22.070,12**

Table 14: Area of retrofitted dwellings by the project

Only 293 (97%) out of the 302 total retrofitted dwellings were connected to district heating. Therefore, those 293 dwellings were considered for the economic performance analysis.

Consumption data (before retrofitting the buildings when natural gas was used).

Year	Consumption (kWh)
2016	1.313.027
2017	1.235.910
2018	1.383.468
Average	**1.310.801**

Table 15: Heating consumption before SmartEnCity project

For the calculation, the overage of consumption between 2016 and 2018 is considered.

Concerning heat consumption after SmartEnCity works, yearly ratio was used. Indeed, the district heating is recently working so that it was not possible no get consumption data for a whole year at the moment of this evaluation. The monitoring data considered has been the one between October 2021 and February 2022. In this period, the consumption was 521 MWh.

Therefore, we made a kind of interpolation to have an estimation of heat consumption for a whole year thanks to some ratios got from our experience.

Month	Monthly ratio
January	22%
February	18%
March	10%
April	9%
May	3%
June	1%
July	1%
August	1%
September	1%
October	5%
November	12%
December	17%
Total	**100%**

Table 16: Heating consumption ratio by month

Based on the monitoring done and those ratios, the consumption estimated for the economic calculations is 940 MWh for a year. In comparison with the consumption in the situation before works (1311 MWh), it has been reduced for 28%.

The gas maintenance costs before SmartEnCity project were also considered. Some examples are shown in Table 17 below (the names of the streets have been hidden on purpose to anonymize the data).

Xxx Street	159 €	Per year and per dwelling
Yyy Street	138,25 €	Per year and per dwelling
Average	**148,63 €**	**Per year and per dwelling**
Total estimated for the considered area /year	**43.547,13 €**	

Table 17: Gas maintenance costs before SmartEnCity project

For the period after the connection to the district Heating network, the system operator indicated us data to estimate maintenance costs. These maintenance costs concern the biomass installation:

Type	Cost	Unity
R21	0.046 €	/m^2.month
R22	21.202 €	/dwelling

Table 18. District heating maintenance costs after SmartEnCity project

Considering the district heating and heat biomass central, obviously maintenance costs are much higher than gas boiler installation.

Apart from the previously mentioned data they were also considered for the project:

- H2020 Grants = 54%
- Guarantee founds: 323.000 €

Currently, grants from Gobierno Vasco and from Ensanche 21 are unknown. Thus, altogether, we consider 60% of grants for this calculation.

Considered KPIs

The following table presents a sum-up of data and KPIs needed in the economic performance evaluation.

The results of the economic protocol are established according to the previous buildings situation before works and the project situation, works achieved.

Type of data	KPI code	Results
EC1 RC - Resident costs		
Investment (€)	-	5.814.412,92
Grant (€)	-	3.462.782,98
Total area (m2)	-	21.412
Resident cost - RC (€/m2)	**EC1**	**109,83**
EC2 GR - Grant rate		
Grant Rate - GR (%)	**EC2**	**60%**
EC3 TAC - Total annual costs		
Total Maintenance Costs (€)	-	18.031,83
KWh uptakes (kWh)	-	940.027,70
KWh country price (€)	-	0,061
Total Annual Costs - TAC (€/m2)	**EC3**	**3,52**
EC4 BF - Total annual benefits for residents		
Old costs (€/m2)	**-**	5,71
Total Benefits for Resident – BF (€/m2)	**EC4**	**2,19**
EC5 CRR - Cost saving rate		
Costing Saving Rate - CRR (%)	**EC5**	**38,3**
EC6 NPV - Net present value for resident		
Net Present Value for resident - NPV (€/m2)	**EC6**	**-80,2**
EC7 ROI - Return of Investment for resident		
Return of investment for resident – ROI (%)	**EC7**	**-12%**
EC8 PB - Payback for resident		
Payback for resident - PB (€/m2)	**EC8**	**-77**

Table 19. Economic protocol KPIs results

With those data of the project, a first economic analysis shows that it needs many years to amortize the investment. It is a current impact of renewable energy system: an important investment and maintenance costs higher.

District heating maintenance costs are higher than individual gas boiler maintenance ones. Nevertheless, a central heating plant enables to improve energy efficiency and to reduce energy consumption by 28% and so customer bills. Finally, customers save up 38% of energy cost (KPI EC5). Unfortunately, it does not quickly balance the high investment: here, 40 years are calculated to get payback (KPI EC8).

However, considering long-term costs evolution, the impact is more positive. Indeed, fossil energy costs are expected to increase highly in the future. Therefore, we can imagine that the investment will be profitable at not such very-long term.

Economic impact assessment

In order to provide a more complete economic analysis, several scenarios have been studied according to some hypothesis of price evolution. The scenarios considered are:

- **Base Scenario: Reference scenario**, it corresponds to the project, and to the results presented before.
  It presents the basic scenario with a grant ratio of 60%. It corresponds to the minimum of grant that may be expected for the project.
- **Scenario 1: Positive scenario**, it is similar to the reference scenario but with a better grant ratio.
  Here, the idea is to assess the economic performance evolution by using a higher grant ratio: 80% is considered here. It is a positive but realist hypothesis since grants from Gobierno Vasco and from Ensanche 21 are still unknown.
- **Scenario 2: Same gas situation without implementation of SmartEnCity**
  In this scenario, the idea is to assess economic evolution if the residents would not have realized any work of energy efficiency improvement, going on consuming gas.
  The point of this scenario is the fact that gas price is quite unstable and can get very high prices.
- **Scenario 3: Gas crisis without implementation of SmartEnCity**
  It corresponds to a worse scenario than the previous one with gas. In this case, the evolution of gas price suits more with current gas crises because of Russian war. The fact is that crisis and gas price increase are supposed to last for years.

The following table presents the KPIs comparison between Reference scenario and Scenario 1. The impact of increasing grants ratio by 20% is to reduce RC (KPI EC1) for a half. We have seen before that investment was the major problem to get an interesting payback of the project for customers.

Type of data	KPI code	Base scenario	Scenario 1
EC1 RC - Resident costs			
Investment (€)	-	5.814.412,92	5.814.412,92
Grant (€)	-	3.462.782,98	4.625.665,56
Total area (m2)	-	21.412	21.412
Resident cost - RC (€/m2)	**EC1**	**109,83**	**55,52**
EC2 GR - Grant rate			
Grant Rate - GR (%)	**EC2**	**60%**	**80%**
EC3 TAC - Total annual costs			
Total Maintenance Costs (€)	-	18.031,83	18.031,83

KWh uptakes (kWh)		-	940.027,70	940.027,70
KWh country price (€)		-	0,061	0,061
Total Annual Costs - TAC (€/m2)	**EC3**		**3,52**	**3,52**
EC4 BF - Total annual benefits for residents				
Old costs (€/m2)		-	5,71	5,71
Total Benefits for Resident – BF (€/m2)	**EC4**		**2,19**	**2,19**
EC5 CRR - Cost saving rate				
Costing Saving Rate - CRR (%)	**EC5**		**38,3**	**38,3**
EC6 NPV - Net present value for resident				
Net Present Value for resident - NPV (€/m2)	**EC6**		**-80,2**	**-35,1**
EC7 ROI - Return of Investment for resident				
Return of investment for resident – ROI (%)	**EC7**		**-12%**	**-14%**
EC8 PB - Payback for resident				
Payback for resident - PB (€/m2)	**EC8**		**-77**	**-34**
Number of years		-	-35	-15

Table 20. KPIs comparison between base scenario and scenario 1

In the scenario 1, thanks to EC1 reduction, the number of years for payback is estimated to 15 years (KPI EC8). It is a shorter number and more acceptable than the one of base scenario.

Economic analysis done before for base scenario and scenario 1 is not applicable for scenarios 2 and 3 since they are scenarios without investment and works. They consist of considering future different possible increases of costs.

An economic analysis is realized to compare cumulative costs for each scenario within 20 years.

The following hypotheses on cost evolution have been considered:

Type of cost evolution	Hypothesis
Inflation	2%
Natural gas	8%
Biomass	5%

Table 21. Costs evolution considered

Here, the idea is to analyse more specifically the evolution of costs and inflation to be more relevant. In the economic protocol, the inflation was .3% and no energy cost evolution was considered. Besides, 2% of inflation evolution seems to be a better hypothesis on average, since with Russian war Spain got a 9% of inflation.

Those assumptions are applied to the energy consumption and maintenance costs. Fossil energy is expected to increase a lot in the future.
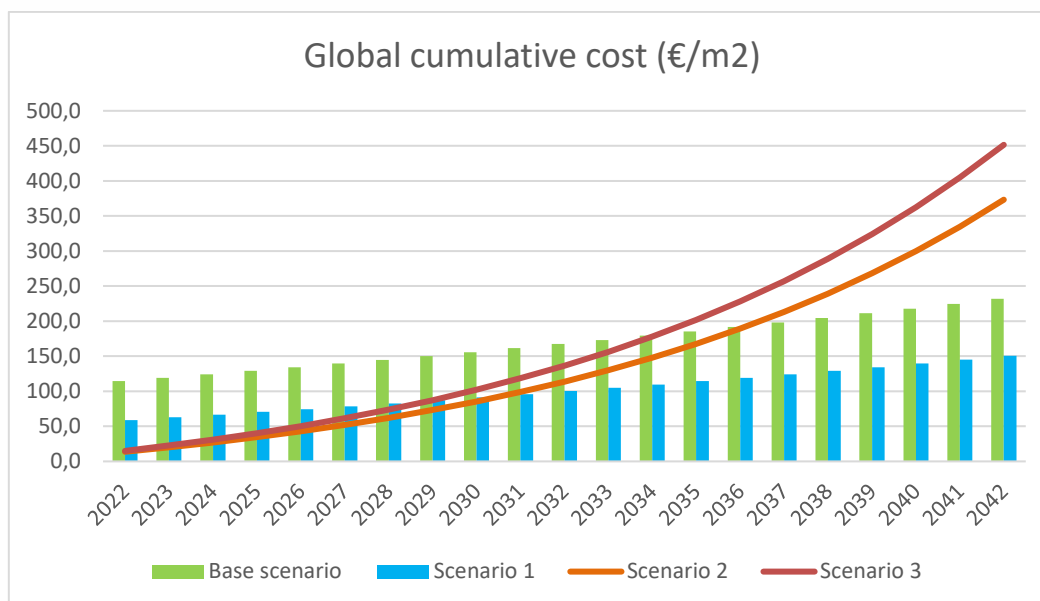
Figure 50: Cumulative costs estimated for each scenario

This graph reveals that the scenarios with biomass district heating have a more stable evolution of costs than the scenarios with individual gas installations. Indeed, the first ones have a linear of costs evolution while the others have an exponential like evolution.

Looking at base scenario and scenario 2, we realize that cumulative costs become higher for scenario 2 after 2036. Thus, the district heating is economically more relevant by 14 years with the cost evolution assumptions considered.

In the same way, looking at scenarios 1 and 2. Cumulative costs for scenario 2 become higher after 2030, so after only 8 years.

Comparing base scenario and scenario 1 with scenario 3, which is the worst prediction of gas price evolution, its cumulative cost is higher respectively after 12 and 6 years.

This cumulative analysis brings additional information to the initial economic analysis with its KPIs that is important to be considered.

Conclusions

The economic analysis reveals that the number of years to get payback for customers maybe be long (35 years) considering 60% of grant but can become shorter (15 years) if the project manages to obtain 80% of grant.

The hypothesis of 80% may be optimistic but not impossible since the project already has got 60% and grants from Gobierno Vasco and Ensanche 21 are still unknown.
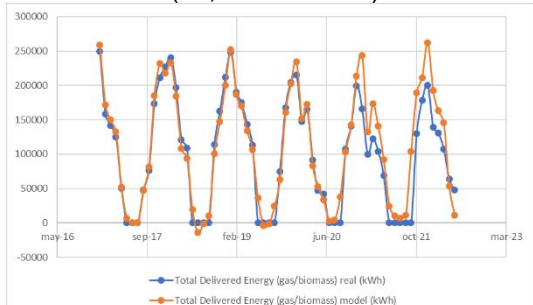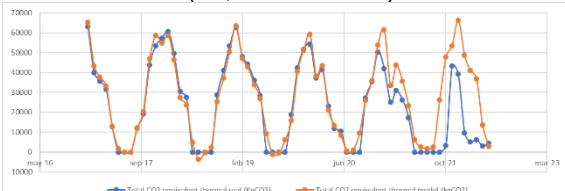
However, customer save 38% on energy bills each year.

Despite uncertainty due to payback period for customers, cumulative costs analysis shows that the costumers will pay less at long-term thanks to the change of energy source to biomass district heating. Besides, the hypothesis of evolution costs taken are conservative ones. If the real evolution is worse (as it seems will be) a better payback would be finally obtained.

5.1.8 City impact indicators

The different key performance indicators used previously on the different protocols are the basis for the definition of other high level of indicators that have been considered for evaluating the impacts of the integrated actions in the different areas addressed on the LH cities. Those indicators were also grouped on different categories related to environment, economic aspects, employment or city plans and governance.

Table 22 below shows the result of those calculated for Vitoria-Gasteiz LH with the available data provided by the partners and other external stakeholders, with the idea of obtaining some extra information of the effect of the interventions at a more global level.

City impact indicators	Results
Energy savings due to district renovation	It has been calculated an 88,70% as average value of reduction obtained from the energy certificates of the buildings in the Primary Energy consumption. Considering the real values of the energy consumption and comparing them to the model generated with the data of 2017-2018 as a function of HDD, the energy savings are 13,74 MWh for 2019, 76,07 MWh for 2020, 472,70 MWh for 2021 (57,1% reduction) and 233,40 MWh for the first semester of 2022 (74,1% reduction)[28]:
CO_2 emissions savings due to district renovation	It has been calculated an 88,50% as average value of reduction obtained from the energy certificates of the buildings for the CO_2 emissions. Considering the CO_2 emissions calculated for the real values of the energy consumption and comparing them to the ones calculated for the model generated with the data of 2017-2018 as a function of HDD, the CO_2 savings calculated are 3,463 tCO_2eq for 2019, 19,169 tCO_2eq for 2020, 150,354 tCO_2eq for 2021 (65,5% reduction) and 141,275 tCO_2eq for the first semester of 2022 (71,1% reduction):

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[28] There is a difference on the percentage of reduction calculated on the basis of the energy certificates of the buildings and the values calculated based on real data compared to the model and using the same climate data for each period. This can be explained among others by the users' behaviour effect, that is reflected on the real data, but not on the energy certificates. The same applies to the different percentages of reduction of CO_2 emissions.
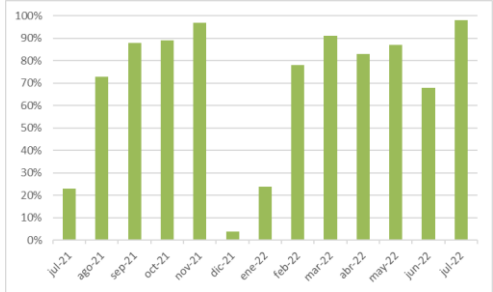
CO_2 emissions savings due to sustainable mobility actions – annual savings	817 728 kgCO$_2$eq BEI estimated annual savings 5 237 kgCO$_2$eq eVehicles total savings so far 1 607 kgCO$_2$eq eBikes total savings so far
Share of renewable energy (applicable once the DH network is working).	Average value of 69% taking all values into account. Filtering the months with works on the DH chimney we obtain 85% which could be more accurate at long term.
Number of dwellings/buildings retrofitted	302 dwelling in 26 buildings.
Number of dwellings/buildings connected to the district heating	302 dwelling in 26 buildings. Additionally, 3 tertiary buildings are now connected to the DH equivalent to 386 extra dwellings
New sustainable vehicles (EV) in the city due to SmartEnCity project	5 eVehicles: (2 VIS + 2 AVG + 1 GIR) 6 eBikes (AVG) 13 buses (BEI)
Total investment of the district from local and regional public funding, EC funding and private funding	For retrofitting and DH connection: 6 889 726 €. • European Commission (H2020): 1 577 697 €. • Basque Government: 1 840 755 €. • Vitoria-Gasteiz Municipality: 302 000 €. Dwelling owners: 3 169 274 €
Investment on mobility actions from local and regional public funding, EC funding and private funding	BEI: 42 850 000€ with 395 000 € of EC funding from a SmartEnCity contribution for the purchase of e-buses/charging infrastructure. eBikes sharing system: 35 618 €
Acquisition of training skills by partners involved in SmartEnCity	75 professionals acquired new skills on ETICs through 2 specialized courses
New plans/programs (intended actions) in the city linked with the project	Integrated Energy Transition Action Plan (PATEI) (2021-2030) Sustainable mobility and public space plan (2007-2023)
New regulations in the city linked with the project	Special Plan for the Coronación neighborhood of Vitoria-Gasteiz. Provisional approval of the Structural Specific Modification of the General Development Plan of Vitoria-Gasteiz.
New economic incentives in the city linked with the project	Real State Tax reduction (50%) for those dwellings getting an A letter on Energy Certificate (all SmartEnCity retrofitted dwellings) Construction works tax reduction (50%)
More collaboration among different authorities from different levels	High co-governance between institutions during the project. Score 4/5 in Likert scale

Table 22. Vitoria-Gasteiz city impacts

5.2 Tartu

In the following sections the main results and KPIs of the SmartEnCity actions in Tartu are given. The results are discussed across Energy Assessment, ICT, Life Cycle Analysis, Mobility, Social Acceptance, Citizen Engagement, Economic performance and City impact protocols.

5.2.1 Energy Assessment Protocol

The Energy Assessment Protocol covers the effects in the district area after the building retrofitting and the implementation of integrated infrastructures actions, which include the Energy Conservation Measures (ECM). Main results expected after the implementation of ECM:

- Energy savings: at least 30% decrease of total energy consumption of the buildings, heat energy consumption decreased by more than 50%.
- Emission reduction: 50% reduction of CO_2 emissions.
- Comfort level: indoor air quality standards achieved (II indoor climate class by standard EVS-EN 15251), thermal comfort. This is based on residents' opinion.

Following Table 23 provides a brief description of the pre-renovation and post-renovation situation by the ECMs implemented on Tartu apartment buildings.

Active and passive measures	Before renovation	After renovation
Passive measures		
Envelope insulation	poor and insufficient	Well insulated, envelope insulation according to energy calculations approx. 0,15 W/m²K
Roof insulation	insufficient	Well insulated, roof insulation approx. 0,1 W/m²K
Windows	replaced some time ago/old, various quality and characteristics U-value 1,7-2,5 W/m²K	Best, with U-value < 0,9 W/m²K
Active measures		
Ventilation system	Natural "free flowing" ventilation	Demand based (controlled by CO_2 level) mechanical ventilation with heat recovery with efficiency of 80%
Heating system	District heating based, "one pipe" system	District heating based "two pipe" system, adjustable with limitaors (adjustable range 18-23 °C)
Domestic hot water system	Dwelling based, natural gas or electricity as source of energy	District heating-based system
PV rooftop panels	Didn't exist	On average ~30 kWp (lowest 15 kWp) PV stations added on every building rooftop
Smart home solution	Didn't exist	Dwelling based system added: adjusting of heating and ventilation, visualization of temp, CO_2 level, energy consumption and PV station production.

Table 23. Brief overview on the changes by Energy Conservation Measures in apartment buildings.

For the main expected results evaluation, energy savings and emission reduction, most essential inputs needed to collect and analyze to compare before (baseline) and after

retrofitting were district heating consumption, hot water usage, electricity flows (import; export), natural gas usage and PV panels electricity production. For indoor quality and thermal comfort evaluation special measurements in selection of locations were performed as well as comprehensive questionnaires for residents supported the evaluation.

For buildings' energy savings assessment mostly annual data is needed to be processed and included into calculation as energy performance certificate methodology and requirements set that includes also normalization of heat usage for space heating. Years are normalized by location based heating degree days.

For data collection, different data sources were used that included data from questionnaires annually sent for apartment board to fulfill and data form Energy Performance Certificates provided by energy auditors. For energy data collection and visualization City Information Open Platform (CIOP) was developed and buildings energy consumption data flows were integrated to help to collect data automatically integrating different energy service providers database and building local meters data that help to compare data quality for different sources, fill missing data fields and help to monitor buildings energy performance beyond project end more easily and with less resources.

The KPIs and the results are brought out in the following Table 24 for Energy Assessment Protocol.

KPI	Data Source	Results
Energy demand	- Buildings main heat meter (before, after) - Dwellings electricity meter and buildings general electricity meter (before, after) - Buildings main gas meter (before, after) - Buildings PV panels electricity on-site consumption	Total energy demand was reduced by 36%, space heating energy consumption was reduced by 54%. Energy Performance of the buildings decreased 60%.
Delivered energy for buildings	- Buildings main heat meter (before, after) - Dwellings electricity meter and buildings general electricity meter (before, after) - Buildings main gas meter (before, after)	Total delivered energy for buildings decreased 37%. District heating (normalized by heating degree days) consumption decreased 36% (as hot water produced before renovation with natural gas or electricity was replaced with district heating), natural gas consumption decreased 78%, electricity (imported) decreased 27% and electricity consumption (import and PV production on site consumption) 21%.
Density of energy demand	- Tartu district heating area - Heat energy consumption of Tartu district heating area	2,9 MWh/m (heat sales), 3,3 MWh/m (heat sales+network loss) (2017) 2,4 MWh/m (heat sales), 2,7 MWh/m (heat sales+network loss) (2020)
Peak load and load profile of electricity demand	- Load profile (average usage/normal usage) - Peak load	Monitoring period monthly peak has been 3,2 kWh/m^2 from January 2018, average 2,4 kWh/m^2 per month. Pattern shows higher electricity consumption is from October to March, same pattern continues after renovation, but peaks are lower.
Degree of congruence of calculated annual final energy demand and	- Final energy demand of building based on annual data of year - Final energy consumption of building	12,6% degree of congruence. Average calculated/simulated by design projects - 90 kWh/m2*a (EPC), after renovation average value based on monitored energy was 101 kWh/m2*a (EPC) – congruence 11 kWh/m2*a.

monitored consumption (DCi,t) [29]	based on annual data of year	Difference comes by that in simulations standard use of buildings should be used that includes consumption profiles, one of the most influencing factor by standard 21 °C indoor temperature should be used, in realty most people prefer 22-24 °C. EPC value still dropped after renovation to 101 kWh/m²a from 257 kWh/m²a and average energy performance increased by 60%.
Degree of energetic self-supply	- Renovated buildings PV panels annual production - Renovated buildings annual electricity consumption - Renovated buildings annual energy consumption	7% of electricity consumption is covered with local renewables consumed on site. 1,6% of final energy consumption is covered with on-site production (potential maximum if all on-site renewable production can be consumed on site is approx. 10,5%)
Share of renewable energy	- Renovated buildings PV panels annual production - Renovated buildings annual electricity consumption - Renovated buildings annual energy consumption	1,6% is share of renewable energy in total energy consumption. District heating in Tartu is sustainable (specific emission factor 0,096 $kgCO_2$/kWh is significantly lower than electricity 0,547 nor natural gas 0,202), but not fully based on renewables. Based on used fuels primary energy DH RES share was 83%. Considering that % an local renewables consumption share of renewables could be 65% total energy consumption.
Internal air temperature	- indoor sensors - questionnaire	By project design requirements (national requirements) it was required to ensure proper indoor climate – in responsibility of designer and constructor of the building. In the project, we additionally verified this with measurements and a questionnaire. **Indoor air quality sensors** Indoor climate study in Tiigi 8 (measuring t, rh%, Co2 for year): *Indoor temperature in summer 18% of time (measurements) higher than 27 degrees. *CO2 level for measuring period 5,09% of time(measurements) higher than 1200 ppm (EVS-EN-15251, 1200 ppm not more than 5%) **Questionnaire**: Satisfaction with indoor air quality increased, before renovation satisfaction was 55% (rather satisfied, very satisfied), after renovation satisfaction was 60%. Very satisfied was doubled from 9% to 20%. Dissatisfaction (Not satisfied at all, Rather not satisfied) decreased from 40% to 16%. Also additional indicator to evaluate satisfaction (Opening the windows of the apartment to ventilate the rooms) supported indoor quality satisfaction. Opening windows "once a day" was decreased about half from 36% to 20% and "less than a few times a week" increased from 9% to 22%
Thermal comfort	Questionnaire	Thermal comfort (sensing the temperature of the apartment): -increased in winter season 57% of answers indicated that best suitable temperature, besides before renovation 37% said so. -decreased in summer season 26% instead of 36% said that they satisfied with the temperature. 45% said that it was hot or very hot after renovation compared with 36% before renovation (very hot increased from 10% to 26%). Summer sensation was expected as no passive or active cooling measures were not included. Higher dissatisfaction was also supported by that last summer (summer before questionnaire) was extraordinarily hot for longer period in Estonia.

Table 24. KPI results of Energy Assessment protocol

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[29] Ratio of the theoretical energy demand of a building or a set of buildings (calculated) and the final energy consumption of a building or a set of buildings (measured) over a period of time (e.g. year)

18 buildings with 664 apartments and 35 218 m^2 (net area) of space (34 402 m^2 of heated space after retrofitting) were refurbished. In 18 PV-stations total installed peak power is 554 kWp. In the perspective in Tartu baseline year 2017 there were 50 renewable energy producers connected to the distribution system operator (DSO) grid.

Before renovation, average energy efficiency value (based on certificates) was 257 kWh/m^{2}a and it decreased after renovation to 101 kWh/m^{2}a. Total energy demand was reduced by 36%, and space heating energy consumption was reduced by 54%, and it is calculated an average total energy performance increased by 60% with retrofitting at medium/long term[30]. Energy savings, emission reduction and comfort level goals, as main goals and results of retrofitting action are listed Table 25.

	Goals	Results
Energy savings	30% decrease of total energy consumption	36% decrease
	50% decrease of heat energy consumption	54% decrease
Emission reduction	50% reduction of CO_2 emissions	52% reduction
Comfort level	Indoor air quality achieved	Achieved by measurements and residents options
	Thermal comfort achieved	Achieved in wintertime, not achieve in summer time

Table 25. Results of main goals of retrofitting action

Buildings emitted 2040 tCO_2 annually before retrofitting, after renovation annual CO_2 emissions are 980 tCO_2, reduction comes from energy savings 580 tCO_2 and 480 tCO_2 savings from extraneous factors such as energy service providers specific emission factors change, due to a change in the fuel mix used in district heating and grid electricity. Emission of energy sources used in buildings were reduced by 52%. In addition to saved energy and emission factor change approximately 430 tCO_2 energy savings is coming from renewable electricity exported to grid.

Comfort level that includes indoor air quality and thermal comfort in general increased, expect the summertime thermal perception. Questionnaire results were supported by measures that showed high temperature (over 27 °C) for 18% of period in 2021. This is explainable as no additional active or passive cooling measurements were included as by required overheating simulations needed to be done for the design project by designer or energy auditor and is done by standard summer, did not show need for additional cooling solutions need. 2021 summer was extraordinary hot. Adding passive or active cooling measures would be next step to consider in near future by apartment buildings as climate change tends to bring more extraordinary hot periods and for active cooling solutions there is lot of potential to use solar panel production so far sent to grid as cooling and PV-production profiles match each other.

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[30] It has to be considered that the measurements giving the actual performance were obtained during the first year after renovation. Practice shows that final better results can be obtained in the third or fourth year, when the moisture from the construction works has left the buildings. For global numbers there is also important to consider an energy balance of both heat energy and electricity.

All main results achieve expected results, in next years it is expected to slight increase in energy efficiency and energy savings as most of the buildings are in their first commissioning years after retrofitting and optimizing the systems (ventilation, heating) for best efficiency can be done by feedback of operation of the buildings.

5.2.2 ICT Protocol

Tartu's long-term vision is to build a Digital Ecosystem for city data and services by integrating various data inputs and sensor systems together into one city ICT platform, where anyone could build their own Value Adding Services on top of city provided platform. The City Information Open Platform (CIOP) concept was introduced by Telia, within the SmartEnCity project. CIOP is the main tool for monitoring SmartEnCity interventions in Tartu.

The challenge in creating of the platform was high due to the nature of data that had to be collected - City Level, Building Level and personalized Apartment Level data all in one platform. Whereas City-level data had to be open for anyone to use and at the same time personalized data had to be protected on the GDPR level.

To best address the above-described challenge, the CIOP was designed with multiple separate modules:

1. IoT platform Cumulocity for easy integration of any sensor systems,
2. Data Access Layer (DAL) for Authentication and Consent Management. This layer also introduces an API for Third Party Access to the data,
3. Data Mapping Tool as a technical service for describing and allocating data for end-users,
4. City Portal for end-user access to City and personal data.

On top of Cumulocity and other data inputs, one of the most important parts of the CIOP is Data Access Layer (DAL). This is a secure gatekeeper module between data producers and consumers. All authentications are controlled by DAL, also sharing, delegation information and consent management is handled in this module. These are the components to secure the data and ensure the GDPR compliance.

City Portal includes two strictly separate parts - Open Data portal and My Data portal. Under the Open part of the portal, everyone can see, free of charge, the data that has been published by the city or other data owners. Currently, there are 12 open datasets.

Technically the CIOP consists of multiple services and technologies that are interconnected through API's. Some of which are only for internal use to ensure the future proofness by modularity, where all the modules could be changed in the system, without changing the whole system itself at once. The rest of the API's are open to using by partners who have joined the ecosystem and want to utilize one or multiple benefits of the CIOP.

Some of KPI-s are calculated automatically within the CIOP, but some indicators (for example: open data-sets available, number of services deployed, types of services (related to society), response time, scalability, extensibility, storage capacity, hours of maintenance, operating hours, non-expected hours off-line) will be calculated manually based on the information from CIOP.

In short, the ICT solution is based on IoT (Internet of Things) technologies that gather information from a number of various sensors and API-s. The real-time data is gathered centrally in a secured distributed cloud platform where it is analysed. The KPIs are brought out in Table 26.

KPI	Description	Measure	Value
Response time	Measurement of time during which the system conforms to the request from outside the system. Data will be taken from database engine.	Time	Max 2 sec
Scalability	This indicator will give information on the how well the ICT systems will be replicated. The data will be obtained by counting the times each class is instantiated	Number of instances per service/class	Average 300
Extensibility	Number of sensors and services integrated. Data will be taken from the platform itself.	Number of services or classes integrated	13 000
Storage Capacity	Total storage space in use needed to service the system. Data will be taken from the platform itself.	Disk/cloud storage space	1,6 TB
Hours of maintenance	Time needed to upgrade and development of the system due to integration of new services and classes. Data will be calculated on basis of information from system.	Time	3600h/year
Non-expected hours off-line	The number of hours the system is not in operation. Data will be taken from the platform itself.	Time	2h
# of HEMS connected	Number of sensing systems installed in the dwellings and integrated in the CIOP. Data will be taken from the platform itself.	Units	More than 2800
# of BEMS connected	Number of sensing systems installed per building and integrated in the CIOP. Data will be taken from the platform itself.	Units	18
# of EV connected	Number of electric vehicles integrated to the system. Data will be taken from the platform itself.	Units (per class)	Bicycles 500
# of mobility equipment connected	Number of other mobility related equipment integrated to the system. Data will be taken from the platform itself.	Units (per class)	Buses 66 Bicycles 250 Traffic sensors 55
Total amount of data generated	The amount of data generated by the system. Data will be taken from the platform itself.	Disk/cloud storage space	541 GB
Recharging points equipment connected	The number of EV recharging units installed in the pilot area and integrated into the CIOP. Data will be taken from the platform itself.	Units	5
Smart lighting equipment connected	The number of streetlights installed in the pilot area and managed by the system. Data will be taken from the platform itself.	Units	321
Number of services developed	The amount of services based on ICTs offered to citizens and third parties. Data will be gathered manually using information from the system and questionnaires.	Units	20
Types of services	The services will be classified by area (mobility, engagement, energy efficiency, management, etc.).	Classification/units	6

	Data will be gathered manually using information from the system and questionnaires.		
Percentage of dwellings connected	The percentage of dwellings of pilot area connected to the system. Data will be gathered from the platform itself.	Percentage	100%
Percentage of Buildings connected	The percentage of buildings of pilot area connected to the system. Data will be gathered from the platform itself.	Percentage	100%
Open-Data sets available	Available number of data sets for citizens and third parties for evaluation and service building. Data will be gathered from the platform itself.	Units	12

Table 26. KPIs for ICT protocol

5.2.3 Life Cycle Analysis Protocol

a) Identification of the purpose

The goal and the purpose of this protocol has been to **characterize the environmental impact through the Life Cycle Analysis (LCA) methodology for the retrofitting and energy measures taken in the Estonian demo site to reveal the environmental impacts from different life cycle stages**. The **objective**, then, is **to be able to compare the LCA results with and without the retrofitting process** and such comparison allows interpreting its environmental footprint showing on the impacts caused by retrofitting and their influence for the operation phase. This means that the reduction of the operational energy achieved due to SmartEnCity actions, in comparison with no intervention and considering a life cycle approach, has been assessed.

b) Functional unit and district characterisation

It is important to note that the conditioned area of Tartu district has finally reached the amount of 35 216 m^2.

The functional unit (F.U.) is the reference unit through which the system performance for this project scenario is quantified. In this case, as mentioned in previous deliverables, the F.U. is defined as 1 m^2 of conditioned area considered for a time period of 1 year. The results for the LCA are expressed by m^2*year then.

Reference study period

Although the F.U. is expressed considering a time period of 1 year, the gross values for the life cycle inventory stage are obtained from a 30 years reference study period.

System boundaries

A **"cradle to grave" approach** is followed in this study, including all life cycle stages of the building proposed by the European standard EN 15978[31].

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[31] UNE EN 15978:2012 Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method

The improvements in the energy system to be considered for the assessment have included the external façade, roof and attic insulation and the commissioning and implementation of the new district cooling system that produces heat for the district heating system by using residual heat from cooling.

c) Scenarios for defining the building life cycle

Two scenarios have been quantified to carry out a simplified LCA focused on the environmental improvements due to the reduction of the operational energy achieved thanks to the project intervention.

> **1. Baseline** scenario: The first scenario evaluated comprised the normal behaviour of the Tartu neighbourhood district functioning before SmartEnCity project and their resources and energy consumptions have been quantified and analysed for 30 years. The details are included in the deliverable D4.2

> **2. SmartEnCity** scenario: This scenario involves the behaviour of the Tartu neighbourhood functioning after SmartEnCity demo site interventions, that is, all energy conservation measures developed during the project in the Estonian demo case. The details are included in this deliverable.

A simplified LCA for the two scenarios has been used because of the complexity of the retrofitting actions.

More details about SmartEnCity demo site interventions scenario in Tartu

The main idea of retrofitting activities in Tartu was to turn the Soviet-time "khrushchyovkas" into "smartovkas" buildings that offer an energy-efficient and high-quality living environment to the pilot area residents. It has included the assessment of:

- **Retrofitting**. The outer walls in the residential buildings of the district have been fully renovated, including the intervention in the façade, roof and attics, improving insulation and installing new low energy windows.
- **A new district cooling system** was installed in Tartu's pilot area buildings involving a **heat pump** that produces heat for the district heating system by using residual heat from cooling. District cooling, district heating and solar PV panels have been integrated as one effective production unit.

Considering the life cycle stages according to UNE EN 15978:2012 (Figure 51):
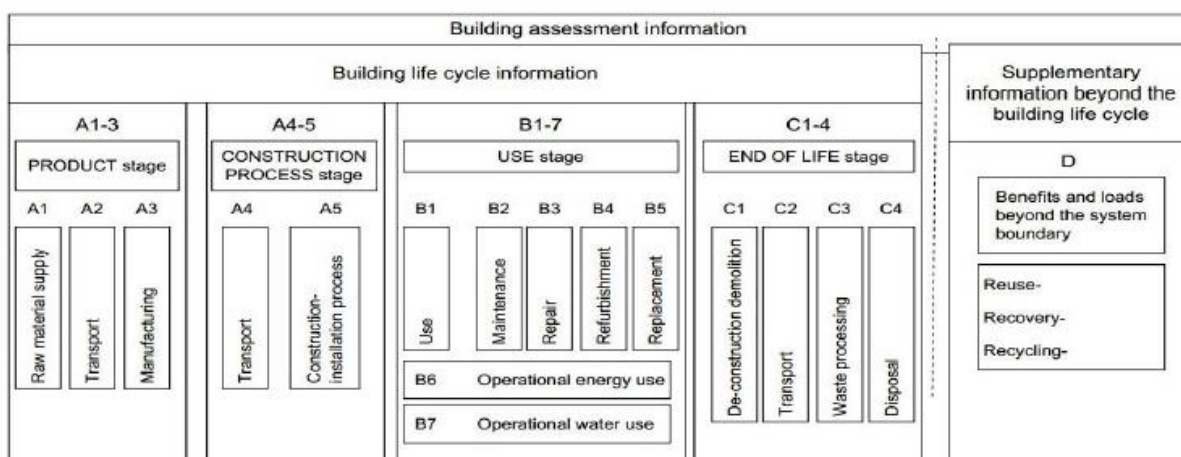
Figure 51. Building assessment information. Life cycle stages according to EN 15978:2012

Next stages have been included for the LCA evaluation in this scenario:

A1-A3 Production stage. The product stage A1-A3 refers to the extraction of materials and the manufacturing of the construction products used within the façade, roof and attics **insulation strategy,** the **heat pump** and the ventilation system with heat exchangers installed as a part of the finished building. Proxy data have used as a starting point.

> About **insulation**. Several commercial systems have been installed. In overall, the insulation consists of 25 % of EPS and 75 % of Rockwool (data from TREA). Due mainly to the lack of information about all the commercial systems used, it was a CARTIF decision to model de whole insultation under the premise of those percentages because they are primary data.

> About the **heat pump.** With support of SmartEnCity project, a heat pump as part of the district cooling plant was integrated into production system. The heat pump capacity is 1,4 MWcool and 1,9 MWheat and its life time is 20 years.

> About the **ventilation system with heat exchangers.** Heat recovery ventilation systems were designed for each residential building. For this reason, a general dataset available within the database Ecoinvent 3 has been extrapolated considering the conditioned area of the district.

A4 Transportation. The emissions occurring from transporting the material for the insulation, the heat pump and the ventilation system from the factory / storage to the application site have been here evaluated. The transport has been calculated:

> For the **insulation**. Based on a scenario which includes an intermediate storage of Reideniplaat® (https://reideniplaat.ee/en/, the biggest EPS producer in Estonia) with a production unit located in Pärnu (170 km travelled), and a theoretical and international storage for the Rockwool transport (900 km travelled).

> For the **heat pump.** The average transport of heat pump installed has been considered 100 km away from the factory gate to Tartu demo site.

For the **ventilation system with heat exchangers**: The selected dataset to model this solution indicates *"This market contains no transport or losses, as they are irrelevant for the delivered product."*

A5 Construction process. The origin emissions from the energy used during construction and waste management processes of the waste generated, both from the replaced materials and the rest of materials for the new products included, should be here evaluated according to EN 15804[32]. However, **the construction process (A5) was neglected** in this scenario as was done in the baseline because no data has been recorded and several studios estimate that these phases account for less than one percent of the total life cycle (Vilches, et al., 2017).

B5 Replacement. Retrofitting in the project scenario has included the necessary material for the replaced windows and the insulation installed as well as the maintenance operations necessary maintenance operations for the heat pump and the ventilation system with heat exchangers

Windows: All old windows were replaced with 3 layers PVC windows. The windows surface renovated in the district has been 5,700 m^2. Life time for this PVC frame is 30 years. This implies that once installed the windows components do not require technical actions or operations until the end-of-life stage therefore no more replacement operations shall be needed during their life time service (30 years) because it equals the reference study period.

The environmental impacts from windows transports (into the system) due to this replacement operations have been calculated within this stage, following EN15804 standard. It has been assumed that the windows were transported 100 kilometres away from the factory gate to Tartu demo site (data from TREA) for the average of the 18 buildings renovated.

Insulation. The reference service life of the insulation has not been provided therefore the performance of the product under consideration leads to the conclusion that its service life equals the reference study period. This implies that once applied, the system components do not require technical actions or operations until the end-of-life stage, so it is considered that the product does not generate environmental loads at this B5 stage.

Heat pump for the district cooling station**.** Maintenance is needed considering the reference study period therefore this heat pump should be replaced and substituted after its life time period. During the 30 years analysed, the number of replacements rate is calculated according to the following scheme:

1 heat pump installed initially (A1-A3 stage) + substitution of this heat pump 20 years after with the incorporation of a new one (allocation rate 10/20).

The environmental impacts during this phase regarding the initially heat pump transport to the district as well as its replacement wastes (in year #20) were calculated within this stage. Because of the lack of detailed transportation data to the building site, transport step was involved in the model with assuming one of final

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[32] This standard indicates *"(…) In case of insufficient input data or data gaps for a unit process, materials and processes can be omitted, if the process contributes with less than 1% (…)"*

scenarios selected in Oregi, et al., 2017[33]: 300 kilometres (distribution within the same member state).

Ventilation system with heat exchangers. Considering the reference study period (30 years) and the life time of the ventilation system (20 years), replacement operations are needed. During the 30 years analysed, the number of the replacement rate is calculated according to the following scheme:

Ventilation system and heat exchangers installed initially (A1-A3 stage) + substitution of them 20 years after with the incorporation of new ones (B5 stage with allocation rate 10/20).

The environmental impacts during this phase regarding replacement wastes (in year #20) were calculated within this stage and transport step was involved in the model with assuming one of final scenarios selected in Oregi, et al., 2017[4]: 300 kilometres (distribution within the same member state).

B6 Operational energy use. The solution introduced in Tartu meets consumer demands for thermal indoor comfort, domestic hot water and floor heating. The use of fossil electric energy to produce hot water with electric boilers has been replaced with residual heat and electricity produced by PV panels.

District heating consumption of the renovated buildings is mainly biomass, but also peat and natural gas for peak loads (data by TREA). Moreover, natural gas usage still remains for cooking and it has been here considered.

Self-consumption from solar panels and global electricity consumption from grid have been also included and modelled within this stage.

C1-C4 End of life stage. Due to the fact that the simplified LCA here developed is focused on assessing SmartEnCity actions, only the environmental impacts at the end-of-life of the new materials installed have been included in these stages once the useful life considered for the building ends.

C1 De-construction, demolition: According to several studies, the construction and demolition processes do not significantly impact the global life cycle (Cabeza, et al., 2014) and as it has been explained in the baseline scenario, demolition of the building after 30 years is not expected in Tartu demo site. The buildings are of enough quality to have a longer life service and, for that reason, at the end of the life phase, the demolition of the whole building is not be assessed.

C2 Transport: The environmental impacts generated for the transport of the products to the waste treatment facilities have been calculated within this stage. It has included:

- The environmental impacts from **windows transports** out of the system, once ended the reference study period. It has been considered assuming that the windows were transported 250 km away from the demo site to the waste facilities (the same assumption as Vitoria-Gasteiz demo site).

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[33] Oregi, X., Hernandez, P. & Hernandez, R., 2017. *Analysis of life-cycle boundaries for environmental and economic assessment of building energy refurbishment projects*. Energy and Buildings (136), pp. 12-25

- The environmental impacts from **insulation transport** out of the system, once ended the reference study period. For the final scenarios it has been selected one theoretical distance (Oregi, et al., 2017[34]): 50 kilometres (distribution within the province) to the landfill considering that EPS and Rockwool as non-hazardous wastes.

- The environmental impacts from **the heat pump transport** out of the system, once ended the reference study period. For the final scenarios it has been selected one theoretical distance (Oregi, et al., 2017[5]): 300 kilometres (distribution within the same member state) to the landfill considering it as waste electrical and electronic equipment (WEEE) waste.

- The environmental impacts from **ventilation system and heat exchangers** out of the system, once ended the reference study period. The environmental impacts during this phase was involved in the selected dataset used for modelling these construction wastes end-of-life.

C3 Waste treatment: Considered for windows, the heat pump and the ventilation system with heat exchangers at year #30. It includes the recycling of PVC and glass

Abiotic depletion (elements) (ADE); abiotic depletion (fossil fuels) (AD); climate change (GWP); ozone layer depletion (OLD); photochemical oxidation (PO); acidification (A); eutrophication (E); use of renewable primary energy excluding energy resources used as raw material (RE1); use of renewable primary energy used as raw material (RE2); use of non-renewable primary energy excluding energy resources used as raw material (NRE1); use of non-renewable primary energy used as raw material (NRE2); hazardous wastes disposed (HW); non-hazardous wastes disposed (N-HW); exported energy (EE) and ecological footprint (EF).

as wastes, the material recovery operations for the heat pump and the construction wastes due to the ventilation system.

C4 Waste disposal: As explained in B5 stage, the life time of the insulation has been assumed as the same as the reference study period, that is, 30 years. It is assumed that 100% of the waste is disposed of in a landfill for non-hazardous wastes and the environmental impacts generated for the waste management have been calculated under this premise. The final scenario has been selected considering the current destination in building demolition/deconstruction, with a good recovery rate.

d) Life Cycle Assessment results for the Tartu demo case. Comparison between scenarios.

LCA has been carried out with the aid of SimaPro 8® software according to ISO 14040 and 14044 standards. The software has provided the environmental impacts and the LCA indicators calculated are the same as in the baseline assessment to allow the comparison, that is:

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[34] Oregi, X., Hernandez, P. & Hernandez, R., 2017. *Analysis of life-cycle boundaries for environmental and economic assessment of building energy refurbishment projects*. Energy and Buildings (136), pp. 12-25

The project scenario calculation method for the environmental impact in Tartu includes the calculation of maintaining the renovated buildings in their current state and with retrofitting-interventions implemented. The scheme followed is:

∿ Environmental assessment for 30 years
∿ Normalization to the functional unit of each area (1 m^2 * 1 yr)

By this way, the results are referred to the entire district of Tartu (35,216 m^2 and 30 years) normalized to the functional unit (1 m^2 and 1 year).

The comparison between the results of the selected Key Performance Indicators calculated for both scenarios is shown in Table 27 and the total environmental results are presented in Table 28, for all the environmental categories selected for the baseline scenario (D4.2) and updated with the project scenario results.

List of indicators	Definition	Value/Unit (Baseline)	Value/Unit (Final)	Data source
Global Warming Potential (GWP)	Index that attempts to integrate the overall climate impacts of a specific action. It relates the impact of emissions of a gas to that of emission of an equivalent mass of CO_2. The duration of the perturbation is included by integrating radiative forcing over a time horizon (e.g., standard horizons for IPCC have been 20, 100, and 500 years). The time horizon thus includes the cumulative climate change and the decay of the perturbation. 100 years has been chosen for the LCA study.	68.5 kg CO_2 eq/m^2/year	47.4 kg CO_2 eq/m^2/year	Ecoinvent database
Ecological footprint	The Ecological Footprint is defined as the area of productive land and water ecosystems required to produce the resources that the system needs and assimilate the wastes generated.	257 m^2/m^2/year	8.19 m^2/m^2/year	Ecoinvent database
Use of renewable primary energy excluding energy resources used as raw material (RE1)	For these four indicators, using the environmental indicator Cumulative energy demand, it will be able to separate the primary energy in renewable and non-renewable, as well as energy used for raw material and other uses	140 MJ/m^2/year	111 MJ/m^2/year	Ecoinvent database
Use of renewable primary energy resources used as raw material (RE2)		5.56 MJ/m^2/year	2.60 MJ/m^2/year	
Use of non-renewable primary energy excluding energy resources used as raw material (NRE1)		862 MJ/m^2/year	429 MJ/m^2/year	Ecoinvent database
Use of non-renewable primary energy resources used as raw material (NRE2)		40.5 MJ/m^2/year	35.4 MJ/m^2/year	
Hazardous wastes disposed	Amount of hazardous and non-hazardous wastes disposed during the life cycle of	0 kg/m^2/year	0 kg/m^2/year	Ecoinvent database

| List of indicators	Definition	Value/Unit (Baseline)	Value/Unit (Final)	Data source
Non-hazardous wastes disposed	the district intervention according to the current European legislation. Directive 2008/98/EC and Annex III to Directive 2008/98/EC.	0.0862 kg/m^2/year	0.00454 kg/m^2/year	
Exported energy	Energy that is produced in the context of the district studied that can be exported from the system to other use out of the systems boundaries.	0 MJ/m^2/year	27 MJ/m^2/year	Data from TEA

Table 27: Tartu baseline and final monitoring KPIs comparison

	AD(E)	AD (FF)	GWP	OLD	PO	A	E	RE1	RE2	NRE1	NRE2	N-HW	EF
	kg Sb$_{eq}$/m²/year	MJ/m²/year	kg CO_2 eq/ m²/year	kg CFC^{-11} eq/m²/year	kg C_2H_4 eq/m²/year	kg SO$_2$eq/m²/year	kg PO$_4$$^{3-}$ eq/m²/year	MJ/m²/year	MJ/m²/year	MJ/m²/year	MJ/m²/year	kg/m²/year	kg/m²/year
A1 – A3 Production stage	8.79E-05	2.57E+01	1.65E+00	5.97E-07	2.79E-03	1.59E-02	3.27E-03	9.69E-01	0.00E+00	2.96E+01	0.00E+00	0.00E+00	4.00E+00
A4 Transport	1.95E-07	8.94E-01	5.99E-02	1.11E-08	7.02E-06	1.41E-04	2.95E-05	1.34E-02	0.00E+00	9.70E-01	0.00E+00	0.00E+00	1.67E-01
B5 Replacement	8.28E-05	2.84E+01	2.02E+00	7.17E-07	5.91E-04	1.36E-02	4.41E-03	3.31E-03	2.60E+00	7.52E-02	3.54E+01	0.00E+00	5.55E+00
B6 Energy	1.07E-04	3.30E+02	4.41E+01	4.12E-06	1.08E-02	2.64E-01	3.13E-02	1.11E+02	0.00E+00	5.30E-04	0.00E+00	0.00E+00	1.75E-04
C2 End of life transportation	9.57E-08	4.39E-01	2.95E-02	5.42E-09	3.47E-06	6.95E-05	1.46E-05	6.43E-03	0.00E+00	4.76E-01	0.00E+00	0.00E+00	8.20E-02
C3 Waste processing	-1.84E-05	-2.24E+01	-8.96E-01	-5.94E-07	-2.23E-04	-3.87E-03	-1.20E-03	-1.03E+00	0.00E+00	-2.69E+01	0.00E+00	0.00E+00	-2.70E+00
C4 Final disposal	1.30E-08	4.22E-02	4.10E-01	3.55E-10	6.72E-07	3.81E-05	3.36E-05	1.02E-03	0.00E+00	4.68E-02	0.00E+00	4.54E-03	1.09E+00
Project scenario	**2.59E-04**	**3.63E+02**	**4.74E+01**	**4.86E-06**	**1.40E-02**	**2.90E-01**	**3.79E-02**	**1.11E+02**	**2.60E+00**	**4.29E+00**	**3.54E+01**	**4.54E-03**	**8.19E+00**
Baseline	**1.24E-04**	**5.25E+02**	**6.85E+01**	**6.17E-06**	**1.01E-02**	**1.95E-01**	**3.95E-02**	**1.40E+02**	**5.56E+00**	**8.62E+02**	**4.05E+01**	**8.62E-02**	**2.57E+02**

Table 28: Environmental results comparison between scenarios. Tartu functional unit (1 m2 and 1 year)

e) Interpretation

Environmental impacts for the project scenario from Tartu have been calculated throughout the LCA methodology. In Figure 52 it can be seen the percentage scheme of responsibility of each stage in the final result of each impact category.

Graphically the comparison is shown in Figure 52 evaluating them as the percentage contribution of each stage in the impact category.
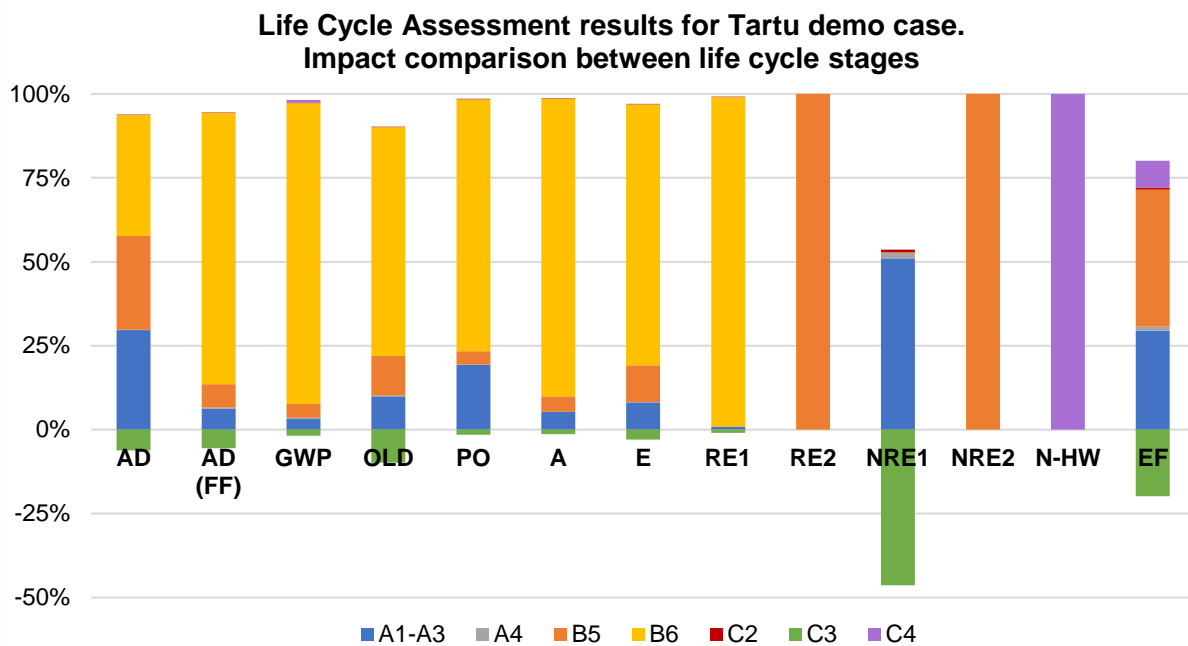
Figure 52: Characterization of the environmental impacts of Tartu project scenario

In this figure, it can be observed that the most impacting life cycle stage in Tartu demo case is **B6 Operational energy** use stage in the following impact categories:
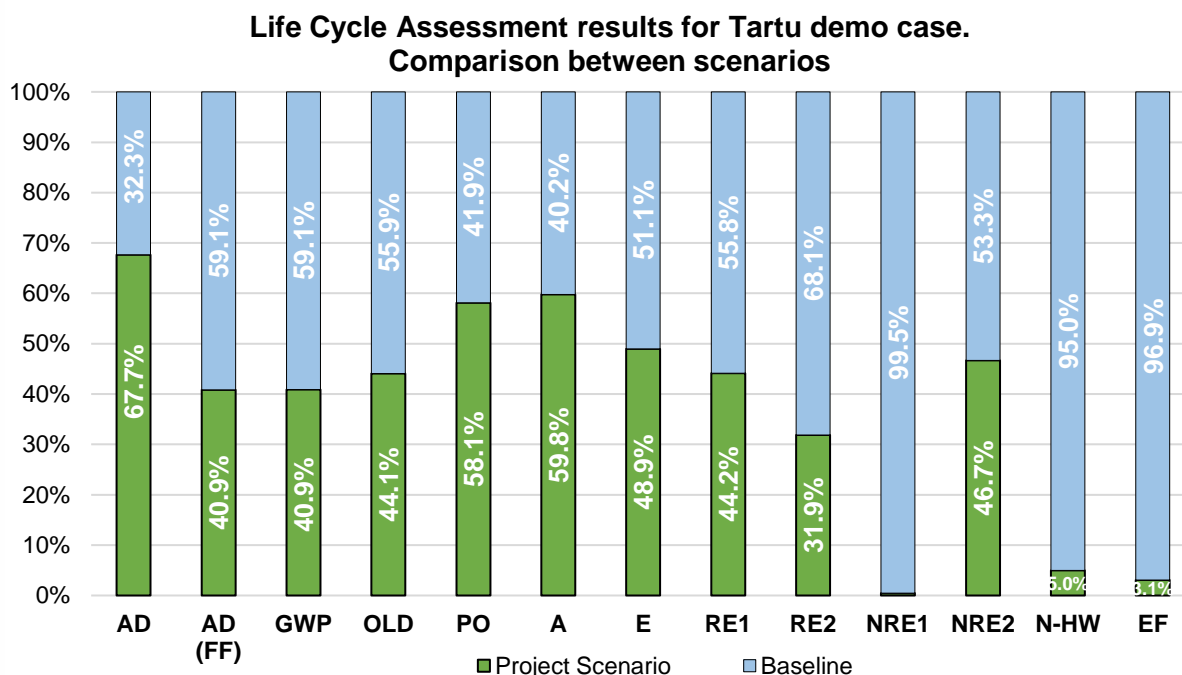
◎ Abiotic depletion

◎ Abiotic depletion (fossil fuels)

◎ Climate change

◎ Ozone layer depletion

◎ Photochemical oxidation

◎ Acidification

◎ Eutrophication

◎ Use of renewable primary energy excluding energy resources used as raw material (RE1)

Only in three impact categories **B5 Replacement** is the most impacting one:

◎ Use of renewable primary energy used as raw material (RE2)

◎ Use of non-renewable primary energy used as raw material (NRE2)

◎ Ecological Footprint

Both stages are the phases of the building that affect most the Life Cycle Assessment and the **C4 Waste disposal** stage is the most impacting phase in the category of non-hazardous wastes.

Figure 53 shows the results for all the impact categories studied compared to the baseline scenario, evaluating them as the percentage contribution of each stage in the impact category for each scenario.

Figure 53: Environmental impact comparison between scenarios in Tartu demo case

In 9 of the 12 categories evaluated, the environmental impacts from the baseline are higher than in the project scenario, only in abiotic depletion, photochemical oxidation and acidification categories the environmental impacts are higher for the SmartEnCity intervention.

5.2.4 Mobility Protocol

The aim and objective of mobility actions in Tartu is to: a) decrease energy consumption in urban transport; b) reduce CO_2 emissions in urban transport, c) increase the efficiency of public transport. Sustainable mobility related measures have been redefined and the new ones have been approved under an amendment signed on June 2018. The new actions fall under following categories (see also Table 29 and Table 30):

- Public charging
- E-bike rental system
- Biogas buses
- Reuse of EV batteries
- Bike-share system

	Project Duration					
	I	**II**	**III**	**IV**	**V**	**VI**
Public charging	5 CP					
E-bike rental system			75	75	150	
Biogas buses		60 BB				
Reuse of EV batteries		1 CP				

Table 29. List of sustainable mobility actions

TARTU DEMO	Vehicle numbers	Km/year	Fuel Saving (Kwh/yr)	Emission Saving (tn CO_2/year)
Rental e-bikes	300	3,000/b	N/C	711
Biogas Buses	60	70,000	6,258,000	5250
Bike share	450	2.000/b	N/C	1076
TOTAL	810		6,258,000	7037

Table 30. Expected environmental impact of mobility actions in Tartu

Public recharging. 5 new 50kW fast charging points have been installed in public locations to cover the demand generated by the future new EVs that are going to be introduced (rentals, taxis and private use). All chargers have dual charging standards – CHAdeMO and CCS.

Figure 54. EV-charger in Tartu

As of June 2019, Tartu City launched a **bike sharing** (450 bicycles + 69 parking stations) and **electric bike rental system** (300 electric bicycles) consisting in total 750 bicycles and 69 parking stations being the e-bike rental is part of the bike-sharing system.

Bikeshare. A bike sharing business model has already been developed and a related analysis was carried out in 2014. Bike sharing is mainly addressed to people who need to travel 2-5 km and it is a great alternative to driving a car. The analysis showed that the

potential number of bike share users could be up to 224,000 annually (more than 90 parking locations, 450 bikes).

Figure 55. Launch of the bike-share system in Tartu in June 2019

E-bike rental system. An innovative e-bike rental system was developed by the City of Tartu. This solution avoids the need to dock bikes for parking, by using GPS technology in combination with ICT solutions, making use of the project's City information infrastructure. There is 300 e-bikes available for rental. Bikes can be unlocked from the distance by using the web application or mobile app. It is possible to get the required information from the e-bike in real time. Thanks to the batteries, the bike is able to stay in connection with stations and server for a long time, giving a wide autonomy. All smartness is integrated into the bike.

Additionally, IT solutions will help to create user profiles in a way that each user can determine how much support from the electric motor he or she needs when cycling. The user profile is saved and each time when the user is identified, the e-bike automatically sets it according to the user profile.

Biogas buses. The City of Tartu implemented 60 brand new biogas buses to serve the public transportation network. This means that from 2020 onwards, 100% of public transportation buses will run on biogas. The annual capacity of the regular public transportation service is currently 3.6 million line kilometres.

Figure 56. Biogas buses in Tartu

Reuse of EV batteries. EV batteries that are not useful for EVs anymore, but still can deliver 70-80% of their original output, will be used for storing energy. As a first application they will be used to provide stability to the power grid through demand response and frequency regulation.

The EV taxis of the private company OÜ Takso will be partially recharged based on renewable energy that is produced on-site with PV panels and stored in used EV batteries. OÜ Takso installed the recharging point (for reusing the EV batteries) and 300 m2 of PV panels.

Figure 57. EV battery re-use system at Takso OÜ workshop in Tartu.

Collection of KPIs and city indicators applicable for the mobility action evaluation

This section provides the specific KPIs that will be used to evaluate the mobility actions of Tartu. For each KPI the variables to be measured is defined. These measures will in general come from sensors (monitoring equipment) and API´s, sometimes from other sources (service providers, registries etc.)

Sensors and equipment generally work flawlessly and data flows are smooth. Data is stored in Cumolocity platform. Regarding bike-share, we get the data from the supplier's database (Bewegen). The overall mileage of the bikes and the number/length of usage session is of particular interest in SmartEnCity project. The data and its quality are closely and continuously monitored by the bike-share system operator and city government. Data about bus traffic is collected from service operator GoBus and accuracy of timekeeping from Ridango. The data passes double-checking procedures. Data from other external sources is usually with a good quality and checked by data provides. However, we perform random checks on the data and in case of deviations, the problem is usually solved quickly by the data providers.

KPIs related to mobility and its values are presented as follows.

Average occupancy (EVs, in Tartu case electric bikes) – number of persons per vehicle/day.

Unit: Number of rentals by bike/day

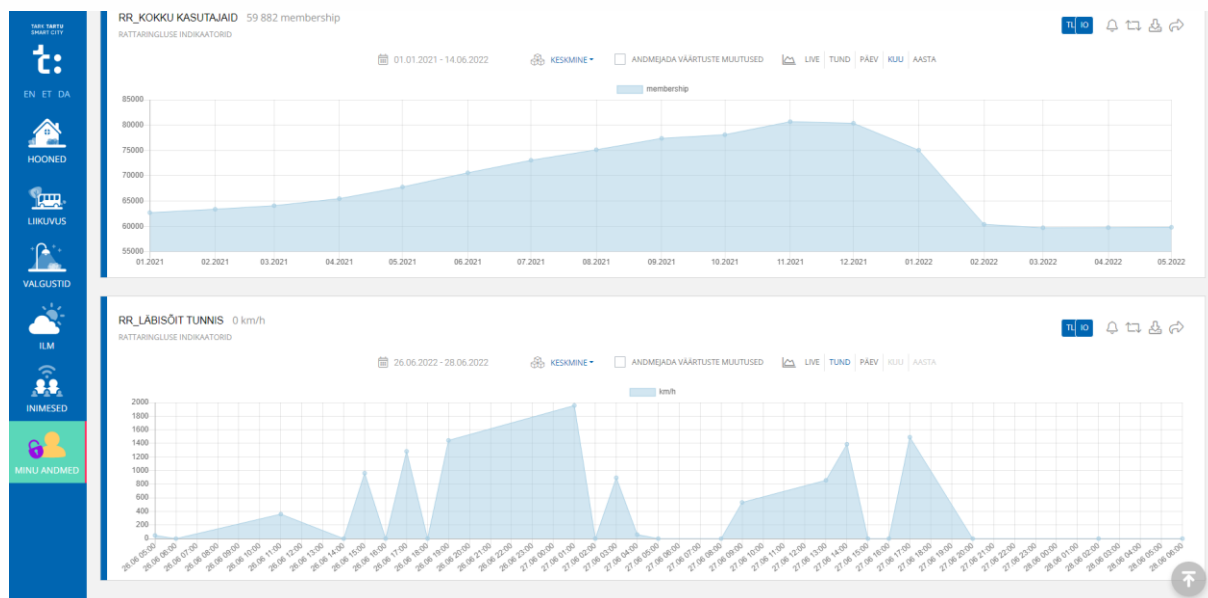Σ = (Num rentals/Num veh)/Num days = (285 183/750)/212 = 1,79

Figure 58. Monitoring data of bike-sharing in CIOP.

Accuracy of timekeeping for public bus – Number and percentage of services arriving/departing on time.

Unit: Number of services, % of services

Σ = (Dep in time/Dep total)*100 = (5 213 456 /5 782 888)*100= 90,15

CO₂ emissions by travelled distance – CO₂ emissions produced by travelled distance (cars).

Unit: kg CO2

Σ = Dst x EmCO2 (Distances travelled – Dst km; Emissions CO2 by km) = 204 972 000 x 0.214 = 43 864 087 kg

Total number of recharges per year (EV) – Total number of recharges during a year in the public and private charging stations.

Unit: Number of recharges
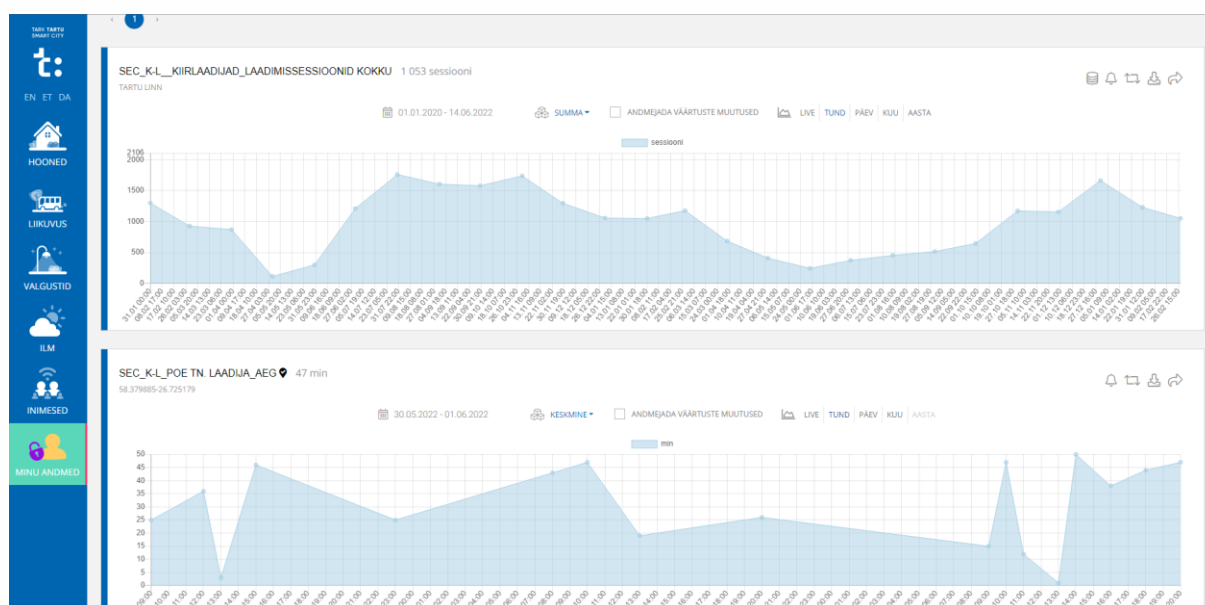
Σ = Num rec (cumulative) = 8098 recharges

Figure 59. Monitoring data of EV-chargers in CIOP

Total kWh recharged in the EV charging stations (EV) – Number of kWh recharged during a year in the public and private charging stations.

Unit: kWh/year

Σ (cumulative) = 125 100 kWh

5.2.5 Social Acceptance Protocol

In order to measure the social acceptance, perception and satisfaction of the actions performed in Tartu, numerous surveys and studies have taken place. Five studies (surveys and individual interviews) have been conducted (Table 31). First survey was conducted in order to map the residents' interest towards energy-efficient reconstruction of buildings in the pilot area and the means of communication people prefer at the very start of the project. Second, a survey of the residents of the pilot area was conducted before the start of the renovation to map the baseline (pre-reconstruction survey). Thirdly, in-person oral interviews were conducted with dwellers living in 8 different khrushchevka-type buildings in the pilot

area. Fourth, a city-wide and mobility survey was conducted as part of a bigger survey called "Tartu citizens and the environment", which is regularly carried out. Fifth, the survey after the reconstruction was conducted (post-reconstruction survey). There were a number of changes of KPIs (wording of the question, changes in the response categories, some KPIs were omitted) when compared to D7.9 that were collectively decided among the Tartu project partners. The changes were made mainly due to limited available space in the survey and confusing wording of the questions in D7.9. All the changes to KPIs have been reported in internal data collection and evaluation reports.

No.	Data collection method	Specific information	Time	Target group	KPIs
1	Survey	Preliminary survey of the demo area	Summer 2016	Pilot area residents	Not used for KPIs
2	Survey	Pre-reconstruction survey	Spring 2018	Pilot area residents	Used for KPIs.
3	Interviews	Structured interviews (14) and in-depth interviews before the reconstruction (6)	February 2018-June 2018; July 2019	Pilot area residents	Not used for KPIs.
4	Survey	"Tartu citizens and the environment"	Summer 2021	City-wide	Used for KPIs
5	Survey	Post-reconstruction survey	Spring 2022	Pilot area residents	Used for KPIs

Table 31. An overview of the social acceptance data collection in Tartu

PILOT AREA SURVEYS

Social background of people living in the pilot area

The response rate for pre-reconstruction survey was 30% and post-reconstruction survey 19%. Thus, the respondents of the surveys do not characterize fully the social profile of people living in a retrofitted apartment building.

More women responded to the survey: 64% (pre-reconstruction survey) and 67% (post-reconstruction survey). The average age of the respondents was roughly 50 years. The language of communication of more than 90% of the respondents is Estonian. More than 30% of respondents have lived in their apartment for more than 20 years, 24% (pre-reconstruction survey) and 27% (post-reconstruction survey) have lived up to 3 years. More than 60% of respondents are owners of the apartment. A more detailed description of the social profile of survey respondents and their dwellings can be found in Table 32.

Characteristics	Category	Pre-reconstruction survey	Post-reconstruction survey
Individual characteristics			
Age of respondent (average)		51	52

Gender (% of categories)	Female	64%	67%
	Male	36%	33%
Highest level of completed education (% of categories)	Basic education	4%	1%
	Secondary education	24%	19%
	Vocational education	6%	4%
	Secondary-vocational education	17%	17%
	Higher education	49%	60%
Primary language of communication (% of categories)	Estonian	91%	94%
	Russian	8%	5%
	English	0%	1%
	Other	0%	1%
Net monthly income of the households (% of categories)	<= 320 €	11%	0%
	321–640 €	40%	37%
	641–959 €	22%	21%
	960–1280 €	18%	15%
	1281–1600 €	4%	16%
	>= 1601 €	5%	11%
Employment (% of categories)	Employed	58%	57%
	Entrepreneurial employer	4%	4%
	Self-employed, freelancer	7%	9%
	Unpaid family worker	0%	1%
	Member of a commercial association	1%	2%
	Student	2%	2%
	University student	11%	10%
	Unemployed	2%	2%
	Long-term unemployed	0%	1%
	Retired	30%	27%
	Stay-at-home	2%	2%
	In other circumstances, a non-working	2%	4%
Size of the household (number of members, % of categories)	1	49%	28%
	2	37%	42%
	3	9%	17%
	4	5%	9%
	5	1%	4%
Dwelling characteristics			
Size of dwelling - heated area m2 (average)		41,5	40,6
Size of dwelling – number of rooms (average number)		2,1	2,2
Dwelling ownership structure (% of categories)	Owner	67%	66%
	Rental	18%	21%
	Apartment belongs to a family member / relative / friend (i.e. I do not pay	15%	13%

	rent)		
Accommodation time (% of categories)	<= 3 years	24%	27%
	4-6 years	13%	12%
	7-10 years	9%	11%
	11-20 years	15%	16%
	>= 21 years	39%	34%

Table 32. Social profile (KPIs) of people responded to the pre-reconstruction and post-reconstruction survey.

Environmental background

Awareness of environmental problems in the city. Since people's perception of one's awareness can be very subjective (people tend to overestimate their awareness), the question was changed and it was decided to ask about the relevancy of environmental problems in Tartu (also, KPI "Environmental awareness" was omitted due to lack of space in post-reconstruction survey). The most relevant environmental problem in Tartu according to the respondents was the increase of waste both in 2018 (very relevant for 49% of respondents) and 2022 (very relevant for 44% of respondents). In 2018, air pollution and noise were considered to be very relevant by 33% of respondents. In 2022, in addition to air pollution and noise, the motoring and low sorting and recovery of waste were also very relevant for more than 30% of respondents.
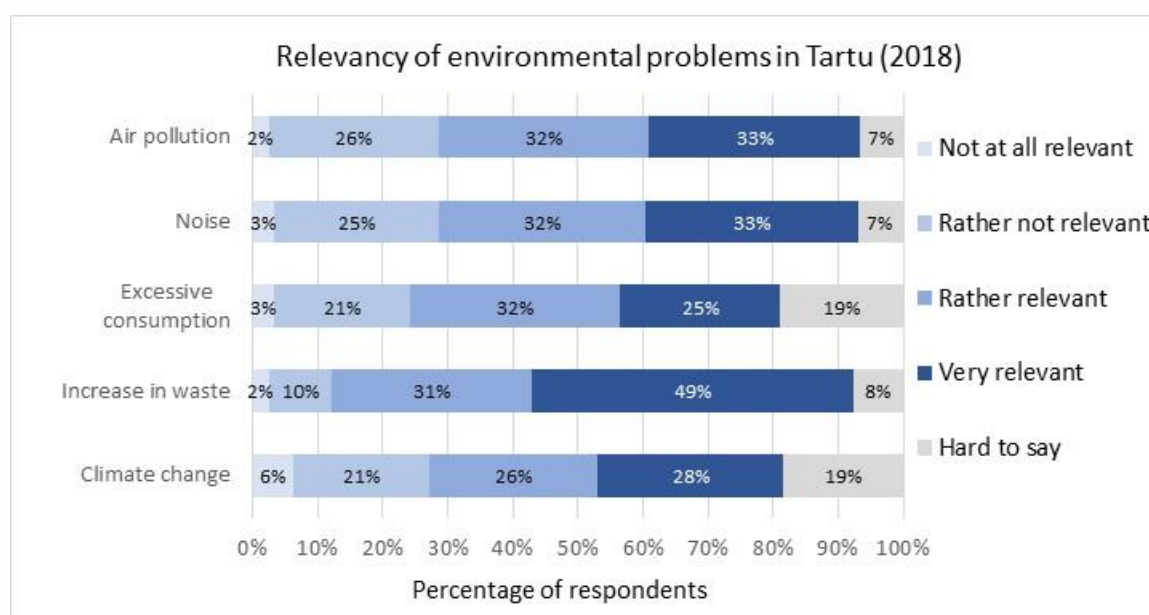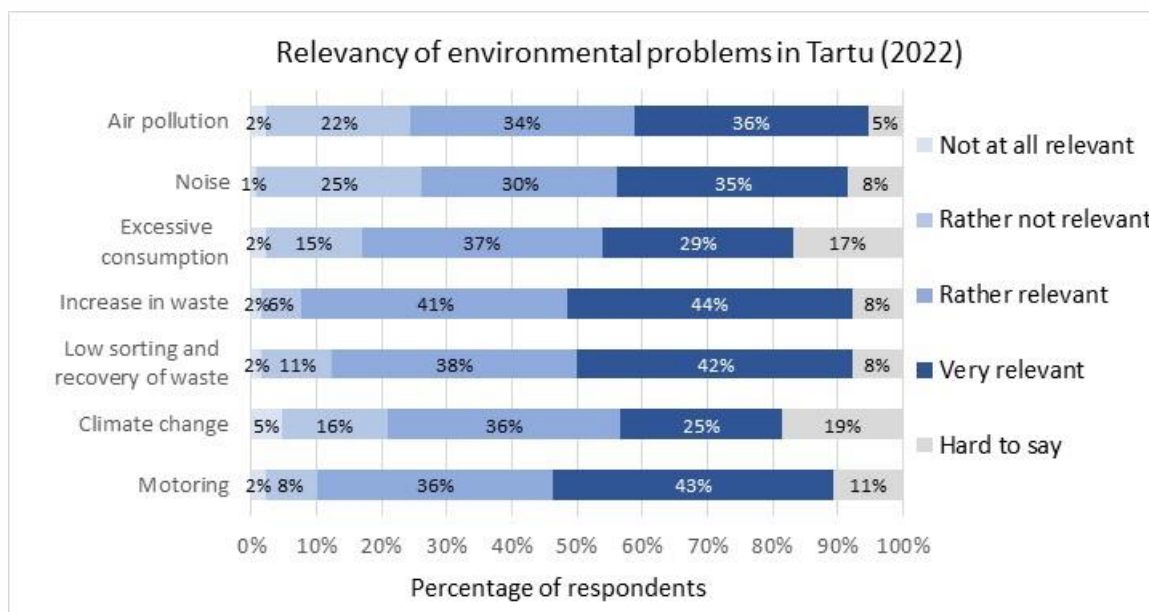
Figure 60. KPI "Awareness on environmental problems in the city" in pre-reconstruction survey (2018) and post-reconstruction survey (2022).

Knowledge about efficient energy measures. Due to similar reasons as stated above, this KPI rating people's "awareness" was exchanged with rating the "importance" of energy efficient measures. In both years (2018 and 2022) of the survey, the dominant important energy saving solutions were insulation of house and energy efficient windows. In the case of both energy saving solutions, in 2022, i.e. after reconstruction, the number of respondents who considered it to be very relevant was larger than 2018, i.e. before reconstruction.
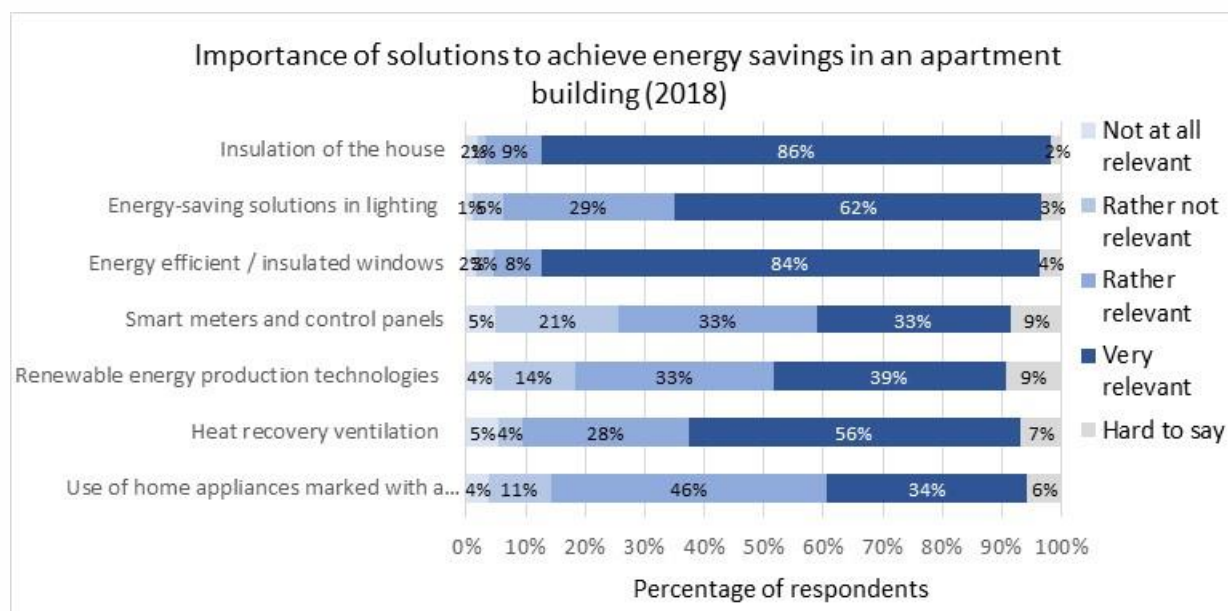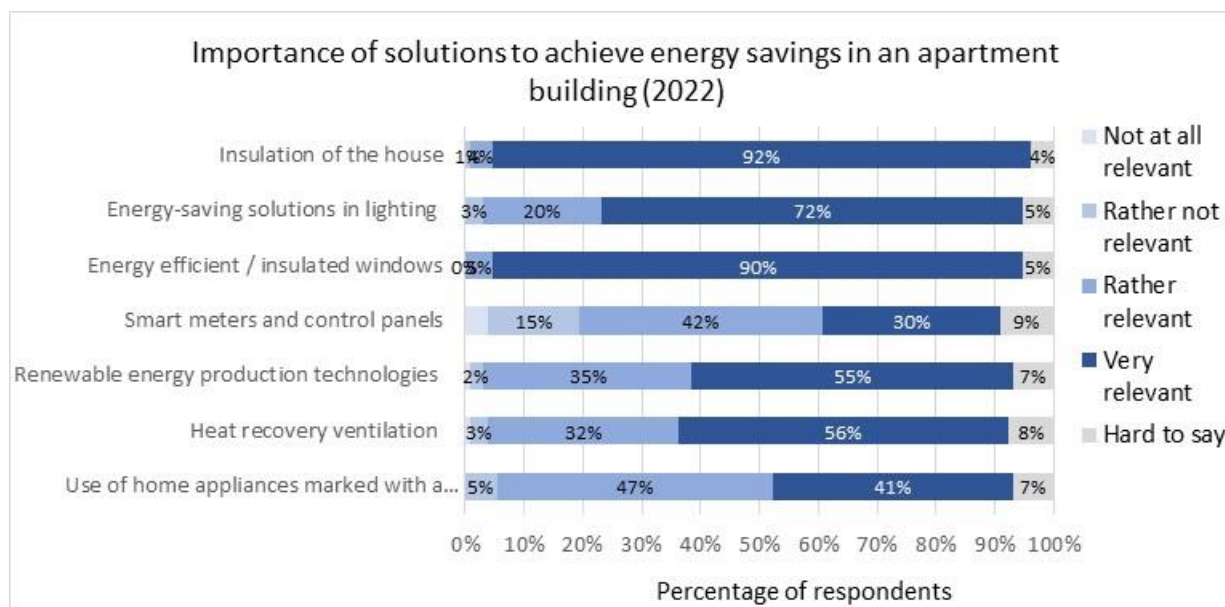
Figure 61. KPI "Knowledge about efficient energy measures" in 2018 and 2022.

Individual perceptions of residents

Residents project satisfaction. The wording of the initial KPI question was too general and it was changed. More than 70% of respondents agreed that the energy-efficient renovation of apartment buildings was a worthwhile undertaking.
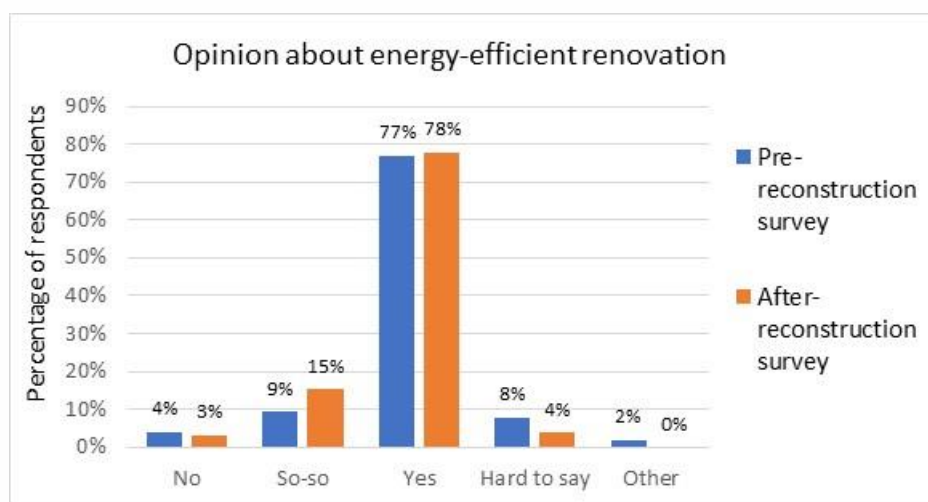
Figure 62. KPI "Residents project satisfaction" in 2018 and 2022.

Satisfaction with the information accessibility. Smart home systems were installed in every apartment of the retrofitted buildings, thus, the information accessibility is 100%. However, more informative aspect is how well residents understand the information retrieved from the smart home system. For approximately half of the respondents, the information on the smart home board is understandable and for 9% it is not understandable.
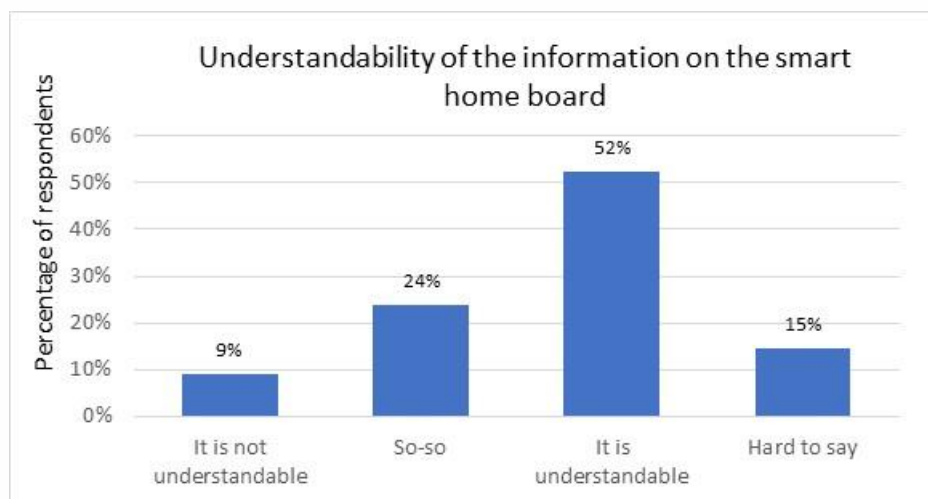
Figure 63. How well people understand the information from smart home system.

Resident information satisfaction, Satisfaction with the communication and dialogue with decision makers. As the engagement was a crucial activity throughout the project done by many parties, it was necessary to get a better picture whose engagement activities were sufficient and whose have a room for improvement; thus, the initial KPI wording was changed. 58% of the respondents are satisfied with the information provided by apartment association, 44% of the project team and 36% of the construction company.
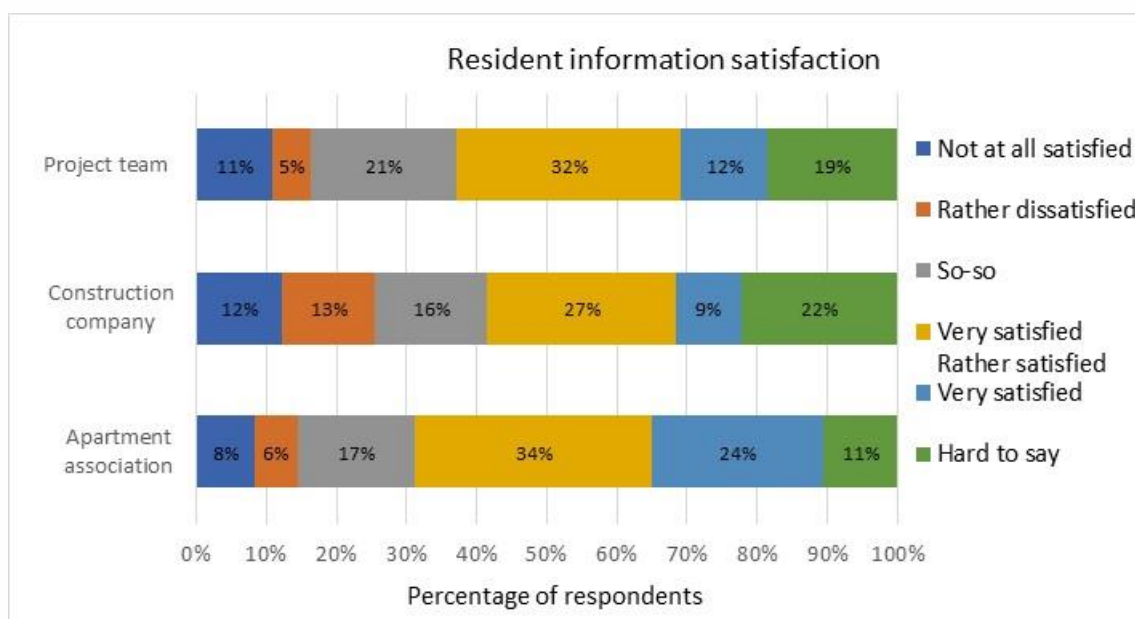
Figure 64. KPIs "Resident information satisfaction" and "Satisfaction with the communication and dialogue with decision makers".

Involvement degree. A third of the respondents felt involved in the renovation process, and a third did not feel involved.
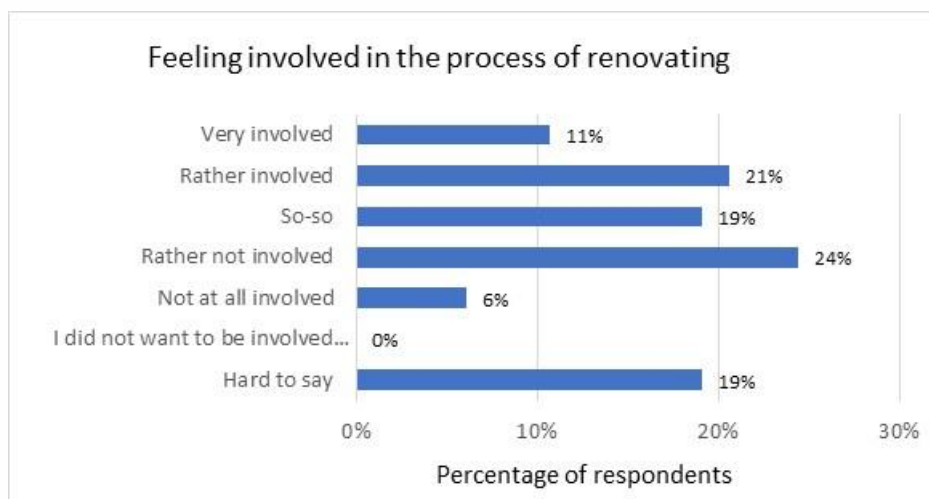
Figure 65. KPI "Involvement degree"

Resident consultation satisfaction. Initial KPI was too broad and a bit repetitive with the previous KPI. Instead, we wanted to understand which channels acted as the main information channels for the residents. The main source where people received information about the SmartEnCity reconstruction project of their apartment building was apartment association (73% of respondents). This was followed by information retrieved from the mailbox of the apartment (36% of respondents) and tarktartu.ee website (30% of respondents).
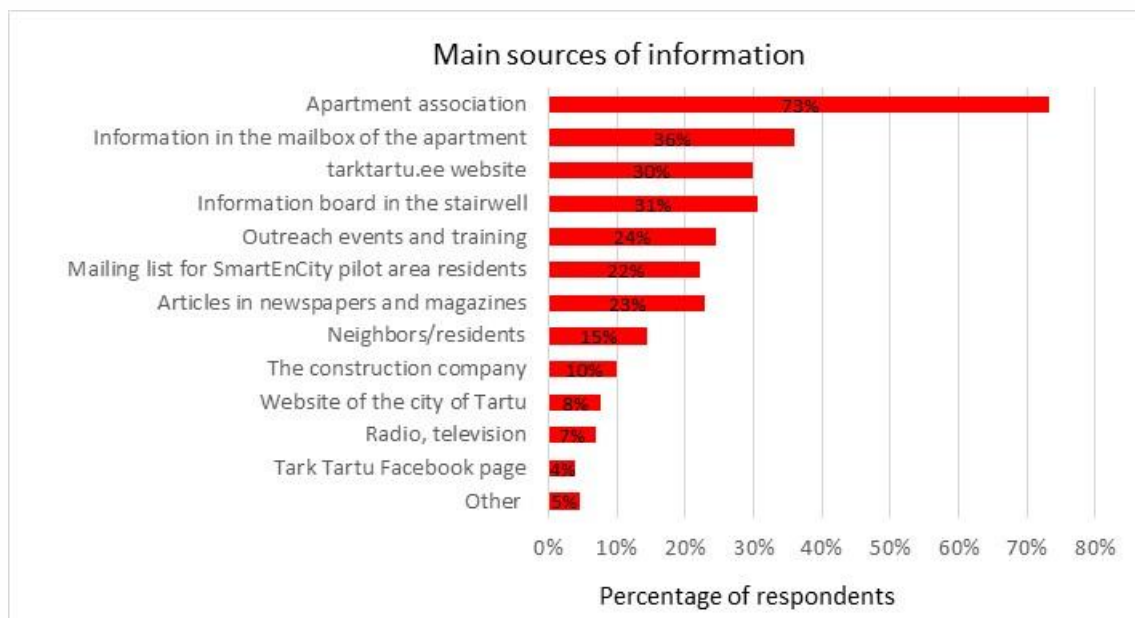
Figure 66. Channels for main sources of information.

Satisfaction with time plan for the execution of actions. Almost half of the respondents (46%) felt satisfied with the execution time plan and 17% were not satisfied.
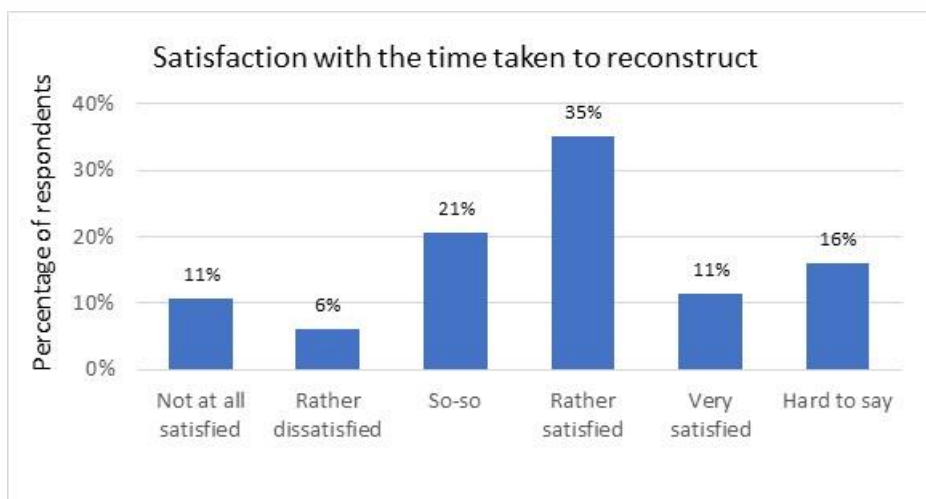
Figure 67. KPI "Satisfaction with the plan for the execution of actions".

Economic value of the solutions

Satisfaction with the investment costs. In terms of economic investment, majority of the respondents (53%) were satisfied with the monthly repayment of the reconstruction loan. KPI "Satisfaction with the payback period" was omitted, because Tartu residents did not have any choice in deciding the payback time period, it was fixed.
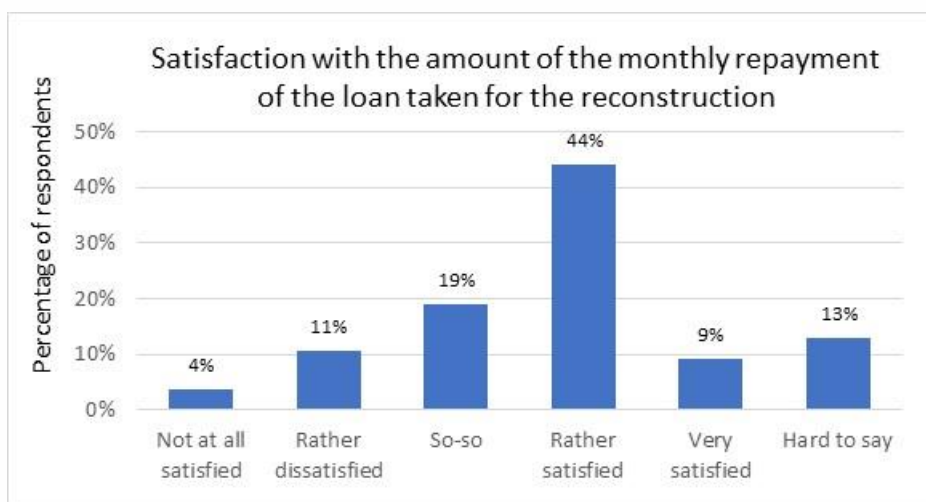
Figure 68. KPI "Satisfaction with the investment costs".

Satisfaction level with the reduction in the energy bills. For this KPI, we asked directly about heating bills, because this was most affected by the retrofitting. Majority of the respondents (72%) report the reduction of the heating bills.
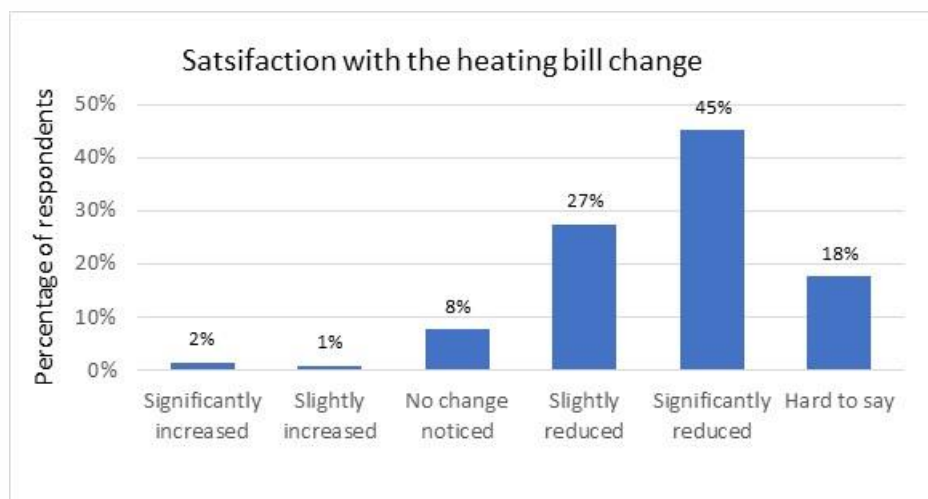
Figure 69. KPI "Satisfaction level with the reduction in the energy bills".

Willingness to invest further energy projects. The answers to this KPI were quite equally divided across response categories and it seems that no one opinion dominates. This can be probably due to the fact, that the respondents still "recover" from an extensive and rather uncomfortable retrofitting and future investments are not yet topical.
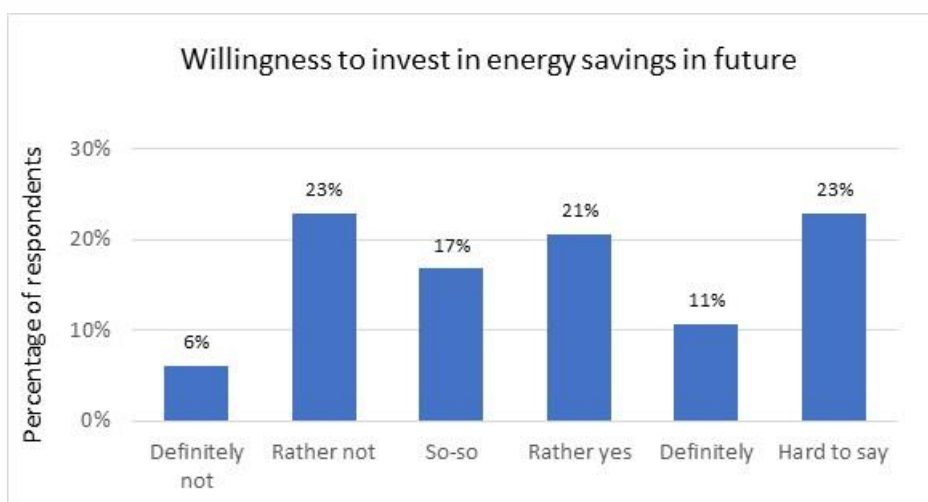

Figure 70. KPI "Willingness to invest further energy projects".

Technical value of solutions

Satisfaction with the solution implemented as a whole, Satisfaction with the quality of reconstruction The initial KPI was changed, because the question was too broad and not very informative. Instead, we asked the respondents to choose which building they prefer to live in, which makes them think about their satisfaction more realistically. 91% of the residents opt to live in a retrofitted building, 9% hesitate and no one wants to live in unreconstructed building. 60% of respondents are happy with the quality of reconstruction and 18% are not.
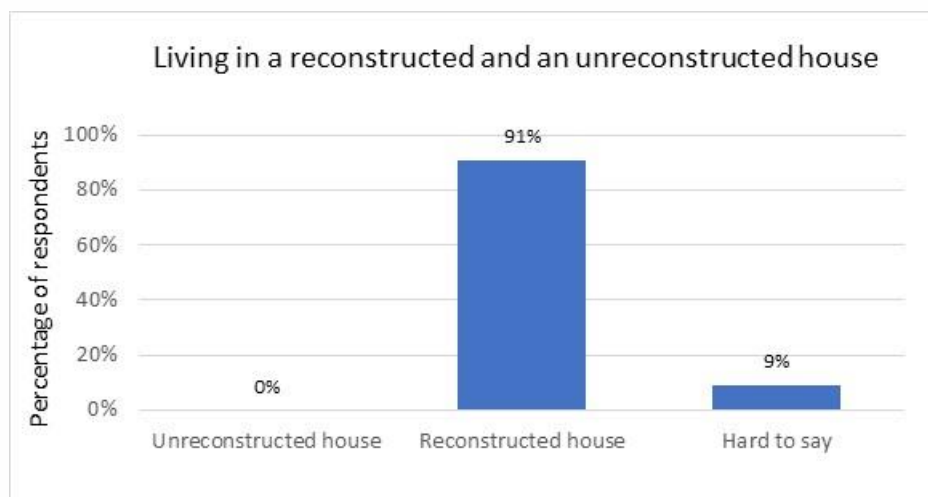
Figure 71. KPIs "Satisfaction with the solution implemented as a whole".
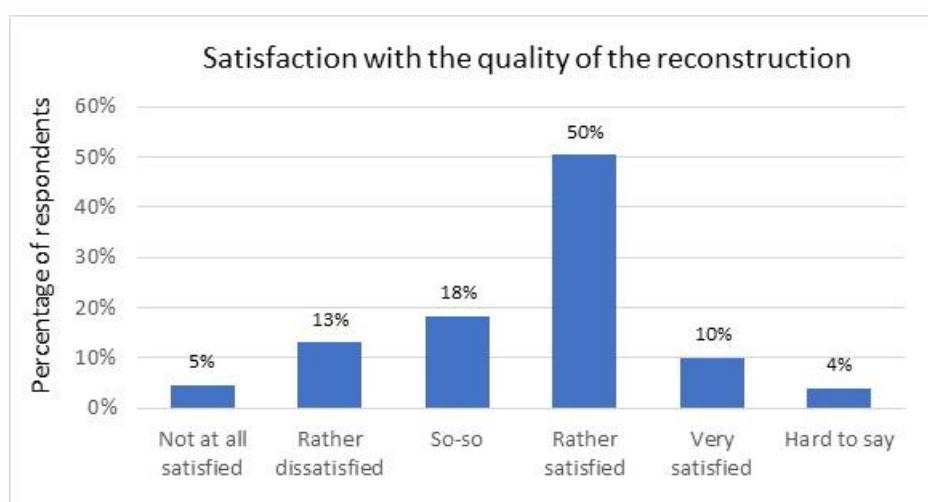

Figure 72. KPI "Satisfaction with the quality of reconstruction".

Satisfaction from the energy perspective (comfort). The internal temperature satisfaction was measured separately for winter and summer as required in D7.9. However, this aspect was measured in the survey with one question for each season instead of three as planned in D7.9. The difference between initial questions were too small and they were poorly worded. New questions are enough to answer this KPI. When compared with pre-reconstruction survey, an interesting result appears. The share of people who report the indoor temperature to be appropriate in winter has increased (from 37% to 56%). However, for summer the share of people who perceive the temperature to be appropriate has decreased from 36% to 26% and the share of people who perceive it to be very hot has increased from 10% to 24%. This indeed can be the case, because Estonian summers are getting warmer every year and in 2021 there was an exceptionally long heat wave. In insulated buildings where the heat loss is minimized, the internal temperatures can become too hot. Majority of the residents are satisfied with the ventilation and the satisfaction with the air quality has also increased when compared with pre-reconstruction time.
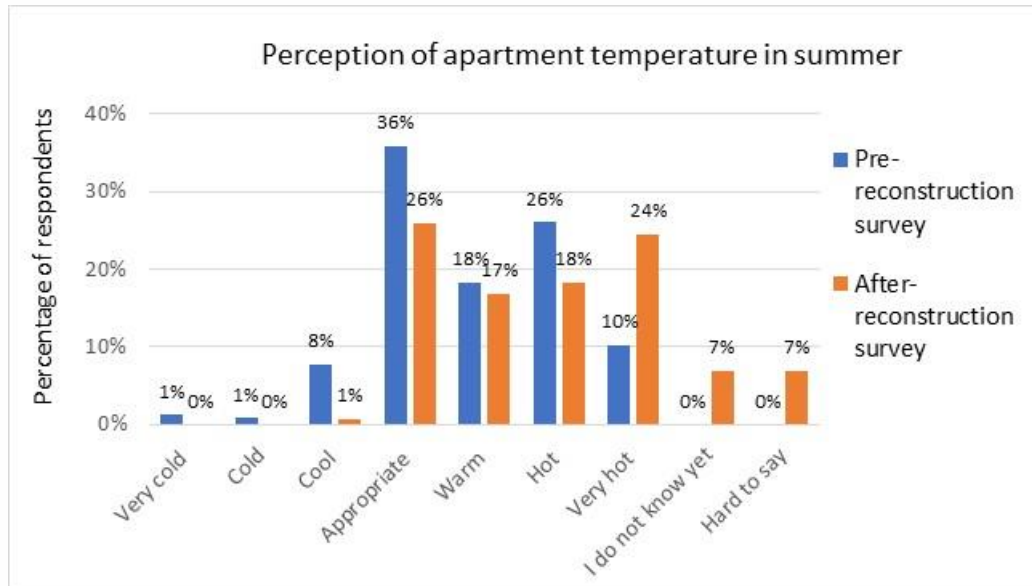
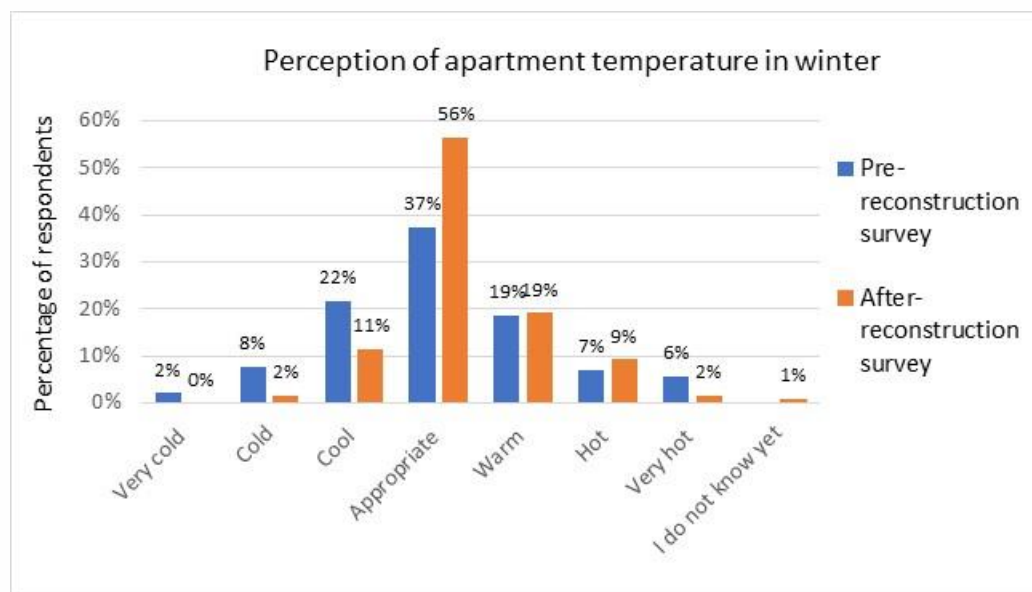**Figure 73. Thermal comfort in summer in 2018 and 2022**

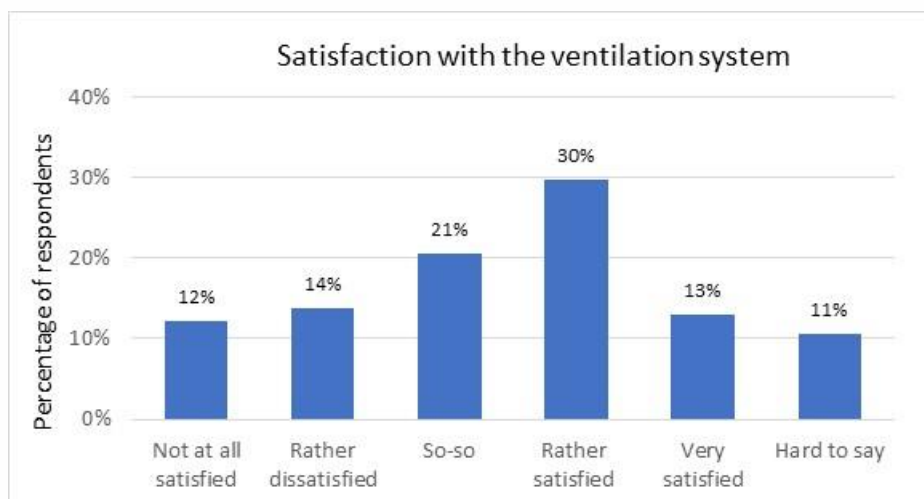**Figure 74. Thermal comfort in winter in 2018 and 2022**

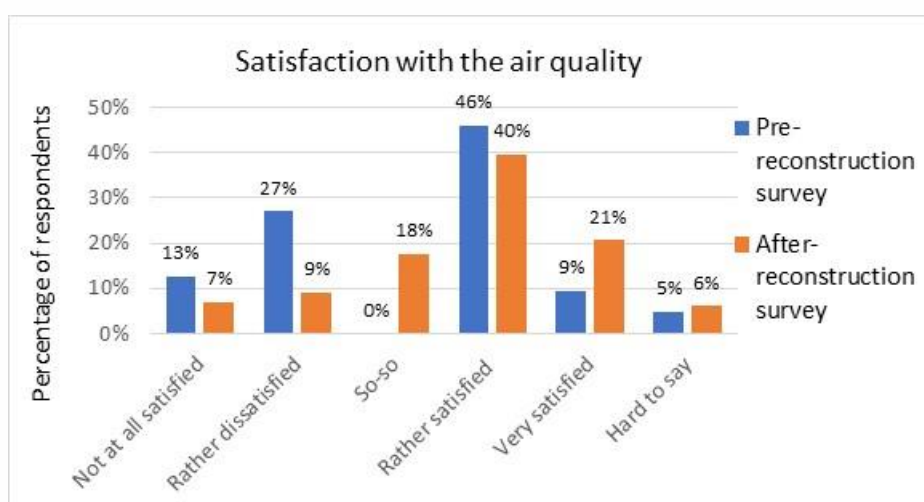**Figure 75. Satisfaction with the ventilation system**

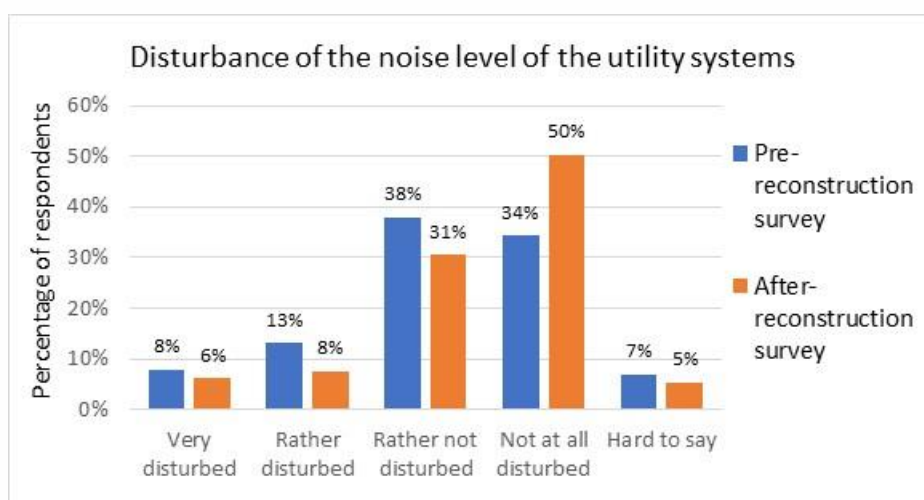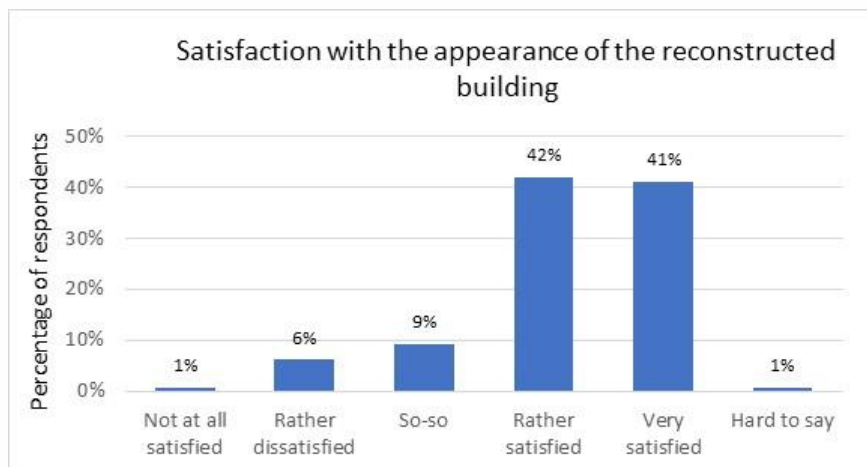**Figure 76. Satisfaction with the air quality.**

**Figure 77. Noise levels of the technical systems.**

Satisfaction with the aesthetic perspective. 83% of respondents are satisfied with the buildings' aesthetical appearance.

Figure 78. KPI "Satisfaction with the aesthetic perspective"
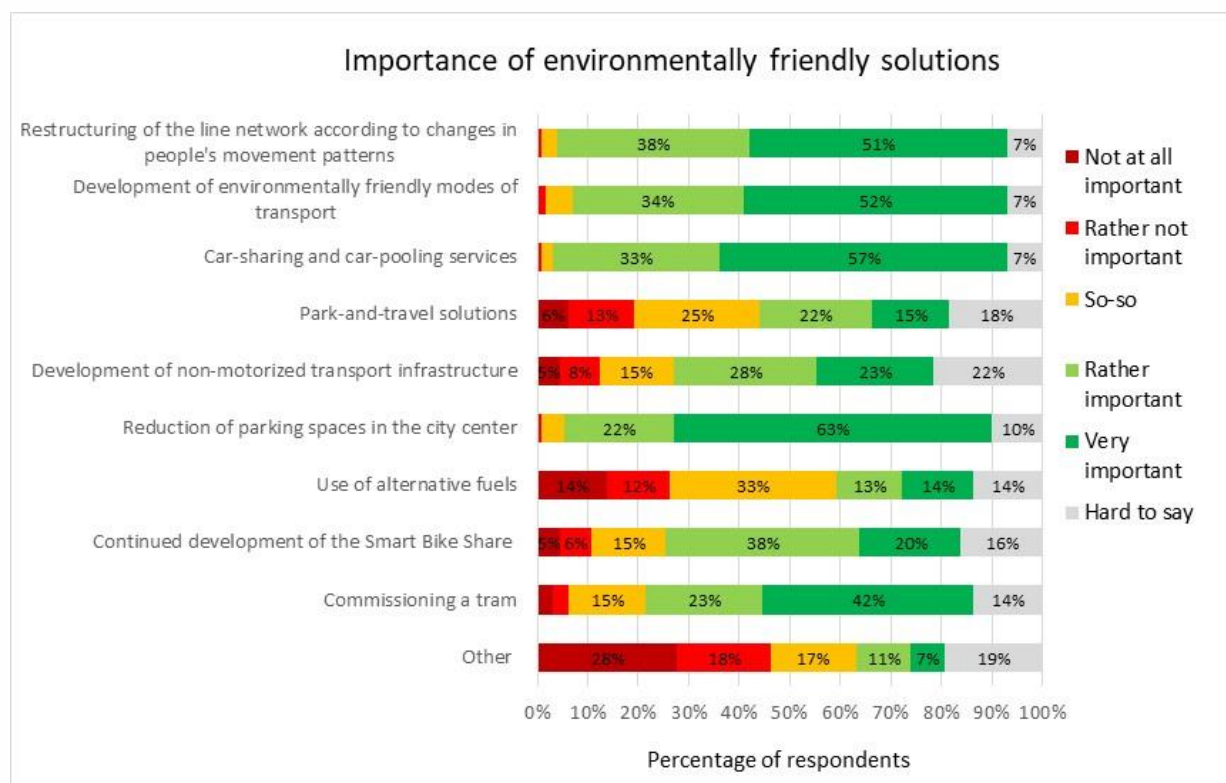
Mobility

Transport modes in summer and winter. Half of the residents of the pilot area walk, both in summer and winter, followed by car and public transport. The share of people using personal bicycle increases from 2% to 12% in summer.
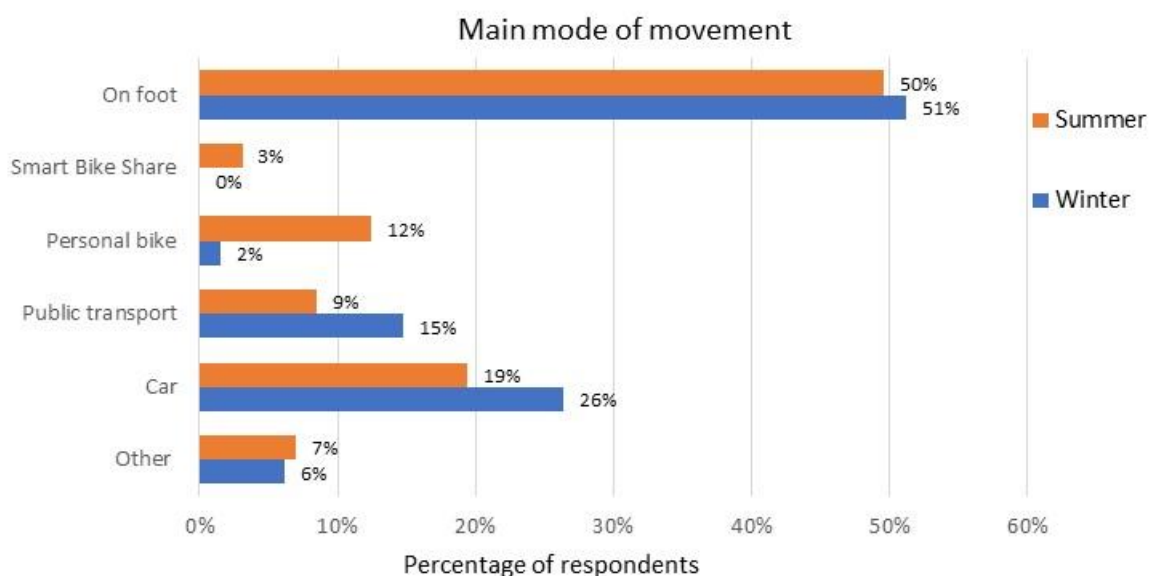
Figure 79. KPI "Transport modes"

Knowledge about efficient energy measures. Since people's perceptions of one's awareness can be very subjective and thus not very informative (people tend to overestimate their awareness), it was decided to change the wording of the question and to link it with Tartu city specifically. Following solutions are considered as very important by majority of the respondents: reduction of parking spaces in the city centre (63%), car-sharing and car-

pooling services (57%), developing environmentally friendly modes of transport (52%) and restructuring the public transportation line network according to people's mobility patterns (51%).


Figure 80. KPI "Knowledge about efficient energy measures".

Use of mobility services. All of the SmartEnCity project mobility services have been used by some demo area residents. A third of demo area respondents have used bike-share system and 68% have used public transport (incl biogas buses), 3% have used EV chargers.
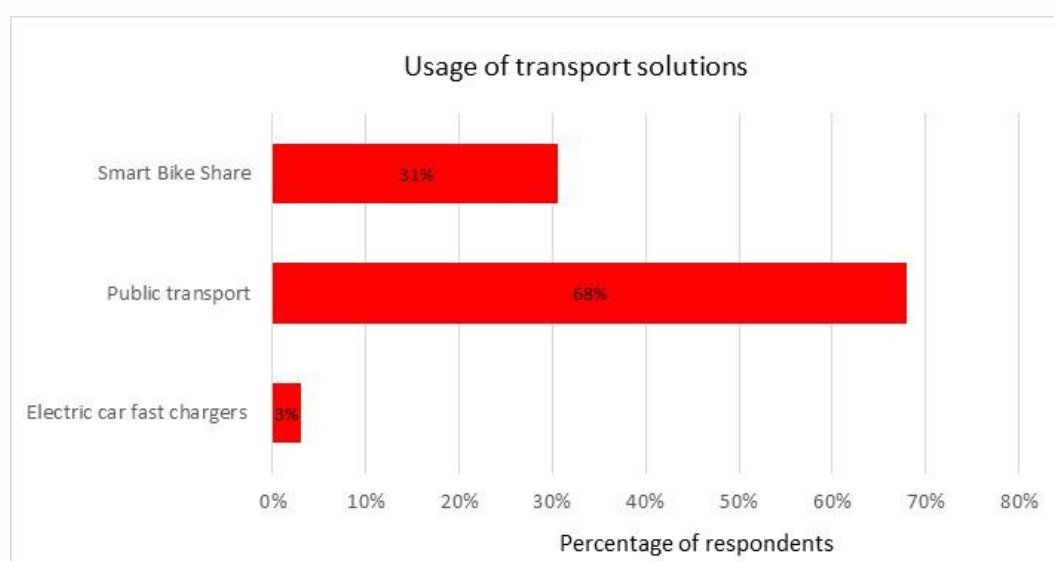

Figure 81. KPI "Use of mobility services"

Citizen's project satisfaction related to mobility, Whole solution satisfaction, Comfort conditions. We merged these KPIs under one question ("How satisfied you are with the next mobility actions in Tartu (incl ease of use and comfort of use)"). Those who have used public transport are mostly satisfied with the solution, and this applies to the bike-share system as well.
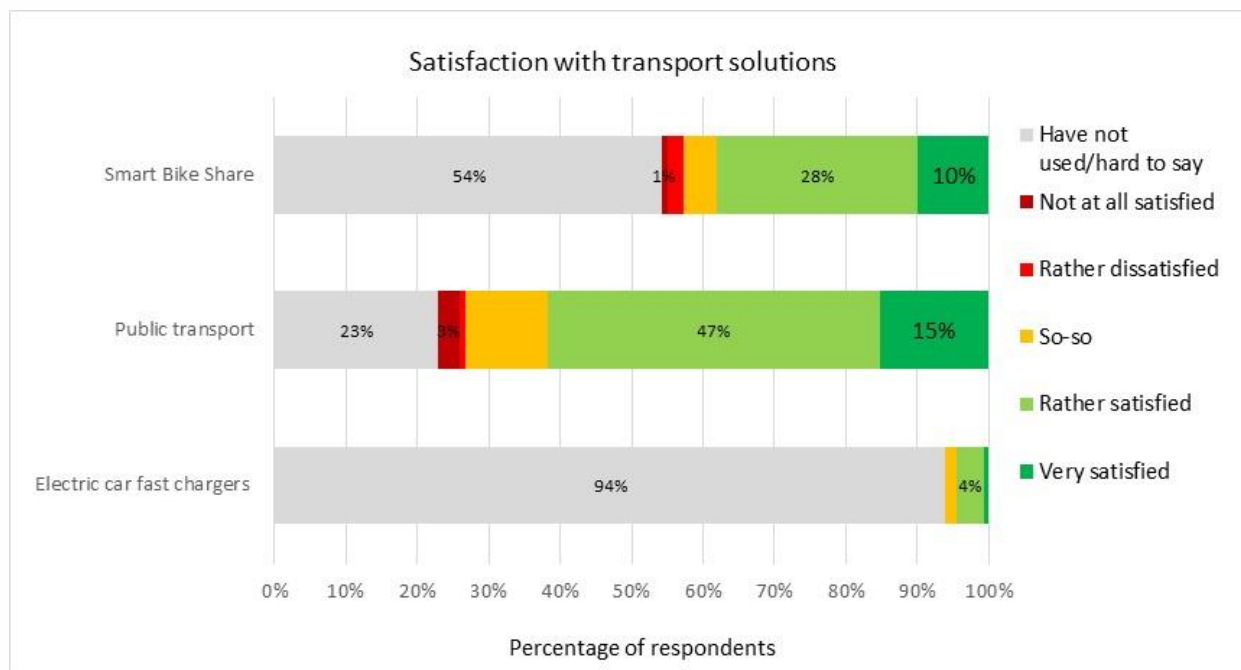
Figure 82. KPIs "Citizen's project satisfaction related to mobility, Whole solution satisfaction, Comfort conditions"

Willingness to purchase/invest in new EV or other energy project related to mobility. Regardless of the type of electric vehicle, the willingness to purchase one remains low among the respondents.
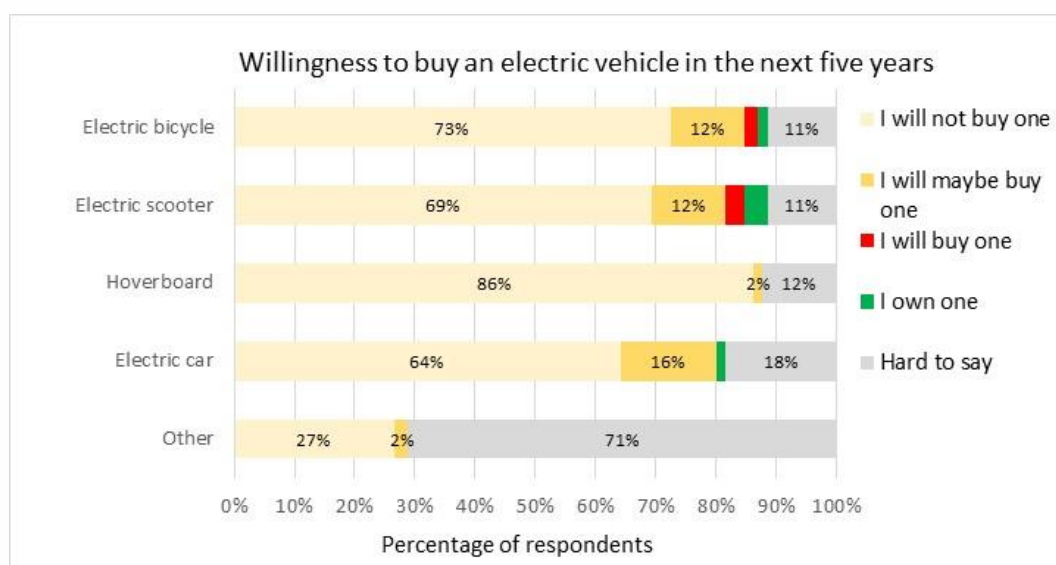
Figure 83. Willingness to purchase/invest in new EV or other energy project related to mobility

MOBILITY AND CITY-WIDE SURVEY

The mobility and city-wide survey were united (see further D7.12). This survey was part of a bigger survey regularly conducted in Tartu, thus, the space allocated to SmartEnCity project questions was limited (see further D7.12). A selection of the most important KPIs was made and included in the survey. Weights for whole Tartu have been applied when reporting the KPIs, so the results presented as follows are generalizable to the whole Tartu in terms of gender and age.

### Social background of the people in the whole Tartu

Among the respondents to the city-wide survey, 57% were female and 43% were male. The average age of the respondents was 48 years. The proportion of people with higher education was 56%. Respondents whose main language is Estonian dominated (82%), there were 15% of Russian speakers and other language speakers 3%. The majority of respondents were employed (71%), retired were 13% and students 8.5%. 63% of respondents were apartment owners.

Characteristics	Category	Results from mobility and city-wide survey
Social background		
Age of respondent (average)		48
Gender (% of categories)	Female	57%
	Male	43%
Highest level of completed education (% of categories)	Secondary education	4%
	High school, vocational, secondary-vocational education	40%
	Higher education	56%
Primary language of communication (% of categories)	Estonian	82%
	Russian	15%
	Other	3%
Employment (% of categories)	Employed	71%
	Student	8.5%
	Retired	13%
	Not working	7.5%
Characteristics of dwelling		
Type of dwelling/building (% of categories)	Single-family house	19%
	Two-family house	5%
	Terraced house	4%
	Less than a five-story multi-apartment building	30%
	Five or more story apartment building:	41%
	Other	1%
Dwelling ownership structure (% of categories)	Owner	63%
	Rental	11%
	Apartment belongs to a family member/relative/friend (i.e. I do not pay rent)	26%

City districts (% of categories)	Annelinn	26%
	Ihaste	3%
	Jaamamõisa	4%
	Kesklinn	7%
	Karlova	9%
	Maarjamõisa	1%
	Raadi-Kruusamäe	5%
	Ropka	5%
	Ropka tööstusrajoon	2%
	Ränilinn	2%
	Supilinn	2%
	Tammelinn	9%
	Tähtvere	6%
	Vaksali	3%
	Variku	2%
	Veeriku	5%
	Ülejõe	8%
	The territory of the former Tähtvere municipality	1%

Table 33. Social background (KPIs) of the respondents in city-wide survey.

Transport modes. The respondents' main transport mode in the summer is walking (43%), followed by driving a car (28%) and personal bicycle (14%). In winter, the most used transport mode is the car (45% of respondents), followed by walking (28%) and using public transport (24%). Bike-share bicycles are used by 3% of the respondents in the summer and 0.2% of the respondents in the winter.
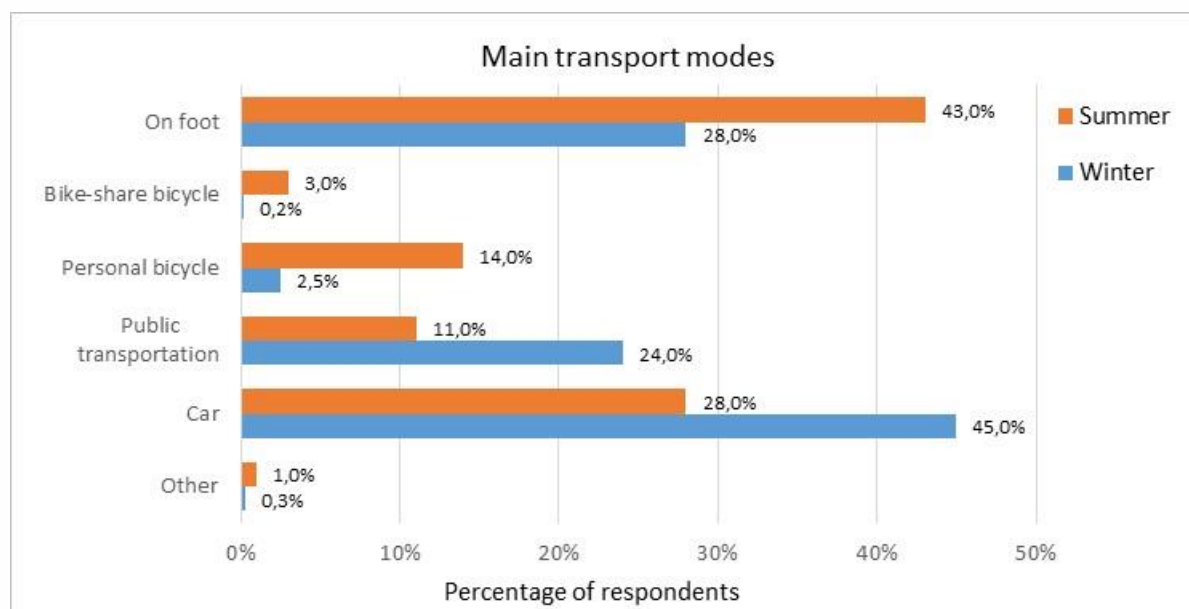
Figure 84. KPI "Transport modes".

Environmental background

Awareness of environmental problems in the city. Since people's perceptions of one's awareness can be very subjective and not very informative, it was decided to change the wording of this question. The most mentioned very topical environmental problem in Tartu are parking issues (43% respondents), excessive number of cars (37% respondents) and the growth of waste (34% respondents). Air pollution, noise and climate change were considered the least important problems.
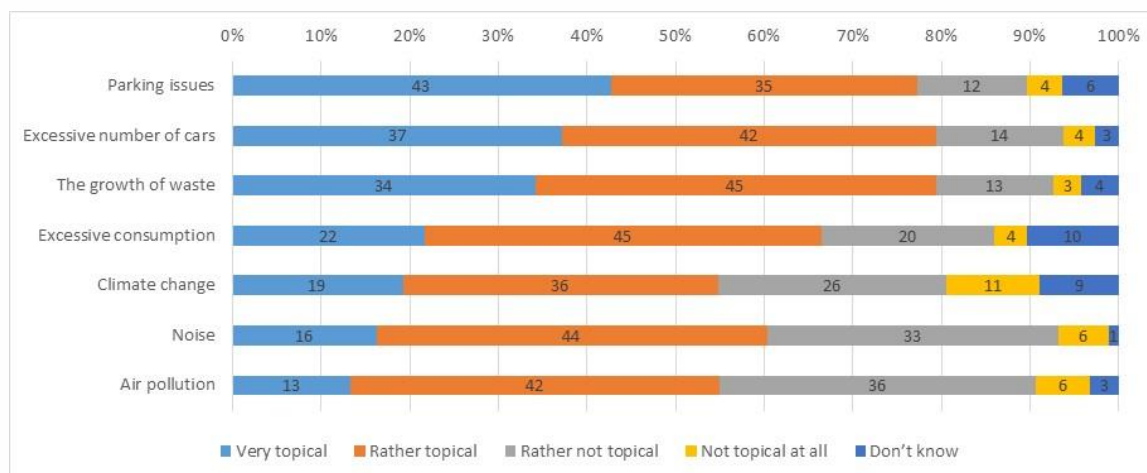

Figure 85. KPI "Awareness of environmental problems in the city"

Knowledge about efficient energy measures. Similarly, as above, awareness was not measured and the wording was changed to measure the importance of different energy saving solutions in apartment building. Most of the respondents said that energy-efficient solutions in lightning (40% respondents), insulation (32% respondents) and energy-efficient windows (26% respondents) are already in use. Insulation (34% respondents), monitoring own energy consumption (31%) and energy-efficient windows (28% respondents) were considered as very important in achieving energy efficiency. Buying green electricity, smart meter and dashboard for monitoring energy use, heat recovery ventilation and technology for producing renewable energy (i.e. solar panels) were considered less important.
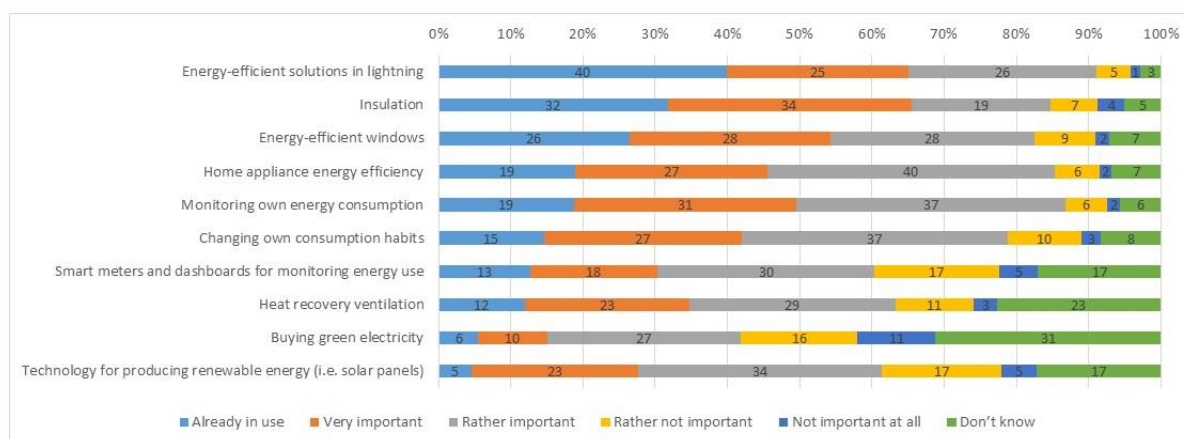

Figure 86. KPI "Knowledge about energy efficient measures"

Knowledge about efficient energy measures in mobility. Similarly, as above, awareness was not measured and the wording was changed to measure the importance of different

energy efficient solutions in related to mobility. The respondents considered developing light traffic network (53% respondents), developing environmentally-friendly transport modes (43% respondents), changes in public transport line network (35% respondents), and public transportation continuous development (34% respondents) to be the most important energy efficient solutions related to mobility. Tram was considered the least important, followed by limiting parking spaces in the city centre, and car-sharing and car-pooling.
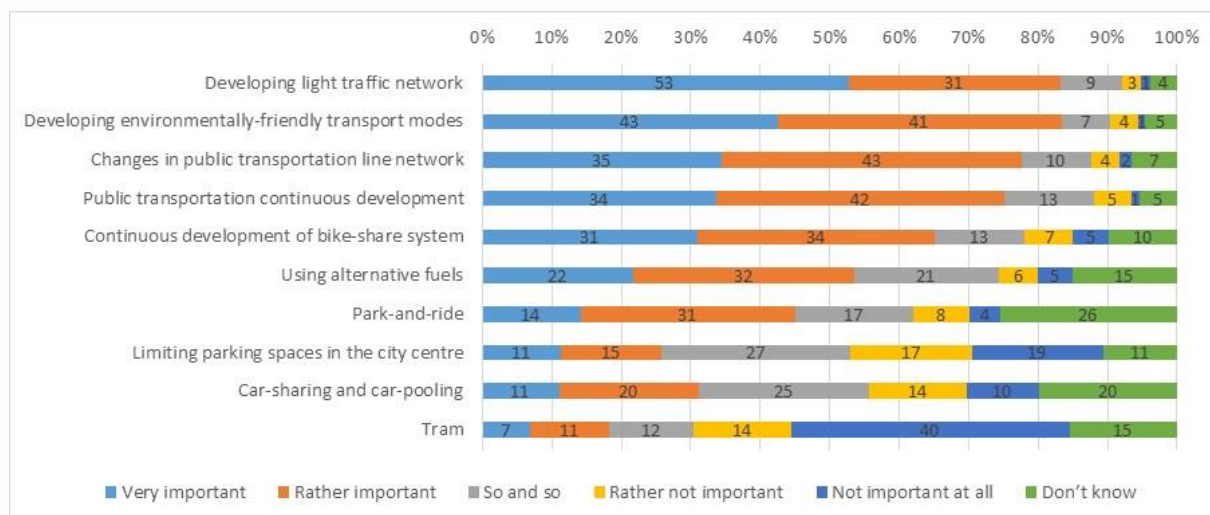

Figure 87. KPI "Knowledge about energy efficient measures in mobility"

Familiarity and satisfaction with the project

Acquaintance with the project. 40% of Tartu's residents have heard of the SmartEnCity project, including 2% of respondents live in one of the reconstructed buildings. 60% haven`t heard about the project. The respondents knew the most about bike-share, biogas buses, and wall murals on the reconstructed buildings. More than half of the respondents did not know anything about cooling station and Tartu SECAP.
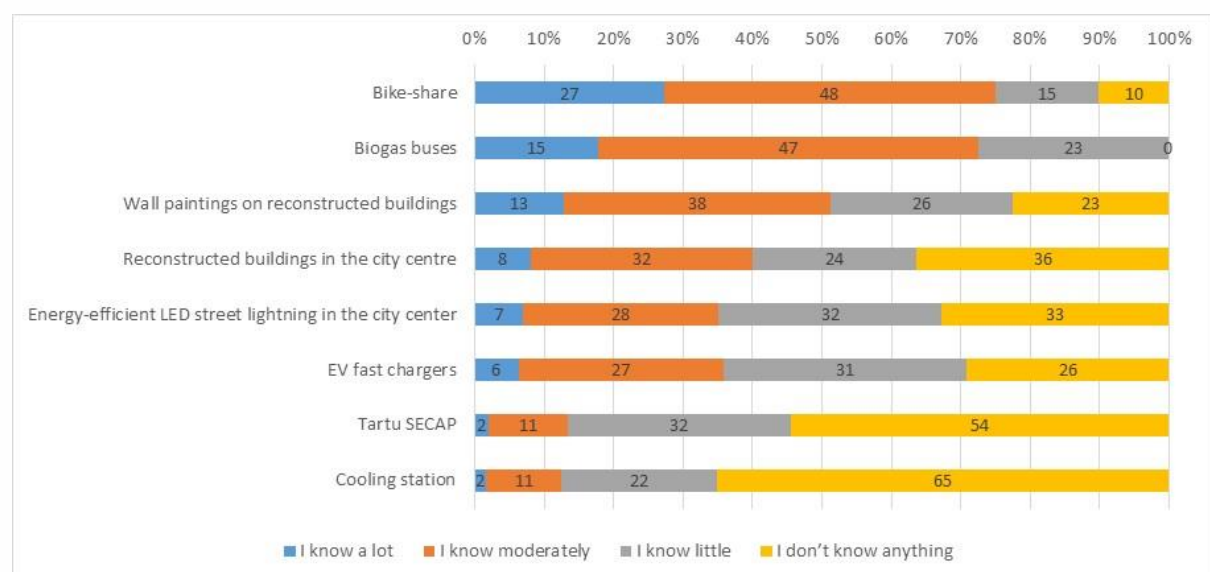

Figure 88. KPI "Acquaintance with the project"

Citizen information satisfaction. This KPI was replaced with the question about the sources of information about the project, because the information satisfaction from the people who do not live in the demo area, is not very useful. The largest number of respondents received information about the project from journals or magazines (66% respondents); from friends and family (46% respondents), and radio or television (40% respndents). The fewest respondents received information via the SmartEnCity e-mail list, which was only for the residents of the SmartEnCity pilot area.
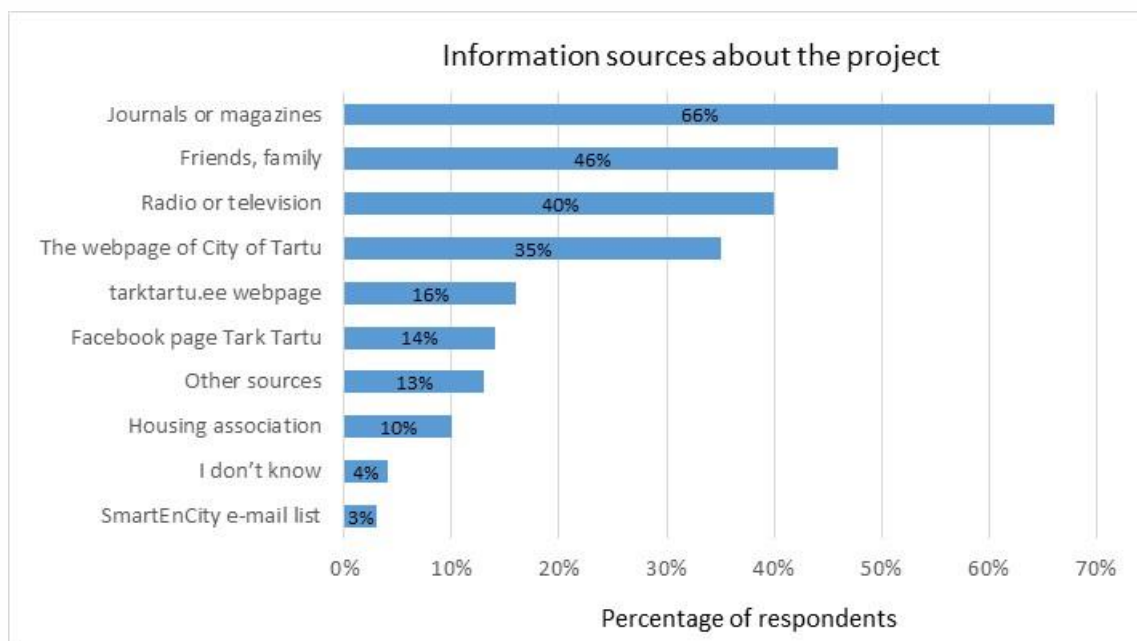

Figure 89. Sources of information.

Use of mobility services. The largest number of respondents had used biogas buses from the infrastructure created during the project (80% of respondents), followed by bike-share (45%) and EV fast chargers (11% of respondents). The main reason for not using mobility services was that "there is no need", followed by "don`t own EV vehicle".
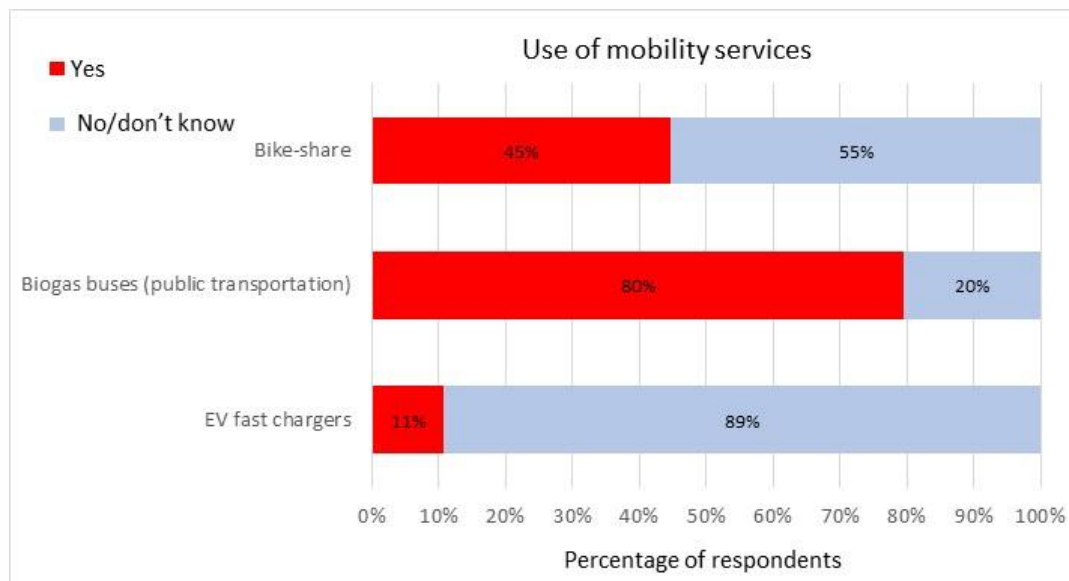
Figure 90. KPI "Use of mobility services".
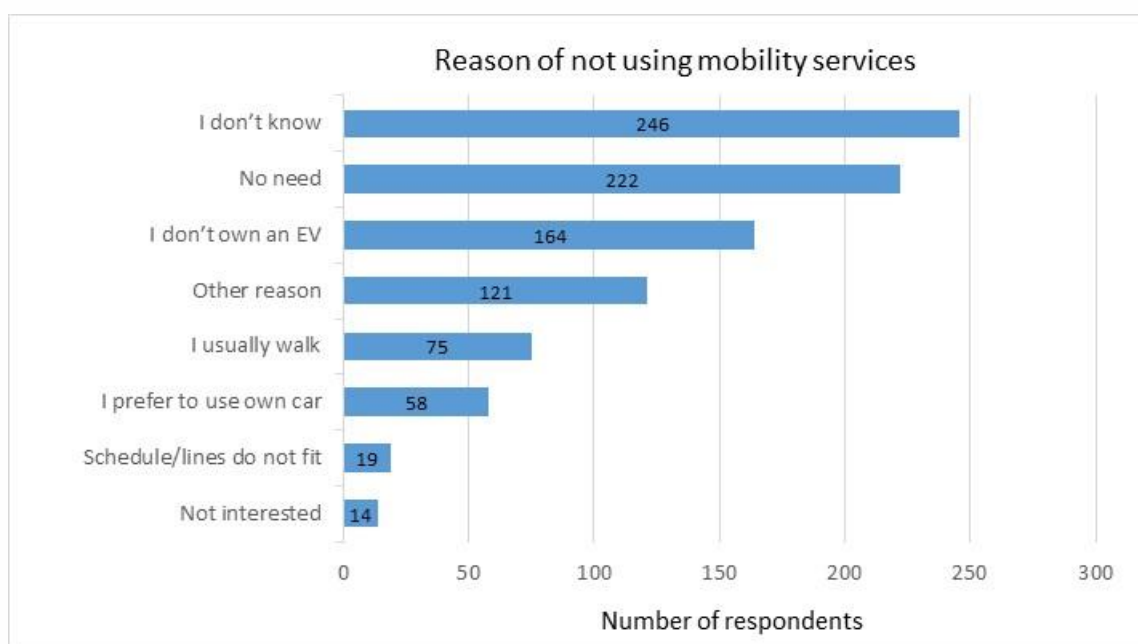
Figure 91. Reasons for not using mobility services.

Citizen's project satisfaction related to mobility. The respondents were most satisfied with biogas buses / public transportation (49% satisfied, including 10% very satisfied). 33% were satisfied with bike-share, including 7% very satisfied, and slightly more than half of the respondents had not used it. 89% of respondents had not used EV fast chargers.

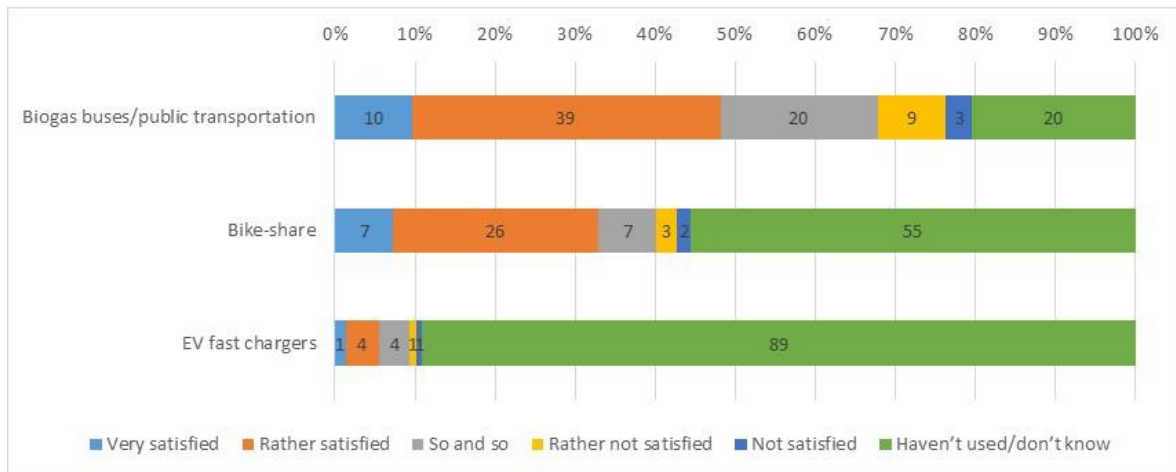**Figure 92. KPI "Citizens' satisfaction related to mobility actions"**

Willingness to invest in further energy projects

Further investment in energy related projects. More than half of the respondents (61%) are ready to invest in their building energy efficiency. 6% of respondents disagree. 83% of respondents think that the city should invest in energy saving projects. Less than 1% think city should not do it.
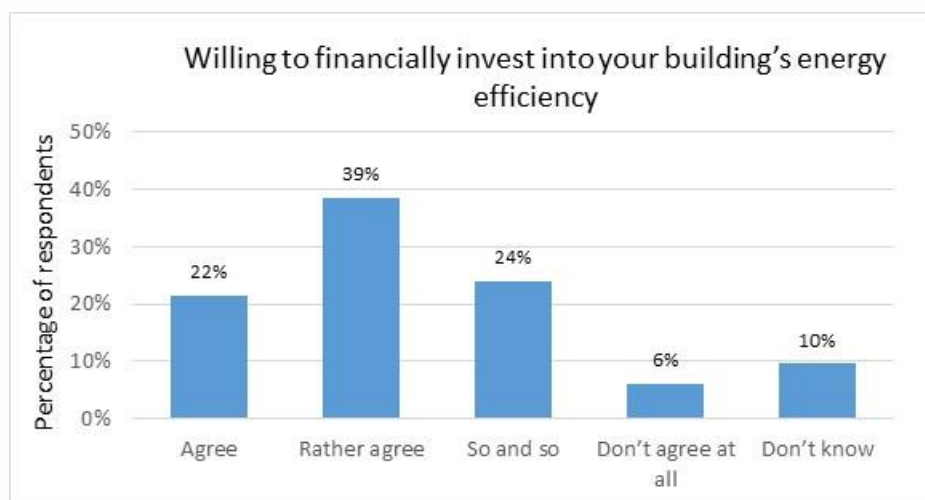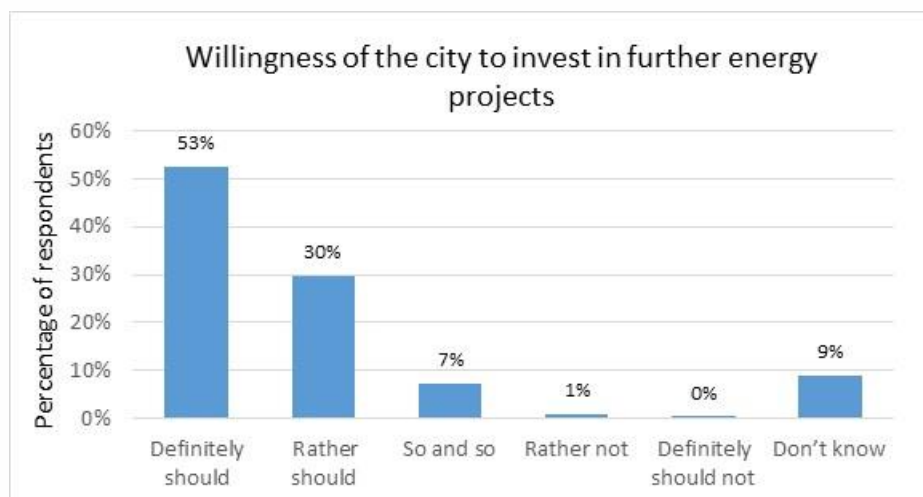
Figure 93.KPI "Further investment to energy related projects"

Willingness to purchase/invest in new EV. The willingness to invest in EV is very low – 5% of citizens either have or plan to buy an electric scooter, 3% electric bicycle and 3% electric car.
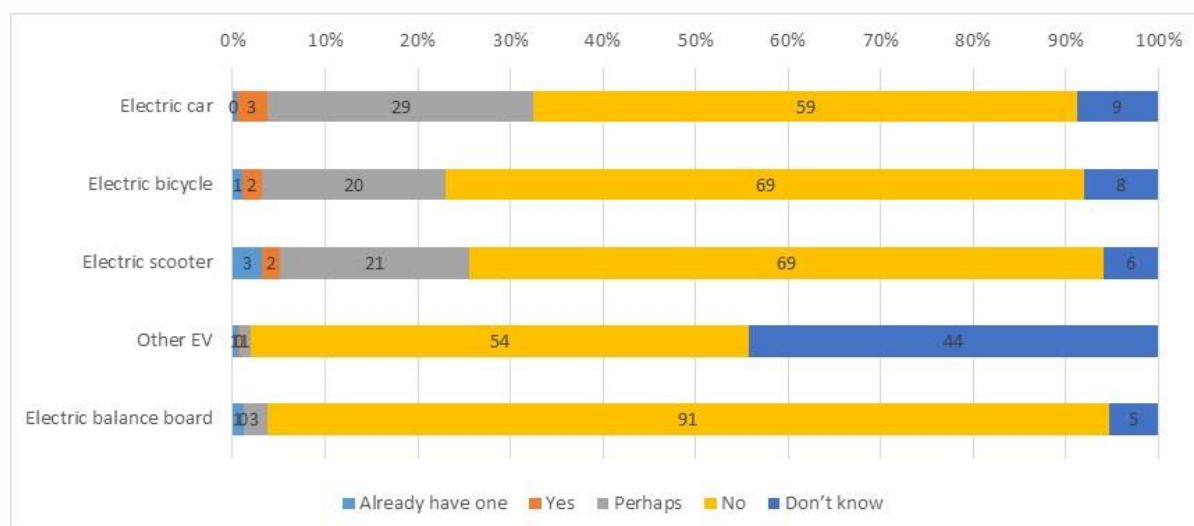
Figure 94. KPI "Willingness to invest in EV"

5.2.6 Citizen Engagement Protocol

For the SmartEnCity project to succeed, active participation of citizens is required. All the buildings in the renovated district are privately owned and the collective decision by the owners is required for the renovation to take place. The SmartEnCity project can support this process but the final decision (including decisions about the technical design and its implementation) has to be made by the representative NGO of the private owners (building association). Because of this, the main focus of engagement is on the building associations and the main task is to include the associations into the renovation process (even if they do not participate in the SmartEnCity project). The single most important act of engagement will be the decision to renovate, made by the housing associations. Everything in the project has to support this decision and help its realization.

In light of this, the main target groups included for citizen engagement are:

1. Pilot area residents
2. Citizens of Tartu

Pilot area residents will be addressed as a whole group but different approaches are used for certain distinct target groups.

The KPIs under citizen engagement strategy (as per D7.9) for resident information satisfaction are:

Respondents who considered to be well-informed – According to the post-renovation resident survey, 44% of respondents were rather or very satisfied with the communication efforts of the project team with only 16% unsatisfied. 19% were not sure which is expected since many of the residents are tenants and have probably changed over the years.

Figure 95. KPI "Residents who considered to be well-informed".

Respondents who answered this question – 132 residents responded to the questionnaire.

In Tartu, our strategy is mostly focused on informing, consulting, involving and co-creating with the citizens, the latter most notably through the artwork creation and selection for each renovated house. As house renovations and other project activities require most input from public authorities, citizens will be mostly communicated with, consulted with and they will be involved in the development of project activities and in certain decision-making processes. In some activities, more collaboration and co-creation is expected, e.g., choosing artworks to go on the facades of their houses, etc. The end goal of Tartu is to have well-informed citizens who feel that they have and they can contribute to the development of Smart Tartu.

The KPIs under citizen engagement strategy (as per D7.9) for citizen engagement satisfaction are:

Respondents who considered to be well-informed – in the "Tartu citizen and environment" city-wide survey, 40% of Tartu citizens had heard of the SmartEnCity project. The most well-known action is bike-share system – 90% of citizens are aware of this mobility solution. People living in the demo area have also used the various services of the project,

e.g. 31% of people have used the bike sharing bikes, 68% have used public transportation and 3% have used EV chargers.

Respondents who answered this question – 1000 citizens responded to the city-wide survey and 131 respondents (100%) to post-reconstruction survey.

Other important aspects of engagement in Tartu are mobility (bike sharing system and mobility habits) and social innovation and mutual learning - not only teaching the pilot area residents how to use new technologies but also ensuring that Tartu as a whole becomes more accepting of new technologies and innovations – this includes both the planned smart home systems and, for example, new EV technologies in mobility.

Resident consultation satisfaction and involvement degree were also explored via various surveys. According to the post-renovation survey in 2022, half of the residents were active participants in various project events:
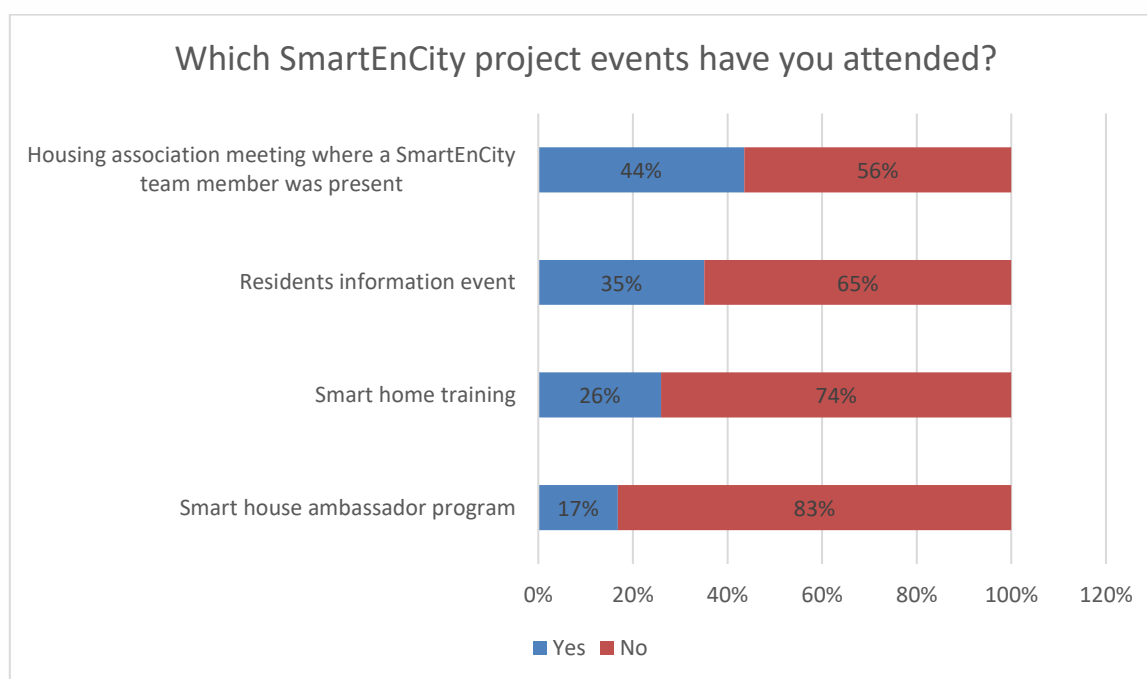
Figure 96. KPI "Resident consultation satisfaction and involvement degree".

Additionally, 36% of respondents had received project information via their mailbox and 31% via the information stand in the hallway (these stands were provided by the project team and print information from the project team is also shared there). 30% of the residents also visit the project webpage. The most popular channel for receiving renovation information was the housing association (73%), which was also a key communication channel for the project team, e.g. putting up posters and invitations on the hallway information stands, forwarding emails to the citizens, etc.

Regarding the project information materials such as the Smart house handbook and the smart home instruction manual, 73% of residents have read them.

The response rates for various surveys are as follows:

- Pre-reconstruction survey were distributed to 816 apartments and 255 answers were received. The response rate was 31% ((255/816) ×100). The response rate for the most active apartment association was 45%.

- City-wide and mobility survey used a quota sample of 1000 residents, thus, the response rate could not be calculated. The sample was constructed based on Tartu's population statistics.

- Post-reconstruction survey were distributed to 688 apartments and 132 answers were received. The response rate was 19%.

The effectiveness of the citizen engagement strategy and its design was also evaluated by the engagement working group. For this, an internal discussion was held, reflecting on the project activities, their successes and shortcomings. All in all, the working group considers the chosen activities effective, which is also supported by the surveys and resident feedback.

Number of activities carried out for informing citizens (including residents) about the project:

Input parameter	Value	Data source
Activity type: **public campaigns** (includes public campaigns about bike sharing, SECAP, art tours, etc.)	30	Citizen Engagement plan
Activity type: **thematic event** (includes citizen information events, smart home trainings, smart home ambassador program trainings, technical meetings with housing association boards)	40	Citizen Engagement plan
Activity type: **newspaper articles**	150	Media monitoring
Activity type: **television**	7	Media monitoring

Table 34. Number of activities carried out for informing citizens

Number of residents involved in the citizen engagement actions (residents, mobility actions) carried out is a KPI that is extremely difficult to measure as mobility actions also include the launching the bike sharing systems which has been used by tens of thousands of Tartu citizens. Other than that, the citizen engagement actions included a wide variety of actions, the reach of some of which is impossible to measure. These include:

- Large-scale open pilot area information events twice a year (with the exception of 2020/2021 pandemic era) – *on average, the turnout was ca 50-100 participants per event.*

- Technical meetings with housing association representatives every 2-3 months – *ca 10-25 participants per event.*

- Regular newsletters twice a year – *disseminated to the residents of every renovated building via mailing lists and installed on the hallway information stands of the houses.*

- Continuous technical consultations – *bilateral meetings between the city of Tartu and/or TREA between housing associations.*

- Personal communication and contacts, several feedback loops – *personal meetings and contact, surveys, emails, etc.*

- Production of print and interactive materials; press releases and media articles disseminated in social and online channels

- Videos of project activities (two every year) – *on Tartu city YouTube channel, they have approximately 5500 view combined, on the project's YouTube channel, about 2500 views. The videos have also been showed at various events and conferences (most notably, the Dubai EXPO), so their reach has been very wide.*

The project has also been featured in several nation-wide news, TV and radio shows, the reach of which is difficult to measure, but nation-wide, the knowledge of "Tartu smartovkas with murals" is very widespread and well-known.

ICT Urban platform will be one important mean to foster further citizen engagement into the development of Smart Tartu. Tartu ICT platform has modular and layered approach. Where lower layer stands for sensors and actuators[35], middle layers represent connectivity and everything related to data management and upper layer is for applications. Security is applied on top of every interaction in the architecture. Communication in-between layers is all built up on, as standardized application programming interfaces (API's) as possible. Such approach allows to separate hardware providers and application developers. Also, applications can be developed over multiple technology and/or business domains.
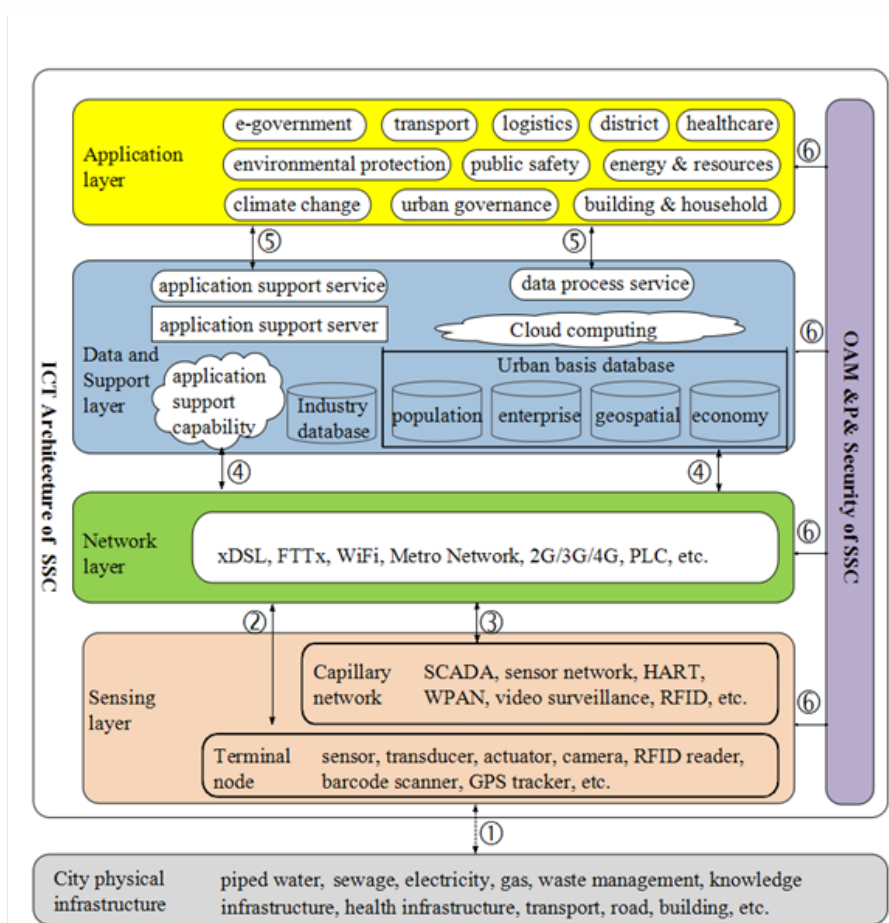

Figure 97. ICT Urban Platform

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[35] In the different layers of a system, the lower one, sensing layer on Figure 97, corresponds to the devices directly connected to field, thus with the sensors that extract the information from the system and send it to the control layers, but also with the actuators that are the devices that act onto the system, depending on the orders produced by the algorithms (typical examples of actuators are valves, motors or pumps).

As received feedback from Telia, in the SmartEnCity project background technology will be provided for the ICT urban platform and this will serve as platform for the third parties to build their applications and additional layers on IT. This means that in case of most of the KPI-s in this protocol we will be dependent on the information given by the third parties and have no direct access to the data by ourselves in the SmartEnCity project.

Other information about the use of the urban platform:

Number of citizens (registered users) using web application: 62

Number of visits (daily/monthly) (in the web application) – Number of daily and monthly visits: registered or anonymous: daily 11 / monthly 50

Increase of new visitors in the web application – Percentage of increase (or decrease) in registered citizens, monthly: 0,5%

Time spent on the web – Average time that people spent on the website. It could be measured monthly: 30 min/months

The smart home solution is an app developed in the framework of the SmartEnCity project and it enables the inhabitants to monitor their energy consumption (electricity, heat, water), and control the ventilation and temperature of their apartment. **The smart home mobile app has been downloaded 300 times on Android and 600 times on iOS**. According to the app use data, about half of the residents use the smart home system regularly to control the ventilation and temperature of their apartments. According to the post-renovation survey, only 21% of the residents do not use the smart home system at all. For everyone else, 23% uses it daily, 7% weekly, 20% couple times a week, 22% couple times a month. 63% of users use it to regulate temperature, 51% to check the time, date and weather information, and 37% to monitor their energy consumption.

The quality of services/added value services can be measured via surveys. Overall, both citizen and resident satisfaction with the new services (such as the bike sharing system) or added value services (the smart home system) remains high. It is foreseen that more added value services will be created after the project lifetime, e.g. creating new services based on the ICT urban platform data.

All in all, **18 dwellings were retrofitted in the project**.

Approximately 1500 residents benefitted by this intervention (the number of apartments benefitted was 600).

5.2.7 Economic performance Protocol

Economic performance protocol aims to evaluate the cost effectiveness of the interventions. Three types of actions will be evaluated in this protocol: district renovation, mobility and citizen engagement actions. Aligned with the nature of the actions implemented in the city, the following target groups have been identified as potential target audience:

- ❖ District intervention: owners and tenants
- ❖ Mobility action: vehicles owners and vehicle users from EV and biogas buses
- ❖ Citizen engagement actions: actors involved in these actions in SmartEnCity project for empowering the execution of the interventions and achieve the project objectives

Tartu has defined here own objectives of interest:

❖ Energy costs savings achieved by owners living in district and housing unions with the implementation of energy solutions in district (in comparison with the initial situation)

❖ Energy costs savings achieved with the rental of EV (cars) and e-bike (in comparison with the initial situation)

❖ Cost of citizen engagement activities carried out in the project to achieve the project objectives.

Tartu	District renovation	Owners and tenants	Energy costs savings achieved by owners living in district and housing unions with the implementation of energy solutions in district (in comparison with the initial situation)	Resident costs
				Grant rate
				Total annual costs
				Total annual benefits for residents
				Cost saving rate
	Mobility	Vehicle owners and vehicle users	Energy costs savings achieved with the rental of EV (cars) and e-bike (in comparison with the initial situation)	Total annual costs
				Benefits by uptake savings
				Benefits
				Cost of saving a kg of CO2
	Citizen engagement	Actors involved	Cost of citizen engagement activities carried out in the project to achieve the project objectives.	Investment
				Grant
				Total annual costs

Table 35. Tartu´s economic performance indicators

District intervention

Resident costs. This indicator measures the monetary amount that the residents must pay at the beginning of the project.

$RC= (Investment-Grant)Total\ Area$ = (15 840 298 – 3 592 175)/35216 = **348 €/m2**

Total area is the sum of overall square meters of all dwellings. Investment and Grant are known values at the start of the project.

Grant rate. It measures percentage of grant of the total investment, making easy their comparability with other demos. Values used in this indicator are the same of previous KPI.

$GR= GrantInvestment\times100$ = (3 592 175/ 15 840 298) x 100 = **22,7%**

Total annual costs. Indicate the annual costs of maintenance and energy per year. Those are the costs for residents. Maintenance costs are monetary amount per installation maintenance, equipment maintenance, retrofits break, and so on of all residents. Energy costs are the uptakes of all residents, and are calculated as multiplication among KWh country price and KWh consumption. This sum is split by total dwelling area. Kw consumption and maintenance costs are the project results. Kw country price: it is the price that residents pay to obtain and uptake a Kwh. This value is an estimation of Estonian average price.

$TAC= \Sigma Maintenance\ costs+Energy\ Costs_{n=n.residents}^{i=1}Total\ Area$ = **285 000 €/a**

Total annual benefits for residents. It is calculated as the subtraction among Old costs and total annual costs (Above KPI). Old costs are annual costs previous to the project, including maintenance and uptakes costs and divided per total area. This "Old cost" must be calculated for Baseline. With this equation it is obtained the annual benefit per square meter with the renovation. Old costs are calculated to the baseline of the project.

$BF = Old\ costs - Total\ annual\ Costs\ (TAC)$ = **163 000 €/a**

Cost saving rate. percentage of annual benefits of the project. Its measure of profitability is annual. It is calculated with the above indicators.

$CRR = \frac{BF}{Old\ Costs} \times 100$ = **36%**

Mobility

Total annual costs. The maintenance costs per year of overall mobility initiatives (including bus costs, bike costs, recharge network and others). Result is the sum of those values

$TAC = \Sigma Bus\ Costs + Bike\ Costs + Recharge\ Costs + Grant\ car\ costs + others$ = **12 738 170 €**

Benefits by uptake saving. The sum of all saved annual kilometres, measured in the cost of fuel, less cost of electricity usage. For example, kilometres realized with electrical energy multiplied per fuel price less cost of electricity multiplied per kilometres.

$BUS = \Sigma(electrical\ Km \times Country\ Fuel\ price - electrical\ KWh\ uptakes \times country\ KW\ price)_{i=1}^{n}$ = (15 970 129 x 0,095) – (15 970 129 x 0,03) = 1 517 162 - 479 103 = **1 038 059 €**

Country fuel price and country Kw price are estimations. The country fuel price is the cost of realizing 1Km with a medium car.

Benefits. The subtraction between BUS -TAC. Measures benefits per year. Indicator shows the net benefit of the project.

$B = BUS - TAC$ = 1 038 059 – 12 738 170 = **- 1 170 011 €**

Costs of saving a kg of CO2. The rate between total costs and Co2 kilograms saved. The overall costs from saving a Kg of CO2 are evaluated.

$C_{co2} = \frac{TAC}{Annual\ Kg\ of\ CO2\ saving}$ = 12 738 170 / 5520 = **2 307,63 €**

Citizen engagement

Investment. The sum of all initiative investments. It is a project value.

$Investment = \Sigma Initiative\ investments$ = **36 990 298 €**

Grant. Defined as a part or percentage of investment. It is a project value.

$Grant\ \% = \frac{Grant}{Investment} \times 100$ = (5 241 728 / 36 990 298) x 100 = **14,17 %**

Total annual costs The total annual costs are defined as the sum of all the costs for deployment the strategy for citizen engagement which include the cost of staff, the purchase of material or the subcontracting cost. The total annual costs is related to the considered interval of time (year).

$TAC = \Sigma All\ costs$ = **58 500 €**

5.2.8 City impact indicators

A set of indicators was selected with the purpose to identify the main features, strengths and weakness of the cities which allow to know their needs and setting the objectives to be considered in the strategy to transform them into Smart Zero cities. In addition, the profile of the cities could be useful for monitoring the improvements achieved due to SmartEnCity over the time.

The indicators chosen came from initiatives which have worked previously in agree an indicator system among a wide sample of stakeholder (SCIS/CONCERTO, CITYKEYS, ISO 37120, ITU, PLEEC, STEEP).

Next, city impact indicators have been brought out.

City impact indicators	Unit	Value
Energy savings due to district renovation	kWh/a	6 420 000
CO_2 emissions savings due to district renovation	tCO2e	911
CO_2 emissions savings due to sustainable mobility actions	t CO2	7 037
Increase of renewable energy usage	MWh/a	107 245
Increase of renewable energy production	MWh/a	15 445,5
Number of dwellings / buildings retrofitted	Number of retrofitted dwellings / buildings	691 / 18
Number of additional buildings in the city that demand a retrofitting or to include energy efficient measures as a result of the SmartEnCity pilots.	Number of buildings	900
Number of EV	Number of electric vehicles	120
Biogas buses	%	100%
Number of EV charging stations (of which public)	Number of EV charging stations (of which public)	(5) 20
Total kWh recharged in the EV charging stations	kWh	125 100
Total investment of the district from local and regional public funding, EC funding and private funding (e.g. dwellings' owners, energy companies, social housing companies, etc.).	€	21 840 000
Total number of jobs created	Number of jobs created	12
Number of jobs created in terms of professional specialization	Number of jobs created, comparison with "working age population with higher education"	3

Total number of new services offered by companies due to district renovation, mobility actions and citizen engagement actions during the whole project	Number of new services	10
Existence of plans/programs to promote energy efficient buildings	Yes/No	Yes
Existence of plans/programs to promote sustainable mobility	Yes/No	Yes
Existence of regulations for development of energy efficient districts	Yes/No	Yes
Existence of regulations for development of sustainable mobility	Yes/No	Yes
Existence of public incentives to promote energy efficient districts	Yes/No	No
Existence of public incentives to promote sustainable mobility	Yes/No	Yes
Involvement of the administration on smart city projects	Estimation based on Likert-scale (1 to 5).	4
Multilevel government	Estimation based on Likert-scale (1 to 5).	4

Table 36. Tartu City impact indicators

5.3 Sonderborg

The following sub-paragraphs will outline the specific results obtained from Lighthouse City Sonderborg following the KPI protocols as defined in D7.3 and D7.9. Furthermore, the city impact indicators will be shown which are with regard to D7.4.

5.3.1 Energy Assessment Protocol

The energy demand in the latest reported monitoring period M55-M67 is 15 % lower than the baseline: 127 kWh/m2 compared to 150 kWh/2. The energy demand includes the heating demand as well as the electricity demand in the dwellings.

The primary energy for the buildings is a little higher compared to the baseline. The primary energy for heating is higher, but the primary energy for electricity is lower than the baseline. The lower electricity is due to the solar plants. The higher heating demand is due to the difference in the outdoor climate, and it can also be due to the tendency, that tenants increase the indoor temperature in connection with energy renovation of their dwellings.

The CO_2 equivalent in the latest monitoring period is lower than the base line.

The degree of self-supply in the renovated demo-buildings has been monitored to 23 % compared to 25 % in the baseline.

The share of the renewable energy has been monitored to 29 % compared to 25 % in the baseline. This is due to the solar PV and battery systems installed during the project.

Thermal comfort in the dwellings has been improved due to new windows, insulation of facades and new ventilation systems in a number of dwellings.

Energy Assessment KPIs	Baseline	M43 – M54	M55 – M67
Energy demand	150 kWh/m2: 123 kWh/m2 for heating 27 kWh/ m2 for electricity.	201 kWh/m2: 186 kWh/m2 for heating, 27 kWh/m2 for electricity minus 12 kWh/m2 solar PV contribution.	127 kWh/m2: 113 kWh/m2 for heating, 25 kWh/m2 for electricity minus 11 kWh/m2 solar PV contribution.
Delivered energy (for buildings)	127 kWh/m2: 95 kWh/m2 district heating 32 kWh/m2 electricity	201 kWh/m2: 186 kWh/m2 for heating, 27 kWh/m2 for electricity minus 12 kWh/m2 solar PV contribution	127 kWh/m2: 113 kWh/m2 for heating, 25 kWh/m2 for electricity minus 11 kWh/m2 solar contribution
Primary energy (for buildings)	5,786 MWh district heating x 0,8 + 1,935 MWh electricity x 2.5 = 9,465 MWh	12,335 MWh heating x 0.8 + 1,769 MWh electricity x 2.5 = 14,290 MWh	7,442 MWh heating x 0.8 + 1,645 MWh electricity x 2.5 = 10,066 MWh
Primary energy (for energy supply units)	**Primary energy factors = 1 for everything but district heating and electricity** • PEF Electricity: 2.5	N/A	**Primary energy factors = 1 for everything but district heating and electricity** • PEF Electricity: 2.5

Baseline detail:

Primary energy input	MWh/year
Wind power	37,972
Solar (photovoltaics)	13,778
Solar (thermal)	14,694
Geothermal	2,944
Heating oil (boilers)	56
Natural gas (boilers)	83,889
Biomass (boilers)	150,222
Heating oil (CHP)	8
Natural gas (CHP)	9,417
Biomass (CHP)	14,859
Waste (CHP)	221,613
Electricity (heating elements and heat pumps for district energy)	8,528*2.5 = 21,320

M55 – M67 detail:

Primary energy input	MWh/year
Wind power	28,083
Solar (photovoltaics)	33,639
Solar (thermal)	17,861
Geothermal	0
Heating oil (boilers)	3,472
Natural gas (boilers)	54,944
Biomass (boilers)	245,472
Heating oil (CHP)	3
Natural gas (CHP)	7,444
Biomass (CHP)	17,319
Waste (CHP)	220,181
Electricity (heating elements and heat pumps for district energy)	18,611*2.5 = 46,528

	Total	570,772			Total	674,947
CO2 equivalent (for buildings)	Electricity consumption: 425 t CO2 District heating: 520 t CO2 In total 945 t CO2 per year		Electricity consumption: 389 t CO2 District Heating: 987 t CO2 In total 1,376 t CO2		Electricity consumption: 329 t CO2 District Heating: 596 t CO2[36] In total 925 t CO2	
CO2 equivalent (for energy supply units)	**Sonderborg municipal area:** Electricity production: 0.22 Tonnes CO_2/MWh District heating production: 0.09 Tonnes CO_2/MWh		N/A		**Sonderborg municipal area:** Electricity production: 0.07 Tonnes CO_2/MWh District heating production: 0.08 Tonnes CO_2/MWh	
Density of energy demand	95.4 kWh per m2		186.4 kWh per m2		122.5 kWh per m2	
Peak load and load profile of electricity demand	SAB Department 22: 19 apartment blocks with 432 apartments = 267 kW. SOBO Department 11: 8 apartment blocks with 88 apartments = 85 kW		SAB Department 22: 19 apartment blocks with 432 apartments = 267 kW. SOBO Department 11: 8 apartment blocks with 88 apartments = 85 kW		SAB Department 22: 19 apartment blocks with 432 apartments = 267 kW SOBO Department 11: 8 apartment blocks with 88 apartments = 85 kW	
Degree of congruence of calculated annual final energy demand and monitored consumption	85 %		71.5%		46%	
Degree of energetic self-supply	Sonderborg municipal area: Thermal: 100%, Electricity: 17.5%. Renovated buildings: Thermal 0%, Electricity: 25 %		Sonderborg municipal area: Thermal: 100%, Electricity: 20.6%. Solar PV production: 792 MWh. Electricity consumption: 2,561 MWh		Sonderborg municipal area: Thermal: 100%, Electricity: 20.3%. Solar PV production: 695 kWh. Electricity consumption: 2,341 MWh	

[36] Monitored heating consumption and carbon emissions have been higher in M55-M67 compared to the baseline, but it has been much lower than in M43-M54. The reason for the increase in heating consumption compared to the baseline is a combination of differences in outdoor temperatures and possibly tenant activities.

Share of renewable energy	Sonderborg municipal area: 32.8%. Renovated buildings: 25 %			Sonderborg municipal area: 2019=31,1% Renovated buildings: avr.31 %	Sonderborg municipal area: 34.2% Renovated buildings: avr.29 %		
Efficiency	**Plant type**	**Electricity**	**Heat**	N/A	**Plant type**	**Electricity**	**Heat**
	Photovoltaics	100			Photovoltaics	100	
	Wind turbines	100			Wind turbines	100	
	Waste-to-energy plants	12.3	73.5		Waste-to-energy plants	14.9	79.9
	CHP plants, combustion engine	38.5	49.3		CHP plants, combustion engine	38	44.1
	CHP plants, gas turbine		99.7		CHP plants, gas turbine	-	-
	CHP plants, boiler		102		CHP plants, boiler		93.3
	CHP plants, heating element		95		CHP plants, heating element		100
	CHP plants, solar		100		CHP plants, solar		100
	Local plants, combustion engine (CHP)	32	17.3		Local plants, combustion engine (CHP)	36	
	District heating plants, boiler		100.6		District heating plants, boiler		99.5
	District heating plants, geothermal		100		District heating plants, heat pump		349.2
	District heating plants, solar thermal		100		District heating plants, solar thermal		100
Thermal comfort	N/A				Thermal comfort has been improved due to new windows, insulation of facades and new ventilation systems.		

Table 37. Energy protocol KPI values for Sonderborg

5.3.2 ICT Protocol

The Sonderborg ICT-platform was shifted during 2018/2019. Instead of the originally Vikingegaarden solution, the decision was made (Amendment 2) to change to the Telia CIOP platform – similar to the CIOP platform in Tartu. Therefore, all the features that the Tartu CIOP platform has are present in the Sonderborg CIOP platform too.

The Sonderborg CIOP is a state-of-the-art platform to allow connections between sensors, systems and services. It is currently (as of M78) collecting data from the housing associations part of the SEC project (electricity consumption and production and heat consumption), other building/city level data (public buildings, educational institutes' buildings, district heating production, biogas production, traffic linked to the Danish Road Directorate, etc). In addition to this an open-source Dashboard (called Public Data) has been developed showing different city-based data.
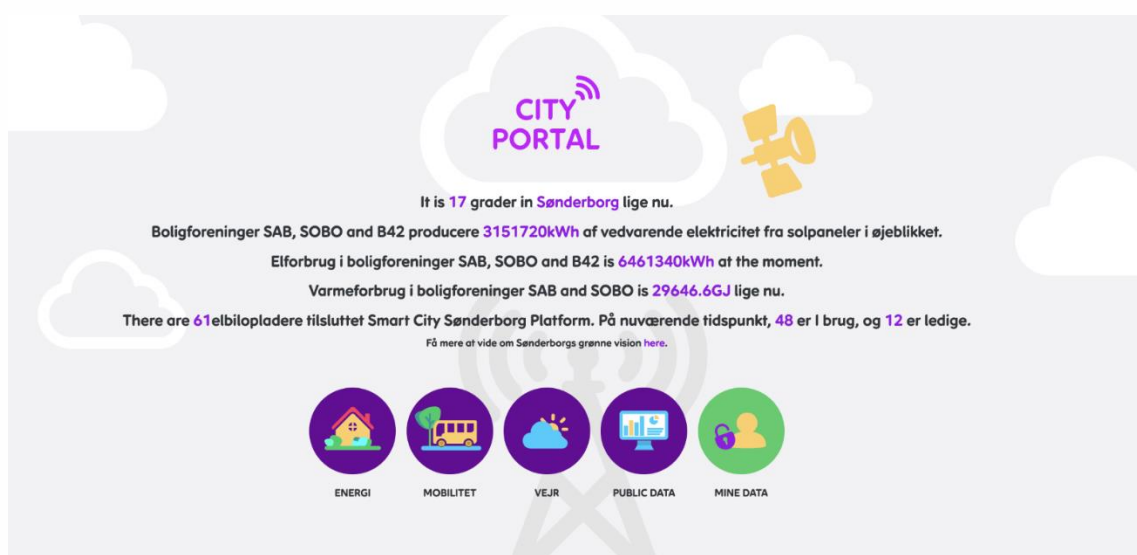

Figure 98. Sonderborg City Portal entry page.

The platform also has a secure log in option where the data owners can securely log in using the Danish authentication system and see their data privately. They of course have the option to share it with specific stakeholders or show it publicly. They can withdraw their consent at any time.

Currently, there are 14 schools, 14 kindergartens, 10 care centres, 3 private households, 2 businesses, 10 district heating production locations, 1 biogas plant, 369 traffic points, 4 other public buildings, 3 housing associations with several buildings in each one of them and 19 EV charger points.

The Table 38 below outlines the results from the ICT indicator protocol set at the beginning of the project. The response time of the platform is 20ms and while there are 3 virtual machines with F5 load balancers running in parallel in 2 physical sites, there have been recorded no hours of maintenance. The total amount of data generated is 148 GB and the connected devices grew 10 times from M48 to M74.

ICT KPIs	Results
Response time	20 ms
Scalability	3 WMWare virtual machines with F5 load balancer, running in parallel in 2 physical sites. Warning on any resource running into 80% capacity, 24/7 manned monitoring will manually accept any needed resource upgrade in seconds
Extensibility	Tens of manufacturers are providing hundreds of interoperable gateways and sensors all over common protocols.
Storage capacity	Local storage, running in parallel in 2 physical sites. Warning on any resource running into 80% capacity, 24/7 manned support team will manually accept any needed resource upgrade in seconds.
Hours of maintenance	0 - F5 and multiple core-nodes allows all maintenance works to be done without any downtime
Non-expected hours offline	About 0.1%
# of BEMS connected	4 – Heat, water, electricity consumption and electricity production
# of mobility equipment connected	3 – EV chargers (14), traffic counters (148), google traffic
Total amount of data generated	148 GB
Number of services developed	4 - Questionnaires, Energy manager, Open data maps, KPI dashboard
Percentage of buildings connected	100% as per M67 however due to Amendment 3 new buildings were added so as per M74 there are 45% of the total buildings incl. new ones connected. It is expected to connect all buildings by the end of the project.
Open-Data sets available	9
Extra KPIs not specified in the protocol	
Total number of connected devices	583 as per M48 vs 5467 as per M74
Average number of monthly API messages / connections	M74 = Approx. 33 mio

Table 38. ICT protocol KPI values for Sonderborg

5.3.3 Life Cycle Analysis Protocol

The LCA provides analysis of the environmental impacts from the buildings in Sonderborg where SEC retrofitting-interventions have been implemented. It is a simplified LCA focusing on the buildings in a coherent perspective, providing analysis of the average impact per square meter compared to a similar LCA of the same buildings at the beginning of the project (without SEC retrofitting-interventions implemented).

Objective of the study

The objective of the study has been to establish the environmental results of Sonderborg baseline scenario in the framework of the project SmartEnCity, considering if no project intervention was implemented in comparison to the retrofitting actions of the project that have been implemented and monitored.

The results obtained in this assessment evaluates the environmental impact of the district performance considering several stages and elements, as it will be described in the following sections. The baseline results have been the starting point for evaluating the Energy Conservation Measures proposed, the heating technology changes and the fuel substitution.

Functional unit

The functional unit (F.U.) is the reference unit through which the system performance for this baseline and final monitoring scenarios are quantified. In this case, the F.U. is defined as *1 m^2 of conditioned area, considered for a time period of 1 year*, in the framework of a baseline scenario where no SmartEnCity activities are considered, supposing that the conventional maintenance operations are developed, and also including the thermal and electricity energy consumption, and in the framework of a final monitoring scenario where the SEC retrofitting-interventions have been implemented.

The results for the baseline and final monitoring LCA will be expressed by $m^2 * year$, a very intuitive and easy to assimilate unit.

Reference study period

Although the F.U. is expressed considering a time period of 1 year, the gross values are obtained from a 35 years reference study period. 35 years should be average expected lifetime of retrofitted buildings – in Sonderborg around 30-40 years if estimating that total lifetime 90 years and construction time was 1960.

System boundaries

In this part, the definition of what is included and excluded for assessment is described. In the system boundaries the activities concerning replacement will be included, mainly regarding to the façade and roof replacement after life time.

Thermal and electricity energy consumption, as well as the end of life of the elements involved will be also included.

Building modelling

The environmental model has been developed working with commercial software SimaPro 8.1.

Life cycle stages

It consists of the stages to be included in the analysis (e.g., product stage, construction process stage, use stage and end-of life stage). They take part of the Modules A, B and C from the scheme of the building assessment information (Figure 1).
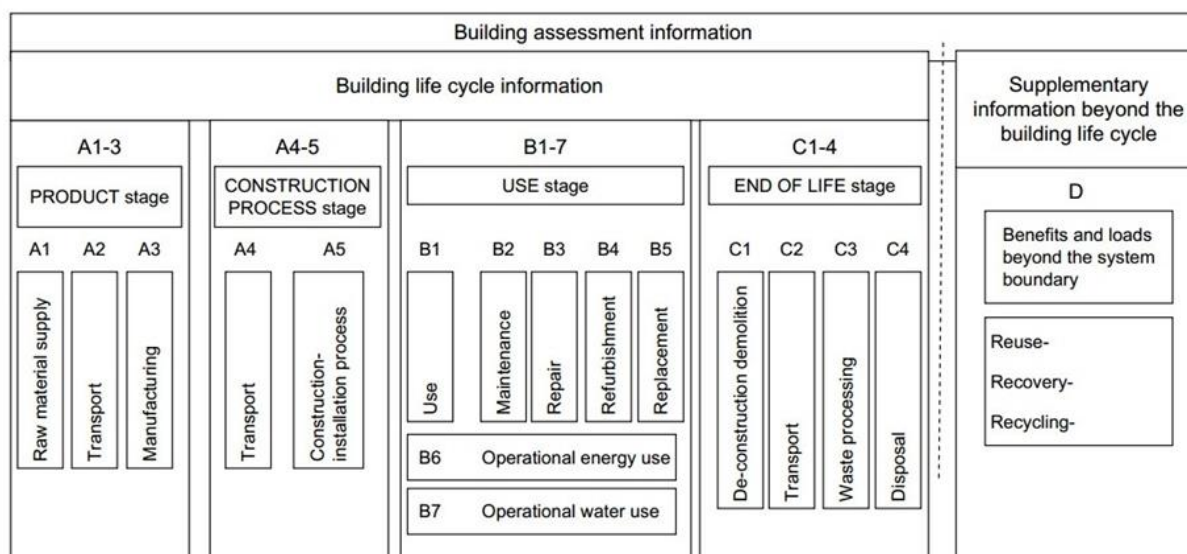
Figure 99. Building assessment information. Life cycle stages according to EN 15978:2011.

The baseline scenario included the district performance before SEC retrofitting-interventions, in order to study the building performance during the reference study period selected by each city, and considering the use stage, end of life and energy consumption of the building. This implied that no retrofitting actions were considered.

The final monitoring scenario includes the district performance after SEC retrofitting-interventions, in order to study the final building performance, considering the use stage, end of life and energy consumption of the building with the SEC retrofitting-interventions.

Buildings in Sonderborg LCA with implementation of SEC-energy efficient retrofitting

The table below provides an overview of buildings in Sonderborg where energy efficient retrofitting interventions have been implemented as part of the SmartEnCity project. For the baseline and final monitoring LCA these buildings are analysed as a coherent set of buildings with average energy consumption and maintenance per m².

Housing association name	Department name	Buildings	Dwellings	Heated area (m2)	Roof area (m2)	Facade area (m2)
SAB -Sønderborg Andelsboligforening	Afd. 22 Hvedemarken-Kløvermarken	19	432	31,802	16,200	12,225
Boligforeningen SOBO	Afd. 11 Borgmester Andersensvej	8	88	8,420	6,880	3,500
B42	Afd. 10 Skriverløkken	1	87	6,699	3,350	2,814
B42	Afd. 12 Sundquistgade	1	16	1,072	858	407
B42	Afd. 13 Ringbakken	4	48	3,796	3,037	1,442
B42	Afd. 21 Morbærhegnet	10	122	7,613	3,807	2,893
B42	Afd. 28 Vissingsgade	2	24	1,280	1,024	486
Total	**7**	**45**	**817**	**60,682**	**35,154**	**23,768**

Table 39. Overall data about Sonderborg buildings set for SEC retrofitting-interventions

Below is an overview of the yearly energy consumption in the analysed buildings before the SmartEnCity interventions. This is used for the baseline LCA of the buildings as assumed yearly energy consumption during the estimated 35 years of lifetime of the buildings.

In the LCA heating for the buildings is supplied by district heating with the local fuel configuration mix in Sonderborg (modelled in Simapro), while electricity is supplied by national grid (Ecoinvent database).

Monitoring	Heat use (total)	Electricity use (total)	Heat use (pr. m2)	Electricity use (pr. m2)
Baseline	5,786,281 kWh	1,935,098 kWh	95 kWh	32 kWh
Final monitoring	6,195,443 kWh	1,414,110 kWh	102 kWh	23 kWh

Table 40. Yearly energy consumption in Sonderborg buildings (2015)

For the baseline LCA of the buildings the below elements of the buildings are assumed being replaced once during the estimated 35 years of lifetime of the buildings, which is according to the plans of the housing associations.

Housing association name	Department name	Roof	Roof actions during lifetime	Facades	Facade actions during lifetime	Other actions during lifetime
SAB-Sønderborg Andelsboligforening	Afd. 22 Hvedemarken-Kløvermarken	Fibre cement roof	none	Outerwalls are bricks w. 50 mm insulation	none	
Boligforeningen SOBO	Afd. 11 Borgmester Andersensvej	Fibre cement roof	Replacement of fibre cement roof and underroof	Outerwalls are bricks w. 50 mm insulation	none	Heat automatic (district heating): Replacement x 4 Replacement of PVC windows
B42	Afd. 10 Skriverløkken	Tiled roof	Repair of existing tiled roofs (= 30 % replaced)	All-masonry gables	Re-insulation of facade (gables)	
B42	Afd. 12 Sundquistgade	Tiled roof	Replacement of tiled roof, underroof and dormers	unknown	none	
B42	Afd. 13 Ringbakken	Steel roof on top of asbestos roof	none	Outerwalls are bricks w. 50 mm insulation	Replacement of outer walls	
B42	Afd. 21 Morbærhegnet	Concrete tiles	none	unknown	none	Ventilation system (25 years old): Replacement of ventilation
B42	Afd. 28 Vissingsgade	Tiled roof	Replacement of tiled roof, underroof and dormers	unknown	none	

Table 41. Baseline maintenance actions in Sonderborg buildings during lifetime

For the final monitoring LCA of the buildings the below SEC retrofitting-interventions are elements added to the buildings in Sonderborg in addition to the elements in the baseline LCA, which altogether comprise the elements for the final monitoring LCA.

Housing association name	Department name	SEC retrofitting-interventions
SAB-Sønderborg Andelsboligforening	Afd. 22 Hvedemarken-Kløvermarken	Installation of 3.000 m2 photovoltaics on roof and installation of battery (approx. 1.320 kWh).
Boligforeningen SOBO	Afd. 11 Borgmester Andersensvej	Installation of 990 m2 building integrated photovoltaics on roof (resulting in 990 m2 less roof replacement compared to baseline) and installation of battery (approx. 440 kWh).
B42	All	Installation of 540 m2 photovoltaics on roof, installation of battery (approx. 240 kWh) and re-insulation of approx. 1.600 m2 façade (resulting in 1.600 m2 less replacement compared to baseline).

Table 42. SEC retrofitting-interventions in Sonderborg buildings during lifetime

Below is a description of the expected end of life treatment for the building elements replaced during the next 35 years. The table includes expected transport and transport of new building elements. These parameters are all used in the LCA of the buildings.

Input parameter	End of life treatment (if reached)	Transport distance (to end of life destination or from pick up destination)	Data Source
Clay bricks (replaced)	Recycling 75%, incineration 25%	10 km	Sonderborg Municipality
Clay bricks (new)	-	25 km	Housing associations/PlanEnergi
Roof tiles (replaced)	Recycling 75%, incineration 25%	10 km	Sonderborg Municipality
Roof tiles (new)	-	25 km	Housing associations/PlanEnergi
Fibre cement roof plates (replaced)	Landfill 100%	10 km	Sonderborg Municipality
Fibre cement roof plates (new)	-	25 km	Housing associations/PlanEnergi
Under roof (replaced)	Incineration 100%	10 km	Sonderborg Municipality
Under roof (new)	-	25 km	Housing associations/PlanEnergi
Light mortar (replaced)	Incineration 50%, landfill 50%	10 km	Sonderborg Municipality
Light mortar (new)	-	25 km	Housing associations/PlanEnergi
Stone wool (replaced)	Recycling 75%, landfill 25%	10 km	Sonderborg Municipality
Stone wool (new)	-	25 km	Housing associations/PlanEnergi
Glazing, double, windows (replaced)	Recycling 75%, incineration 25%	10 km	Sonderborg Municipality
Glazing, double, windows (new)	-	25 km	Housing associations/PlanEnergi
PVC window frames (replaced)	Recycling 100%	10 km	Sonderborg Municipality
PVC window frames (new)	-	25 km	Housing associations/PlanEnergi
Aluminium/wood window frames	Recycling 100%	10 km	Sonderborg Municipality

(replaced)			
Aluminium/wood window frames (new)	-	25 km	Housing associations/PlanEnergi
Ventilation control and wiring, central unit (replaced)	Recycling 85%, incineration 15%	10 km	Sonderborg Municipality
Ventilation control and wiring, central unit (new)	-	25 km	Housing associations/PlanEnergi
Sawnwood (replaced)	Recycling 100%	10 km	Sonderborg Municipality
Sawnwood (new)	-	25 km	Housing associations/PlanEnergi
Zinc (replaced)	Recycling 100%	10 km	Sonderborg Municipality
Zinc (new)	-	25 km	Housing associations/PlanEnergi
Photovoltaics (replaced)	Recycling 80%, landfill 20%	10 km	Sonderborg Municipality
Photovoltaics (new)	-	20,653 km	PlanEnergi/routescanner
Batteries (replaced)	Hydrometallurgical treatment 100%	10 km	Sonderborg Municipality
Batteries (new)	-	20,653 km	PlanEnergi/routescanner

Table 43. End of life treatment used in Sonderborg LCA

Assumptions

In this section different elements involved in the baseline scenario will be considered:

Factor	Amount	Unit	Source
Estimated remaining building lifetime	35	years	Torben Esbensen
Total conditioned area	60,682	m2	Housing associations
Roof area pr. dwelling area- 3-storey building	0.5	m2/m2	Assumption based on SAB and SØBO areas (PlanEnergi)
Roof area pr. dwelling area- 2-storey building	0.8	m2/m2	Assumption based on SAB and SØBO areas (PlanEnergi)
Facade area excl. windows (total) pr. dwelling area - 3-storey building	0.42	m2/m2	Assumption based on SAB and SØBO areas (PlanEnergi)
Facade area excl. windows (total) pr. dwelling area - 2-storey building	0.38	m2/m2	Assumption based on SAB and SØBO areas (PlanEnergi)
Facade area (only gables) pr. dwelling area	0.05	m2/m2	Assumption (PlanEnergi)
Bricks per wall area	0.09	m3/m2	Ökobau.dat
Bricks per wall area	158	kg/m2	Ökobau.dat
Roof tiles per roof area	30	kg/m2	Ökobau.dat
Fibre cement roof plates	17.6	kg/m2	Institut Bauen und Umwelt (IBU)
Mortar per wall area	30	kg/m2	Ökobau.dat
Mortar per wall area	0.02	m3/m2	Ökobau.dat
Under roof (EPDM) per roof area	0.2	kg/m2	Ökobau.dat
Insulation material per wall area	0.2	m3/m2	Ökobau.dat
Insulation material per wall area	5	kg/m2	Ökobau.dat
Dormers per building	6	pcs	Google maps

Construction wood per dormer	0.01	m3/pcs	Assumption based on Ökobau.dat
Window area per dormer	2.25	m2/pcs	Assumption (PlanEnergi)
Glazing area per window area	0.8	m2/m2	SBi
Zink cladding per dormer	25	kg/pcs	Assumption (PlanEnergi)
Glazing weight per window area	20	kg/m2	Ökobau.dat
Window profile wood	7	kg/m2	Ökobau.dat
Window profile alu	1.5	kg/m2	Ökobau.dat
Window profile PVC	31.2	kg/m2	Institut Bauen und Umwelt (IBU)
Sawnwood	500	kg/m3	Assumption (PlanEnergi)
Photovoltaic lifetime	35	years	Danish Energy Agency
Photovoltaic mass	10	kg/m2	REC and metsolar
Battery lifetime	15	years	Xolta
Battery mass	10	kg/kWh	Xolta

Table 44. Assumptions used in Sonderborg LCA

Life Cycle Environmental Impact Assessment

The baseline and final monitoring calculation method for the environmental impact in Sonderborg includes the calculation of maintaining the buildings in their current state and with SEC retrofitting-interventions implemented. The scheme followed is:

- Environmental assessment for 35 years
- Normalization to the functional unit of each area (1 m^2 * yr)
- Surface ratio allocation
- Results expressed by functional unit for the Sonderborg district

LCA KPIs	Definition	Value/Unit (Baseline)	Value/Unit (Final)	Data source
Global warming potential	Index that attempts to integrate the overall climate impacts of a specific action. It relates the impact of emissions of a gas to that of emission of an equivalent mass of CO2. The duration of the perturbation is included by integrating radiative forcing over a time horizon (e.g., standard horizons for IPCC have been 20, 100, and 500 years). The time horizon thus includes the cumulative climate change and the decay of the perturbation. 100 years has been chosen for the LCA study	22.42 kg CO2 eq/m^2/year	15.88 kg CO2 eq/m^2/year	Housing association / Ecoinvent database
Ecological footprint	The Ecological Footprint is defined as the area of productive land and water ecosystems required to produce the resources that the system needs and assimilate the wastes generated.	119.67 m^2/m^2/year	94.95 m^2/m^2/year	Housing association / Ecoinvent database
Use of renewable primary energy excluding energy resources used as raw material	For thees four indicators, using the environmental indicator Cumulative energy demand, it will be able to separate the primary energy in renewable and non-renewable, as well as energy used for raw material and other uses	314.06 MJ/m^2/year	266.80 MJ/m^2/year	Housing association / Ecoinvent database
Use of renewable primary energy resources used as raw material		MJ/m^2/year	MJ/m^2/year	*Not available*

Use of non-renewable primary energy excluding energy resources used as raw material		409.25 MJ/m^2/year	312.40 MJ/m^2/year	Housing association / Ecoinvent database
Use of non-renewable primary energy resources used as raw material		MJ/m^2/year	MJ/m^2/year	*Not available*
Hazardous wastes disposed	Amount of hazardous and non-hazardous wastes disposed during the life cycle of the district intervention according to the current European legislation. Directive 2008/98/EC and Annex III to Directive 2008/98/EC	0.0006 kg/m^2/year	0.0006 kg/m^2/year	Housing association / Ecoinvent database
Non-hazardous wastes disposed		Kg/m^2/year	Kg/m^2/year	*Not available*
Exported energy	Energy that is produced in the context of the district studied that can be exported from the system to other use out of the systems boundaries.	0 MJ/m^2/year	245 MJ/m^2/year	Housing association

Table 45. Sonderborg Baseline – LCA

In the following Figure 100, the results are expressed on the basis of different environmental indicators selected, considering 1 m^2 * yr as functional unit, and disaggregated by life cycle stage (maintenance, energy consumption and end of life treatment), as it has been structured in the inventory section.
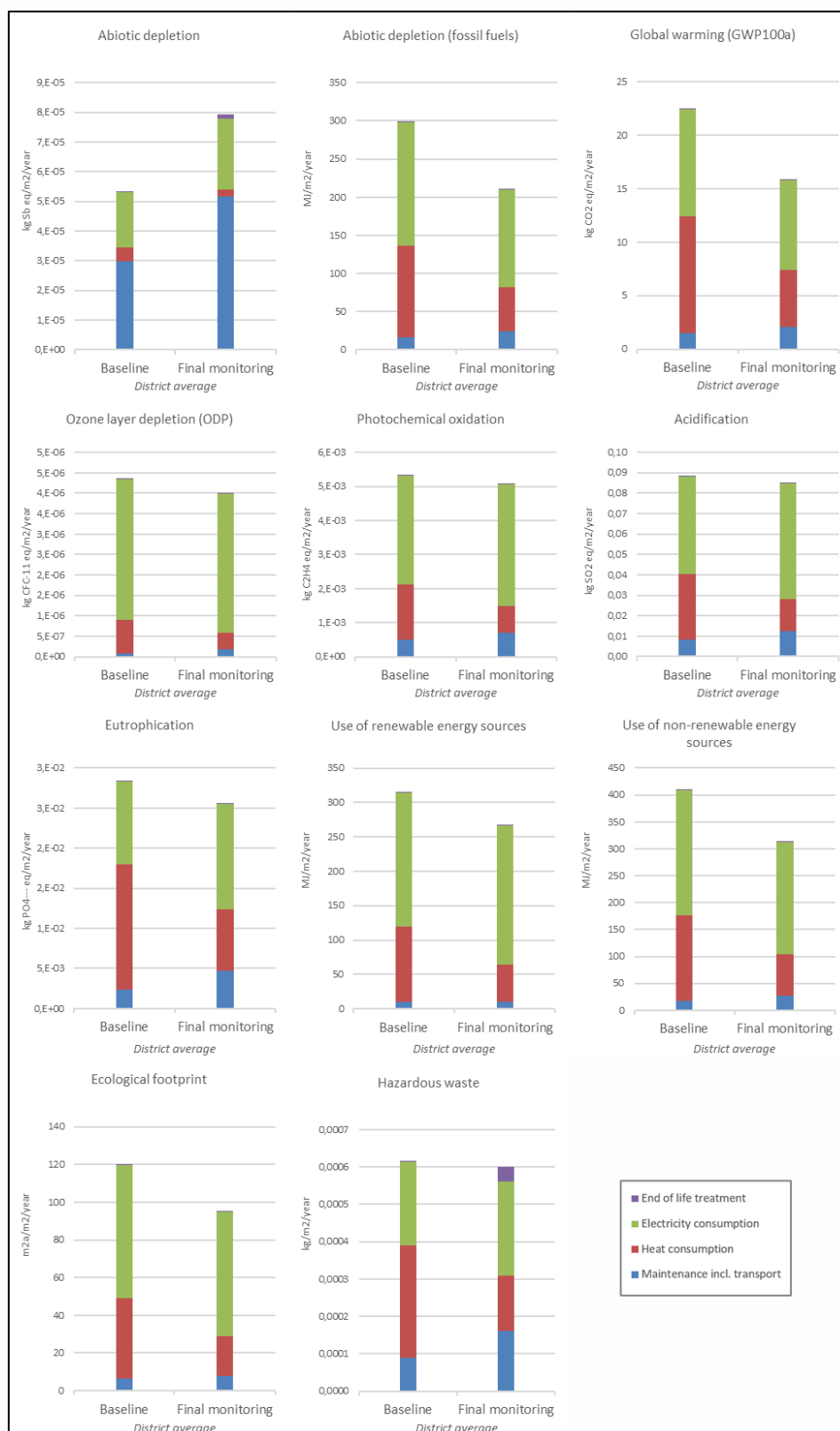
Figure 100. Graphic representation of the LCA results for Sonderborg

5.3.4 Mobility Protocol

44 modern biogas-fuelled buses have replaced old diesel buses making public transportation a pleasant journey experience and allowing citizens to bring on board up to two bicycles for modal-shift. The buses were implemented in June 2019 and have functioned very well,

reliability of arrival have stabilized at a very high level and the bus-drivers and citizens report that driving the biobus is a much nicer and quiet experience. 97 - 98% of the bus-arrivals arrive within +5 minutes to schedule.

The annual driven distance by the 44 buses is app. 2.5 mio km and the fuel efficiency is app. 2,5 km per M3 gas. The CO2-emissions saved per km-driven is app. 1 kg per km driven in the bus compared to the former diesel fuel. Creating a total saving of app. 2,406 ton CO2 per year.

COVID-19 have had a major impact on public transportation – still leaving the number of passengers down by almost 30% compared to post COVID-19 times.

Not all citizens have access to public buses and need a personal car. The solution approached is e-mobility, which requires a new EV-charging infrastructure to be planned and implemented. 24 public chargers have been installed as part of the SmartEnCity project in public spaces supporting and paving the way for a growing interest for e-mobility. Additional 6 chargers we installed initially by the project, but failed due to technical reasons and were not replaced.

During the project, the number of BEV and PHEV have multiplied in numbers by factor 6 – 7. The number of charging events and the charged power capacity have since M49-M55 multiplied by a factor 6+ and is expected to increase further in 2022+.

Both measures have a major impact on the transport-related emissions in Sonderborg and have also catalysed additional climate actions, like establishment of a central filling gas-station, establishment of two huge local biogas production facilities, conversion of waste-management vehicles to biogas fuel and a (Masterplan2029) planning/implementation process for additional EV-charging capacity.

Mobility KPIs	Results
Accuracy of timekeeping for public bus (On time arrival is defined as within +5 minutes to schedule)	On time arrival in percent of all arrivals M37-M42: 89.1% M43-M48: 94.9% M49-M54: 97.8% M55-M60: 97.3% M61-M67: 98.0% M68-M74: 96,3%
(Annual) distance travelled for public bus in km driven. Reported per 6/7 months (reporting periods) for comparison reasons	M37–M42: 1 201 255 km M43-M48: 1 310 723 km M49-M54: 1 109 117 km M55-M60: 1 223 291 km M61-M67: 1 231 144 km M68-M74: 1 454 002 km
Energy consumption as per reporting periods (biogas in m3 units)	M37–M42: 447,297 m3 M43-M48: 444,640 m3 M49-M54: 420,532 m3 M55-M60: 461,000 m3 M61-M67: 494,631 m3 M68-M74: 569,548 m3
Vehicle fuel efficiency as per reporting periods	M37–M42: 2,68 km/m3 M43-M48: 2,94 km/m3 M49-M54: 2,64 km/m3 M55-M60: 2,65 km/m3 M61-M67: 2,49 km/m3 M68-M74: 2,55 km/m3

Emissions saved / travelled distance (preconditions: 2.7 km driven per litre diesel 2.66 kg CO2 emitted per litre diesel)	**M37–M42**: 1 201 255 km /2,7*2,66 = 1 183 458 kg CO2 /1,201,255 km = **0,99 kg CO2/km** **M43-M48**: 1,310,723 km /2.7*2.66 = 1,291,304 kg CO2 / 1,310,723 km = **0,99 kg CO2/km** **M49-M54**: 1,109,117 km / 2.7*2.66 = 1,092,685 kg CO2 / 1,109,117 = **0,99 kg CO2/km** **M55-M60**: 1,223,291 km /2.7*2.66 = 1,205,168 kg CO2 /1,223,291 km = **0,99 kg CO2/km** **M61-M67**: 1,231,144 km /2.7*2.66 = 1,212,904 kg CO2 /1,231,144 km = **0,99 kg CO2/km** **M68-M74**: 1,454,002 km /2.7*2,66= 1,432,461 kg CO2 / 1,454,002 km = **0,99 kg CO2/km** Average for all reporting periods: **M37-M74**: 7,529,530 km /2.7*2.66 = 7,417,983 kg CO2 / 7,529,530 km = **0,99 kg CO2/km**
Charging Point identification data GID-numbers 45.0.0.6400.xx xx= 12, 17, 18, 19, 20, 21, 22, 23	24 operating charging points All are available for public charging
Total number of recharges per year/day/year/month Specified per. reporting period	M49-M54: 404 M55-M60: 1,174 M61-M67: 931 M68-M74: 2,736
Amount of kWh recharged per day/month/year Specified per. reporting period	M49-M55: 4,796 M55-M60: 7,307 M61-M67: 10,024 M68-M74: 32,620
Lower emissions of CO2 in the city due to sustainable mobility actions	Se above calculation for all periods 7,417,983 kg CO2 / 37 x 12 = 2,406 tonnes CO2 per year (12 months)
New sustainable vehicles (BEV) in the city due to SmartEnCity-project Specified per. reporting period (Source: Bilstatistik.dk)	The growth in BEV numbers in Sonderborg can´t be corelated 1:1 to SEC-project, but the SEC-established infrastructure have supported the growing numbers M43-M48: 26 M49-M54: 40 M55-M60: 104 M61-M67: 117 M68-M74: 163 M74-M77: 40 (only 3 months) Registred population of BEV-cars in Sonderborg by end of reporting periods M48: 146 M54: 190 M60: 327 M67: 526 M74: 838 M77: 973
New sustainable vehicles (PHEV) in the city due to SmartEnCity project Specified per reporting period (Source: Bilstatistik.dk)	The growth in PHEV-numbers in Sonderborg can´t be corelated 1:1 to SEC-project, but the SEC-established infrastructure have supported the growing numbers M43-M48: 32 M49-M54: 58

	M55-M60: 135 M61-M67: 248 M68-M74: 195 M74-M77: 49 (3 months) Registered population of PHEV-cars in Sonderborg by end of reporting periods M48: 155 M54: 237 M60: 411 M67: 750 M74: 1 065 M77: 1 132
New sustainable vehicles (biogas buses) in Sonderborg due to SmartEnCity project	44 since June 2017
Increase of the number of EV charging infrastructures in the city (only public or public & private	+50 public (guestimate) + 2 000 private (guestimate)
Increase in the use of EV charging infrastructures due to the project Count based on # of charging events at the 24 charging points	M49-M54: 404 M55-M60: 1 174 M61-M67: 931 M68-M74: 2 736

Table 46. Mobility results for Sonderborg

5.3.5 Social Acceptance Protocol
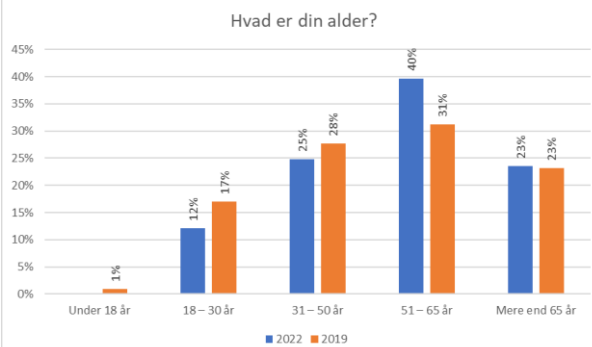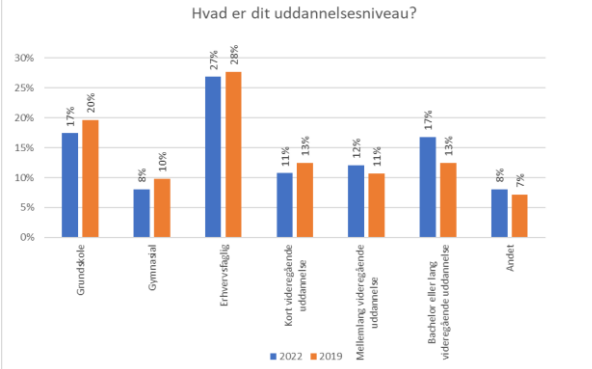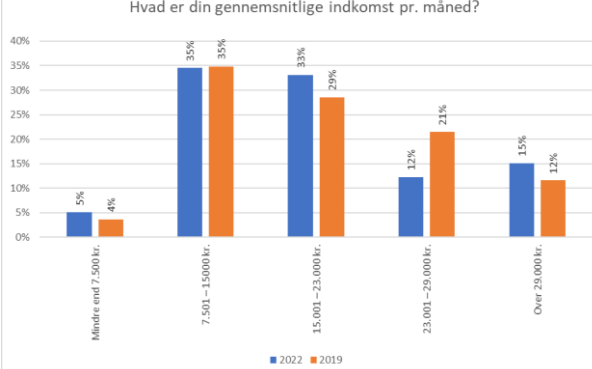
Two residents' surveys have been conducted focused on resident-families living in apartments involved in the SEC-energy retrofit program. The first survey (#1) was carried out in June/July 2019, the second survey (#2) in May/June 2022.

The surveys have been targeted residents in SAB, SOBO & B42 housing associations.
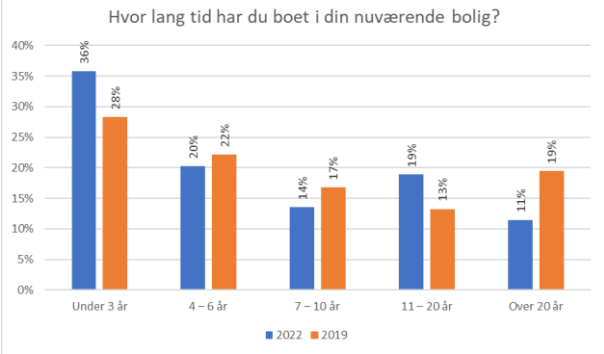
First survey (#1) was based on a paper-questionnaire, the second (#2) was based on an electronic survey distributed to all email-named residents in the target-group. Demographic variables are "similar" for both surveys, reflecting that same population are contained in both surveys. However, app. 30% of the respondents have moved-in within the last 3 years.

Comprehensive feedback has been collected and is now being digested for further improvement in the housing associations on-going improvements with residents' social acceptance – and as an integrated part of the newly developed Energy and Sustainability strategies in the housing associations.

Social acceptance KPIs	Results	
	Individual characteristics	
	Survey #1 (2019)	**Survey #2 (2022)**
Age	Under 18 = 1% 18-30 y = 17% 31-50 y = 28% 51-65 y = 31% Over 65 y = 23%	Under 18 = 18-30 y = 12% 31-50 y = 25% 51-65 y = 40% Over 65 y = 23%

Hvad er din alder?

Highest level of completed education of inhabitants	Basic school = 20% Gymnasium = 10% Vocational = 28% Short higher education = 13% Medium higher education = 11% Bachelor (long education) = 13% Other = 7%	Basic school = 17% Gymnasium = 8% Vocational = 27% Short higher education = 11% Medium higher education = 12% Bachelor (long education) = 17% Other = 8%
Nationality It is estimated by the housing association administrations, that app. 20% af the residents have a foreign nationality (non-Danish). Asking about nationality was considered discriminating in survey #1 and therefore also not part of survey #2	N/A	
Net monthly income of the households	Less than 7.500 DKK = 4% 7.501 – 15.000 DKK = 35% 15.001 – 23.000 DKK = 29% 23.001 – 29.000 DKK = 21% Over 29.000 DKK = 12%	Less than 7.500 DKK = 5% 7.501 – 15.000 DKK = 35% 15.001 – 23.000 DKK = 33% 23.001 – 29.000 DKK = 12% Over 29.000 DKK = 15%

Hvad er dit uddannelsesniveau?

Hvad er din gennemsnitlige indkomst pr. måned?

Characteristics of the dwelling		
Type of building	Multistorage: 90% Detached: 9% Single non-detached: 1%	Multistorage: 96% Detached: 3% Single non-detached: 1%
Size of dwelling - heated area	Below 50 m2 = 10% 51 – 70 m2 = 27% 71 – 90 m2 = 40% 91 – 110 m2 = 16% Over 110 m2 = 8%	Below 50 m2 = 8% 51 – 70 m2 = 25% 71 – 90 m2 = 42% 91 – 110 m2 = 20% Over 110 m2 = 5%
Accommodation time in the apartment	Below 3 y = 28% 4-6 y = 22% 7-10 y = 17% 11-20 y = 13% Over 20 y = 19%	Below 3 y = 36% 4-6 y = 20% 7-10 y = 14% 11-20 y = 19% Over 20 y = 11%
	 Surprisingly many residents change homes within 3 years and this might impact the longer term "memory" of climate actions taken and engagement in decision-making.	
Knowledge and environmental awareness on environmental problems		
Environmental awareness	None = 6% Little = 11% Medium = 40% Big = 32% Very big = 12%	None = 1% Little = 15% Medium = 54% Big = 26% Very big = 4%
Knowledge and benefits of the solutions implemented in energy efficient retrofit projects		
Knowledge/awareness of implemented efficient energy measures	LED light: 66% Insulation: 58% New windows: 62% Better ventilation: 45% Rooftop PV-systems: 60% PV-battery systems: 18%	LED light: 47% Insulation: 19% New windows: 22% Better ventilation: 22% Rooftop PV-systems: 75% PV-battery systems: 27%
Fairness and inclusiveness in the decision-making process: satisfaction with the project, with the level of information received, with the involvement degree		
Residents project satisfaction (general satisfaction with the implemented measures)	N/A	1-not satisfied: 7% 2: 19% 3-satisfied: 39% 4: 20% 5- very satisfied: 15%
Satisfaction with the information accessibility (energy consumption)	1-not satisfied: 17% 2: 19% 3-satisfied: 28% 4: 16% 5- very satisfied: 19%	1-not satisfied: 9% 2: 18% 3-satisfied: 38% 4: 16% 5- very satisfied: 20%

Residents' involvement degree How much have you felt yourself involved in the decision to implement energy retrofit solution?	1-not involved: 34% 2: 21% 3-involved: 26% 4: 11% 5- very involved: 7%	1-not involved: 46% 2: 23% 3-involved: 25% 4: 4% 5- very involved: 2%
Economic value of the solutions		
Satisfaction with the investment cost	N/A	1-not satisfied: 7% 2: 19% 3-satisfied: 39% 4: 20% 5- very satisfied: 15%
Energy bill reduction Satisfaction with the implemented actions and energy savings versus increase in rental cost	1-not satisfied: 21% 2: 17% 3-satisfied: 35% 4: 17% 5- very satisfied: 11%	1-not satisfied: 12% 2: 23% 3-satisfied: 44% 4: 13% 5- very satisfied: 8%
Further investments in energy related project (how interested are you in new/further energy retrofit projects)	1-not interested:22% 2: 17% 3-interested: 32% 4: 17% 5- very interested: 13%	1-not interested:8% 2: 11% 3-interested: 35% 4: 21% 5- very interested: 26%
Technical value of the solutions		
Whole solution satisfaction	1-not satisfied: 7% 2: 15% 3-satisfied: 37% 4: 27% 5- very satisfied: 15%	1-not satisfied: 11% 2: 23% 3-satisfied: 41% 4: 16% 5- very satisfied: 9%
Comfort conditions	1-no improvements: 33% 2-little improvements 7% 3-medium: 29% 4-large: 22% 5-very large: 8%	1-no improvements: 61% 2-little improvements: 13% 3-medium: 18% 4-large: 8% 5-very large: 1%
Energy savings satisfaction (heat)	1-not satisfied: 11% 2: 14% 3-satisfied: 35% 4: 23% 5- very satisfied: 17%	1-not satisfied: 18% 2: 23% 3-satisfied: 39% 4: 10% 5- very satisfied: 10%
Energy savings satisfaction (electricity)	1-not satisfied: 10% 2: 13% 3-satisfied: 39% 4: 23% 5- very satisfied: 15%	1-not satisfied: 12% 2: 19% 3-satisfied: 37% 4: 11% 5- very satisfied: 20%
Esthetical satisfaction	1-not satisfied: 10% 2: 11% 3-satisfied: 39% 4: 18% 5- very satisfied: 21%	1-not satisfied: 7% 2: 17% 3-satisfied: 46% 4: 19% 5- very satisfied: 11%

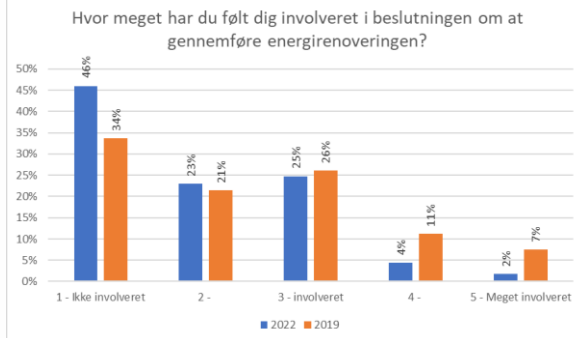**Table 47. Social acceptance results for Sonderborg**
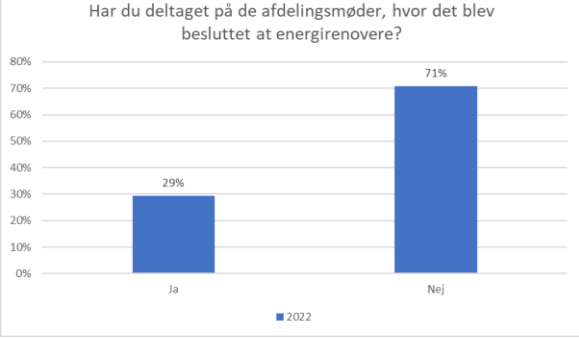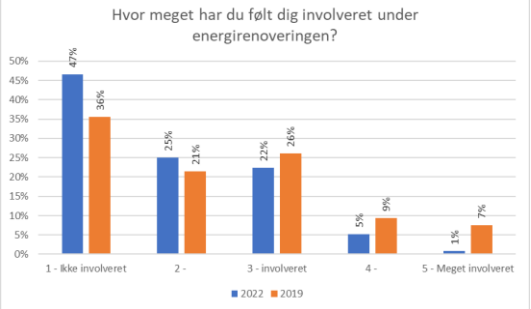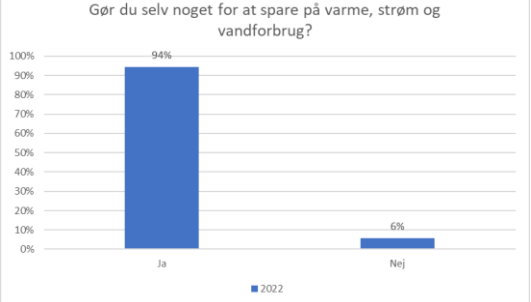
5.3.6 Citizen Engagement Protocol

Citizen engagement has been an integrated part of the above mentioned two residents' surveys.

It is surprising how little the respondents themselves see (or remember) their direct involvement in the decision-making process, however it is (positively) surprising to learn that 96% of the responding residents answer yes to "do you take own actions", but also that an increasing number of residents are now "wanting more actions" to be implemented. Maybe not a big surprise, as majority of residents see their energy bill increase due to the current European energy supply crises.
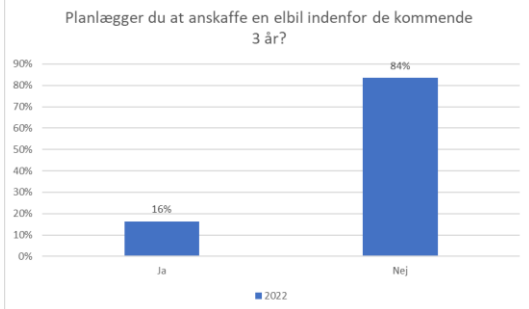
16% of the respondents expects to purchase an e-car within next 3 years. The figure will create a strong push for more planning/implementation actions regarding EV-charging solutions/capacity in the housing association departments. The planning/decision-discussions have already started in several departments.

Comprehensive feedback has been collected and is now being digested for further improvement in the housing associations on-going improvements with residents' engagement – and as an integrated part of the newly developed and approved Energy and Sustainability strategies in the housing associations.

Citizen engagement KPIs	Results	
Citizen engagement strategy		
	Survey #1 (2019)	**Survey #2 (2022)**
Residents involvement degree How involved did you feel yourself <u>when the decisions were made</u>?	1-not involved: 34% 2: 21% 3-involved: 26% 4: 11% 5- very involved: 7%	1-not involved: 46% 2: 23% 3-involved: 25% 4: 4% 5- very involved: 2%
	  The feedback is a surprise, but probable a true picture of how the residents see their involvement in the decision-making process. There is a need for establishing constant energy renovation as a burning climate platform and secure that discussions of results measured versus department goals and ambitions are discussed at all annual residents' meetings.	

Residents involvement degree Did you participate in the meeting where the energy retrofit measures were agreed?	**Har du deltaget på de afdelingsmøder, hvor det blev besluttet at energirenovere?** 29% answered yes, 71% answered no. The feedback is a surprise, but probable a true picture of how the residents see their involvement in the decision making process.	
Residents involvement degree How involved did you feel yourself <u>during the implementation of the energy retrofit measures?</u>	1-not involved: 36% 2: 21% 3-involved: 26% 4: 9% 5- very involved: 7%	1-not involved: 47% 2: 25% 3-involved: 22% 4: 5% 5- very involved: 1%
	Hvor meget har du følt dig involveret under energirenoveringen? The feedback received is a surprise and signal the importance of not only information, but also visibility during and after the completion of the energy retrofit measures.	
Number of surveys fulfilled by residents / Number of residents informed about the citizen engagement actions In the 2019-survey the 900 residents were requested to fill in a paper-based questionnaire and return it physically – the 2022-survey was electronically distributed to all registered email-addresses across the 1,800 potentially involved residents.	107 respondents / 900 intervention families = 12%	177 respondents out of 1,800 interventions = 9,8%
Additional question added to the 2022-survey: Do you, yourself, contribute to saving heat, power and water?	**Gør du selv noget for at spare på varme, strøm og vandforbrug?** 94% of all respondents answered YES, 6% answered no. The feedback received confirms that residents are deep engaged in taking personal responsibility and climate actions.	

Additional question added to the 2022-survey: Do you plan to buy a BEV-car within the next three years?	Planlægger du at anskaffe en elbil indenfor de kommende 3 år? ■ 2022 16% of the respondents answered yes, 84% answered no. The positive feedback from the residents will help the housing association admin plan how the EV-charging capacity should be allocated in years to come.	
Perception of success or failure by actors involved about citizen engagement activities performed	N/A	The Advisory Board concluded in an evaluation-workshop on 10. June 2022 that the citizen engagement activities has been very successful, but also that the initiated CE-activities will be strengthened, potentially with additional resources allocated.
Citizen Engagement plan (Urban platform)		
Number of citizens using web application	80	
Number of logins (monthly) in the web application	600	
Time spent on the web	From 15 min to 90 min in the range from M43 to M67	
Number of mobile app downloads in the framework of SmartEnCity	N/A as there are no mobile applications separately to download	
Citizen engagement strategy + plan (project objectives in district)		
Number of dwellings retrofitted	Renovation phase: 51 buildings with 815 dwellings Solar+battery phase: Additional 86 buildings with 1639 dwellings. Involved in total in the project: 137 buildings with 2454 dwellings.	
Number of buildings connected to the District Heating	All 137 buildings are connected to the District Heating in Sonderborg.	
Number of residents benefitted by the intervention	All 2454 dwellings benefitted by the interventions.	
Number of residents who were against project	No dwellings/residents voted against.	

Table 48. Citizen engagement results for Sonderborg

5.3.7 Economic performance Protocol

The resident costs due to the investment vary between the 3 housing associations.

SAB has the lowest investment costs of 26.3 Euro/m2, because SAB has primarily invested in solar PV and batteries and not much on the more expensive measures like new windows, outside insulation etc. B42 has the highest investments costs of 212 Euro/m2, because they have focused more on the building envelope.

The building renovation phase has a cost saving rate of 23 % – 36 %, and the solar PV + battery phase has a cost saving rate of 45 %.

Economic performance KPIs	Results (SAB)	
Resident costs	26.3 Euro/m2	
Grant rate	7.54 Euro/m2 = 23%	
Total annual costs	Baseline	After
	Renovation phase: 22.5 Euro/m2. Solar battery phase: 10.0 Euro/m2.	Renovation phase: 23.3 Euro/m2 Solar battery phase: 10.4 Euro/m2
Total annual benefits for residents	Reduction of costs in renovation phase: 2,3 Euro/m2. Reduction of costs in solar battery phase: 4.7 Euro/m2	
Cost saving rate	Cost saving rate in renovation phase: 10% Cost saving rate in solar battery phase: 46%.	

Table 49. Economic performance results for SAB

Economic performance KPIs	Results (SOBO)	
Resident costs	61.8 Euro/m2	
Grant rate	21.46 Euro/m2 = 26 %	
Total annual costs	Baseline	After
	Renovation phase: 22.0 Euro/m2. Solar battery phase: 12.0 Euro/m2	Renovation phase: 23.3 Euro/m2. Solar battery phase: 12.9 Euro/m2
Total annual benefits for residents	Reduction of costs in renovation phase: 8.2 Euro/m2. Reduction of costs in solar battery phase: 5.8 Euro/m2	
Cost saving rate	Cost saving rate in renovation phase: 36%. Cost saving rate in solar battery phase: 45%	

Table 50. Economic performance results for SOBO

Economic performance KPIs	Results (B42)	
Resident costs	212 Euro/m2	
Grant rate	27.61 Euro/m2 = 12 %	
Total annual costs	Baseline	After
	Renovation phase: 11.5 Euro/m2. There is no solar battery phase for B42.	Renovation phase: 15.3 Euro/m2. There is no solar battery phase for B42.
Total annual benefits for residents	Reduction of costs in renovation phase: 3.5 Euro/m2.	
Cost saving rate	Cost saving rate i renovation phase: 23%	

Table 51. Economic performance results for B42

5.3.8 City impact indicators

The Table 52 below provides an insight on the results impacting the city due to the SmartEnCity project. Due to building retrofitting 2,980 MWh energy savings and 485 tons CO2 emissions were saved. In total 137 building consisting of 2454 dwellings were retrofitted. The total investment of the district from the housing associations and the EC funding amounts to 11,517,000 EURO.

The mobility action taking into account the 44 biogas-based buses contributed to 2406 t CO2 yearly.

In addition to this a total of 31 EV charging points have been installed in the city. The monitored recharged electricity in the EV charging stations for a total of 2 years amounts to 54,747 kWh (almost tripled during the last reporting period).

City impact indicators	Results
Energy savings due to district renovation	2 980 MWh
CO2 emissions savings due to district renovation	488 tons CO2
CO2 emissions savings due to sustainable mobility actions – annual savings	2 406 tons CO2 based on biogas-based buses replacing diesel fuelled buses
Share of renewable energy	44.6% (48.4% without transport)
Number of dwellings/buildings retrofitted	51 buildings with 815 dwellings retrofitted on the 1st phase
Number of dwellings/buildings with new PV/batteries installations	By M30: 51 buildings with 815 dwellings (renovation phase) By M67: Solar+battery phase = Additional 86 buildings with 1639 dwellings. In total in the project: 137 buildings with 2454 dwellings.
Number of buildings connected to the district heating	All 137 buildings are connected to district heating for the whole period
Biogas buses	44
Number of (public) EV charging stations	24 EV charging points
Total kWh recharged in the SEC-projects EV charging stations	M49-M74 = 54,747 kWh
Total investment of the district from local and regional public funding, EC funding and private funding" (e.g. dwellings' owners, energy companies, social housing companies, etc.).	Investments in renovation of housing associations + in solar PV and battery systems from housing associations: EUR 12,6 Million. EU Grants: 2 007 000 Euro Investments in EV-charging, 44 biobuses and filling stations: EUR 10,4 Million Total investments: EUR 23,0 Million

Table 52. Sonderborg impacts at city level

6 Deviation of the plan and recommendations to followers

This section tries to give an overall summary of the main deviations from the original plans that affected the implemented measures and therefore their evaluation.

Specific mention is done of the impact of the COVID19 pandemic that affected sometimes forcing changes on the initial plans or adaptations of methodologies, and in many cases caused delays.

This section is also intended as a "warning for all seafarers" by speaking about the problems that can be found on the way and give some recommendations based on the lessons learnt along the follow-up process.

VITORIA GASTEIZ DEVIATIONS OF THE PLAN

For the city of Vitoria- Gasteiz, the deviations in the **retrofitting actions** were related to the technical part but not to the economical part, where final costs fulfilled to a high extent the initially forecasted costs with no big deviations (average deviation >5%). Regarding retrofitting works themselves, some time-deviations were suffered due to several causes:

- Local SMEs where not used to participate in public tenders so some time was needed to train them in this field and inform about the special characteristics and needs of the public tendering processes
- Adhesion deadline was postponed twice in order to get the maximum amount of participants. This made the retrofitting works start later than planned.
- Once retrofitting works started, some delays were observed in specific cases due to material delivery problems
- Monitoring sensors installation process was very long and difficult to accomplish, It was necessary to access to every individual dwelling and, to do this, it was necessary communicate and schedule a great number of appointments with each and very tenant. It took much more effort than planned.

For the case of the **district Heating Network** deployment, it was delayed due to the difficulty on finding the appropriate legal approach to start the works. A first public tender was declared void and it was necessary to adapt and tailor the process and the design so the network could be deployed. Once the works started, planification remained on time.

The **mobility measures** in Vitoria- Gasteiz have changed a lot from the initial stages of the project to the last phases. The finally main mobility action, Smart Electric Bus (BEI), started later than planned due to a conflict during the public tendering process. The result of the process was appealed by the non-winning company. The final decision about the submitted appeal took some time in order to fulfil all the necessary legal aspects to avoid any eventual future problem.

The **COVID-19** pandemic affected all the tasks in several ways:

- Inability of hosting meetings with beneficiaries to take decisions and move forward in the retrofitting projects
- Inability to access to the dwellings to continue with the deployment of the sensors network

- Halt in construction activities due to the lockdown. This affected to the retrofitting works as well as the district heating network and Smart Electric Bus deployment civil works
- Difficulties to obtain the necessary materials for the works
- Difficulties with the communication with the neighbours
- Labour force adjustment plans in construction companies that led to a lack of workforce after the lockdown

TARTU DEVIATIONS OF THE PLAN

Deviations of the plan in Tartu are mostly related to changes in the initial time schedule. Delays and changes were mainly caused by the implementation of innovative solutions and the absence of previous know-how. One of the most time-consuming activities was the process of planning. Even though it took a lot of time, it was crucial for achieving good results. Some major conclusions from **retrofitting** process are as follows:

- Delays at the start of the project due to the novelty of the undertaken task.
- Shortage of building designers and construction companies, which resulted in delays and rising prices.
- Rising costs of materials
- More precise communication with the financing institution KredEx, which was also co-funding renovation: agreements regarding financing should have been reached at the start of the project.
- Delivery problems (including the influence of COVID-19).

There were some problems with the low quality of the delivered technology, namely with sensors for street lightning and inverter for EV battery reuse.

Mobility actions. Regarding bike-share, information systems may go out of line in active use, people tend to use bicycles unintentionally and also vandalize. In order to reduce the impact of possible problems, it is advisable to have different operational strategies in the start-up phase for a flexible response. It is very important to pay attention to security (IT systems, traffic, general security) and to inform the public proactively. In case of installation of quick EV chargers, we had to carry out more than one procurement in order to reach a satisfactory final result. Our experience shows that market participants need to be consulted in order to obtain similar low-profile and innovative solutions. It´s crucial to identify the technical nuances that will affect the later operation of the solution as well as the business model.

District heating and cooling system. Long term planning is needed for establishing the new district cooling network. Starting district cooling services scratch requires a very good understanding about market, business model, investment and operation costs of services. The development of district cooling network together with connected customers takes time.

Citizen engagement and social acceptance. Due to the pandemic, in person events, meetings and trainings had to be cancelled. To mitigate this effect, regular newsletters were sent to the residents, planned trainings were organized online and a short survey was disseminated to ask the residents' feedback and inquire about any troubles that could be addressed by the project team. Additionally, the team still regularly kept in touch with all housing associations via phone and email. Focus group study on the use of smart home

system was cancelled, because the topic was comprehensively covered with post-reconstruction survey.

SONDERBORG DEVIATIONS OF THE PLAN

For the case of Lighthouse City Sonderborg, the COVID-19 pandemic has influenced some of the data collection and reporting such as causing:

- Difficulties connecting some meters to the data logger system. The main reason being difficulties with access to the main district heating meters due to COVID-19 restrictions.

- Citizen engagement activities being delayed due to the COVID-19 societal closure in the country and restrictions.

- Data is overall affected based on the pandemic and would be more difficult to compare to periods prior the pandemic i.e.: number of passengers using the bus has been down with more that 30% during COVID-19.; citizens driving less during pandemic close down and therefore also charging less; housing association energy consumption going up as residents have been working from home; eating less out etc.

- COVID-19 have also lowered the citizen interest and use of public transportation. Campaigns have been initiated in spring 2022 focused on less carbon by public transport – but so far unfortunately with limited results.

RECOMMENDATIONS FOR OTHER CITIES BASED ON THE FOLLOW-UP PROCESS

One main intention of SmartEnCity has been to guide the follower cities, as well as to other potential cities, on their path to decarbonisation. In this line the following lines try to present the main lessons learnt along the follow-up process.

The following lessons and conclusions extracted by the three lighthouse cities can be taken as best practices for other cities:

- The tendering process is a crucial stage of the implementation activities. It must be developed in detail, including a clear description of each and every aspect expected from the contractor and deadlines. Once the tender is published, further modifications of the aspects included could represent increase on costs.

- Another aspect that needs to be clearly detailed from the first stages and properly introduced in the tenders is data collection. In case a special monitoring or additional data rather than the "business as usual" wants to be monitored, special mention and attention must be paid on every stage of the development process.

- Whenever public tenders apply, the workplan must consider the reclamation periods included by law in any public procurement. Any reclamation could enlarge the time estimated and delay the processes.

- Bear in mind that large-scale buildings´ renovation actions can lead to saturation of the market of project designers and construction companies, which causes the

tendering processes to be deserted or with little concurrence. It is recommended to plan in phases, bidding continuously, instead of in large blocks.

- Additional budget should be foreseen and allocated from the first stages as back-up in case increase on costs happens, such as increase on prices of equipment or material.

- In case of cascade funding, it must be considered that the delay of the first stages would delay the following ones.

- The preparation phases of the retrofitting activities in block of buildings are more likely to take longer than in single homes as a larger number of owners are involved. The implication of higher number of stakeholders makes the processes of agreement more unpredictable and lead to possible lengthening of some phases.

- Urban processes involving citizens (homeowners) require slower speed rate than expected from the administrations and financing programs (H2020, etc.). A previous phase (two or three years) of awareness in the neighbourhood ("sowing" phase) is recommended.

- In the case of building renovation projects, it is important to involve technical experts (ventilation, heating, electricity, etc.) in the early stages of the process to ensure that the right solutions are already in place during the design phase.

When speaking about risks, the main ones encountered during SmartEnCity project execution include:

- Delays due to municipal administrative burden.
    - Potential impact: beginning of works have to wait until permits are obtained.
- Lack of bidders (construction companies) in the tendering process:
    - Potential impact: delays in the beginning of works.
- Decision of the homeowners to give up the project.
    - *Potential impact: decrease of the total area (m^2) retrofitted.*
- Bankruptcy of the companies that participate in the project.
    - Potential impact: delays in the beginning of tasks and works.

CONCLUSIONS FROM THE FOLLOW UP PROCESS

The supervision and follow-up of the actions carried out in demonstration activities is crucial in order to reduce the uncertainty on the related works, ensure a high quality in the interventions and make secure the correct implementation of the evaluation and monitoring protocols.

In order to detect possible deviations and gaps, an exhaustive revision on the status of the implementation of the different cluster of actions has been carried out along the project. Corrective actions have been suggested to correct or minimise delays when encountered.