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Integrated local energy systems (Energy islands)

RENergetic

Community-empowered Sustainable Multi-Vector Energy Islands

Project Nº 957845

D7.3 – Initial Evaluation of Common Demonstration Results & Impact

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Executive Summary

The goal of this deliverable is to give an overview on the baseline assessment of KPIs, the expected impact of RENergetic, and measurements of impact so far. The focus lies on presenting the relevant baseline assessments per pilot, which are the basis for depicting impact throughout the course of the project and some preliminary impact calculations of the activities within the Epics, together with descriptions of expected impact for each Epic.

After a first introduction to clarify purpose and organization of the document, challenges of impact assessments on technical, economic and social level are discussed. For technical impact, this mainly refers to the availability and collection of data, while for economic impact, challenges refer to the dependency on technical and business model parameters to conclude reliable assumptions. For social impact, data assessment issues and difficulties in measuring social KPIs, particularly regularly, are discussed as challenges.

In the following, impact assessment of RENergetic pilot activities is reported separately for each pilot, based on the differentiating activities within the pilot sites. This includes the evaluation of key performance indicators (KPIs) based on the metrics defined priorly (see D7.1, D7.2). For each pilot, baseline assessments along the respective KPIs are presented, and first impact results if available. Further, expected impacts are defined and explicated. For each epic, i.e., the translation of the epic in the pilot context, reporting about impact or expected impact is presented in terms of technical and economic assessments. Where available, preliminary results and models for the impact analysis are given. The social KPIs are not measured particularly for one specific epic, but rather overall for each pilot. This is reflecting that all activities together as such should positively affect the social KPIs, which is also discussed within the social impact assessment challenges.

For the Ghent pilot, the epics included and reported are the ones of Social Campaigning, Heat DR, EV DR and Electricity Demand Response. Next to the technical baseline assessment for the heating and electricity domain, experiments and (expected) impacts for these epics from perspective of the Ghent pilot are described. The baseline assessment for Ghent includes the self-sufficiency indicator, the electricity efficiency and electricity potency indicator as well as share of fossil-fuel / RES based electricity and CO2 intensity for electricity. Additionally, the social KPI baseline is reported. For Social Campaigning, EV DR and Electricity DR, activities and expected impact are described. Additionally, preliminary impact of Heat DR, the multi-vector optimizer and PV dimensioning are elaborated.

The Poznan pilot concentrates on the epics of Social Campaigning, Local Waste Heat Optimization and Electricity Supply Optimization. First, the baseline assessment is given for the Heating network, including the self-sufficiency indicator, the energy potency indicator, the share of RES / Non-RES, CO2 intensity and energy savings for the Heat Network. Further, baseline assessments for electricity, and for social KPIs are presented. Afterwards, the activities and experiments within the Social Campaigning epic and the Waste Heat Reuse epic are described, and the expected impact for Heat DR and Electricity supply optimization is set forth.

In the Segrate pilot, the epics which are focused on within the project and this report are the ones of Social Campaigning, Heat Supply Optimization, EV DR and Electricity Supply Optimization. The impact assessment for the Segrate pilot first includes the activities related to the electricity vector, particularly for the OSR EV facility and the social KPI baseline assessment. Further, we describe expected impact (on technical and/or economic level) for Heat Supply Optimization, EV DR and Electricity Supply Optimization.

Finally, the impact of virtual pilot activities within RENergetic are described. This is done by a description of the virtual pilot electricity supply activities, and the technical impact calculated, depending on different grid scenarios.

The objective of RENergetic is to demonstrate the viability of so-called ‘urban energy islands’. Energy islands seek to achieve the highest possible degree of self-sustainability with regards to the supply of its energy demand, be it electricity or heat through local renewable resources.

At the same time an urban energy island may offer ancillary services to the public grid surrounding it.

These islands place the consumer at the centre of the energy transition, giving them an active part in energy communities capable of producing their own energy, sharing the surplus with the rest of the public grid and optimizing consumption. RENergetic will demonstrate that Urban Energy Islands increase the amount of renewables in these areas as well as the energy efficiency of local energy systems. RENergetic will demonstrate the viability of this energy islands in three site pilots, each of them of a different nature: New Docks, a residential area in Ghent – Belgium, Warta University Campus in Poznan, Poland and San Raffaele Hospital and its investigation and research campus in Segrate-Milan, Italy. The impact of the Urban Energy Islands is assured as technical, socio-economic and legal / regulatory aspects are considered while safeguarding economic viability.

RENergetic is being carried out over the stretch of 42 months involving 12 European partners: Inetum (Spain, France, and Belgium), University of Stuttgart and the University of Passau (Germany), Clean Energy Innovative Projects and Gent University (Belgium), Poznan University of Technology, Veolia and Poznan Supercomputing and Networking Center (Poland), Ospedale San Raffaele, Comune di Segrate and University of Pavia (Italy), Seeburg Castle University and Energy Kompass GMBH (Austria).

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BESS	Battery Energy Storage System
DR	Demand Response
DSO	Distribution System Operator
EI	Energy Island
EMS	Energy Management System

GHG	Green House Gas
HP	Heat Pump
KPI	Key Performance Indicator
LEC	Local Energy Community
MARR	Minimal Acceptable Rate of Return
MCDM	Multi-Criteria Decision Making
NPV	Net Present Value
RES	Renewable Energy (sources)
TSO	Transmission System Operator

I. INTRODUCTION

I.1. Purpose and organization of the document

This is the first deliverable in RENergetic that deals with impacts of the project, after a little over 2 years of project runtime. At the current status of the project this can only be a first endeavour of understanding where the approach that the consortium has defined will lead to, based on the methodology developed throughout the project: The RENergetic system is based on a set of so-called “epics” that are tightly linked to system service components: an epic is a specific scenario in the context of which RENergetic aims at increasing the level of energetic self-sufficiency. For instance, the epic “EV Demand Response” designs our vision to deal with supply side constraints of REN-energy by adapting demand through either asking end-users to shift their charging times accordingly or through a smart algorithm that modifies charging profile and speed once the EV is plugged in. It turned out that there is no one-size-fits all approach to an epic, but rather that each pilot has a different “flavour” of implementing it, considering its geo-locational, infrastructure and inhabitants’ characteristics. The RENergetic system is composed of 7 epics (see Figure 1) covering social aspects, optimization and DR for both heat and electricity and aspects of enhancing the infrastructure. Additionally, the two epics “Interactive Platform” and “Forecasting” are affecting all other epics horizontally. These epics are defined in a trans-disciplinary way relying on technical, social and economic requirements and constraints. As the implementation of an epic, as mentioned, needs to be adapted to a pilot site, also the impact is individual, albeit there is a great overlap in the general KPIs that are being tackled.

This leads to the following approach of evaluation and impact assessment of the RENergetic system components: based on the KPIs defined for the project in D7.2, for each pilot site, there is a baseline assessment. Subsequently, for each pilot site, the considered epics are evaluated regarding associated activities and impacts. As the project is just entering into the phase of testing the first algorithms and functionalities, the impact assessment is done mainly in terms of expected impact assessed. Whereas technical and economic impacts can be assessed per epic, the social impact of RENergetic activities will be gradually developing over time, as a result of the amalgamation of all epics implemented in a pilot site and specific conditions of the social fabric as well as external events, be they political, economic, social or environmental.

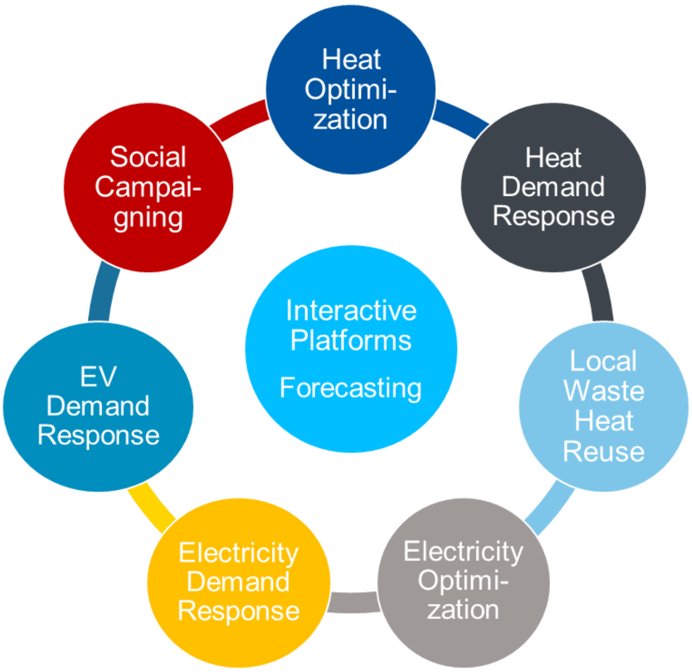

Figure 1: RENergetic Epics

One issue that prevented earlier implementation is that data collection proved a much higher challenge than originally assumed, so that in some cases, the impact assessed and expected will be evaluated in a qualitative way. This is also why the document, before turning to the evaluation per pilot, starts with a short elaboration of the challenges faced at collecting the KPIs.

The organization of this document follows suite of the approach described above: Section II explains challenges of impact assessment in all 3 different areas of evaluation, i.e., social, technical, economic. Sections III - V document the evaluations of the activities in the pilots Ghent, Poznan and Segrate, accordingly. Section VI is dedicated to the so-called “virtual pilot”, a lab infrastructure set-up at the University of Passau that in a small-scale grid emulation analyses the electricity epics. And finally, section VII concludes the document. Additional data can be found in the appendix, section VIII.

I.2. Scope and audience

This is a public deliverable and is set out to offer an exciting read not only internally and to interested third parties as researchers in our network or municipalities. Beyond that it is aimed at the general public that wants to understand the potential outcome of a European project that is dedicated to offer solutions for the challenges of the energy turnaround in cities and other urban areas.

II. CHALLENGES OF IMPACT ASSESSMENT

As reported in D7.2, the major goal of the RENergetic impact assessment is to measure the impact of the epics developed. By means of the different technical, economic and social KPIs identified in D7.2. we want to quantify the actual impact of our epics in different pilot sites. The goal is furthermore, to provide a method to replicate this impact assessment methodologies in replicator initiatives, as will be described in WP8.

As quantified impact assessment largely depends on quantitative data that is to be gathered at the pilot sites, this is where the major challenge lies. Given the different maturity level of the different epics at the different pilots, together with a different level of automation in the data gathering itself, diverse practical challenges pop up. More insights for the three impact dimensions are given below.

II.1. Technical Impact Assessment

Technical impact assessment by means of the technical KPIs identified in D7.2 largely depends on technical input data, that can be gathered by talking to system engineers or from its pilot dashboards. The major barrier here is availability of people and effort/time spent in order to get a good view and understanding of the data.

Ideally, this type of calculation can rely on IT dashboard like the Grafana Dashboard already implemented in the Ghent pilot site. Replication guidelines to be developed in WP8 will suggest the development for similar dashboard at other pilot sites or replicator cities.

Many KPIs, defined in D 7.2 could not be calculated completely, because the data was not at all or was not yet available. For instance, in the case of the Poznan pilot site not every building in the energy island has the monitoring devices required for an accurate measurement of electricity supply, so that only one dormitory building was considered in this impact assessment. Furthermore, often data must be collected manually by energy managers, which poses another communication overhead between pilot and project.

Non-working or malfunction sensors are a common occurrence in complex systems which produce large amounts of data every day. For that reason, data cleaning and outlier detection is a practice required, before any data analysis can be done.

Another challenge comes from the fact that the pilot sites are not fully self-sufficient and data collection requires cooperation from the side of the external energy suppliers. For the Ghent pilot site, detailed hour to hour data from the Christeyns waste heat supply could not be acquired and a yearly average of CO2 emissions per kWh was considered instead. The same applies for the Veolia heating provider in Poznan. For electricity supplied by the national energy grid a yearly average from the “Our World in Data” project[1] was used.

In energy islands which depend mostly on renewable energy sources, energy supply and demand vary a lot with different weather conditions. In order to derive a consistent comparison between the as-is and the post-application scenarios would require almost identical weather conditions which obviously is not given in reality.

II.2. Economic Impact Assessment

What concerns the economic KPIs, the needed metrics (input data) involve financial data, which is not known to the system engineers and might be confidential. For these reasons

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[1] https://ourworldindata.org/

gathering the required data for this type of analysis is an extremely difficult and lengthy process.

As opposed to the situation for technical impact assessment, the economic impact assessment does not rely merely on technical parameters, like energy demand and supply figures. Also, investment data is needed, as well as operational expenses and pricing schemes. Those data have a different nature than the technical data and typically are also treated more confidentially. This makes it even more difficult to gather.

A solution was found in describing different scenarios that link to implemented epics, paying a lot of attention to bringing forward all relevant cost and benefit figures here. It often concerns actual investment decisions, based on passed investment of revenue numbers or detailed estimated supporting future investment plans. This can be combined with making reliable assumption for missing data points.

Thanks to this approach, actual scenarios for all pilot sites have been or will be assessed based on their economic impact.

II.3. Social Impact Assessment

For measuring social impacts, scales and metrics were proposed in D7.2 V.2. It is important to take into consideration that social impact assessment (SIA) is not a fixed point, but it is about process and outcome of social change from interventions (Vanclay, 2003). This approach is especially important due to the lack of research on social impact of energy islands. So far mostly qualitative data has been collected. This assumes that social impact is said to have a qualitative nature and is hardly measurable with an objective KPI. However, by concretely defining the concept of social KPIs, quantitative recording is certainly possible (Bielig et al., 2022).

Social impact assessment is a scientific approach which does not include public participation automatically. For a genuine community engagement, it is necessary to have a meaningful interaction with local parties (Esteves, Franks, Vanclay 2012). Especially self-identification with local level energy production is important to get community engagement.

SIA is often underestimated, but it brings a major benefit for local communities. Thus, work should be done on communication about social impact assessment to overcome hurdles from regional stakeholders. Helping the affected citizen to understand, participate in and cope with proposed actions, is to make sure the project and its impact is aligned with a socially just energy transition (Burdge 2003).

The elicitation of social KPIs with additional qualitative data collected with interviews has one major difficulty: This collection is based on self-evaluation, which can be biased due to social norms or social desirability. The goal should be a pilot specific pre-post comparison for the development of social assessment, but this is difficult to measure due to non-replicability of the sample. As we don’t have the exact group of participants in all pilots, it would be helpful to gather qualitative data besides the quantitative assessment. This approach with using mixed method-designs is also recommended by Sovacool et al. (2018). In addition, it must be noted that it is not only difficult to collect data but also to assign the change over time to an epic. Rather, it is an interplay of different interventions that create a social impact. Beside named challenges, there is a difficulty in differentiation of process and outcome (Vanclay, 2002). The impact value chain from Clark et al. (2004) is therefore introduced to understand the differences between input and output. In this approach social impact represents the portion of total outcome achieved due to an organization’s activities, on top of what would have happened anyway. Especially this approach shows the emphasis of the organization’s actual contribution to social change, which is important for RENergetic.

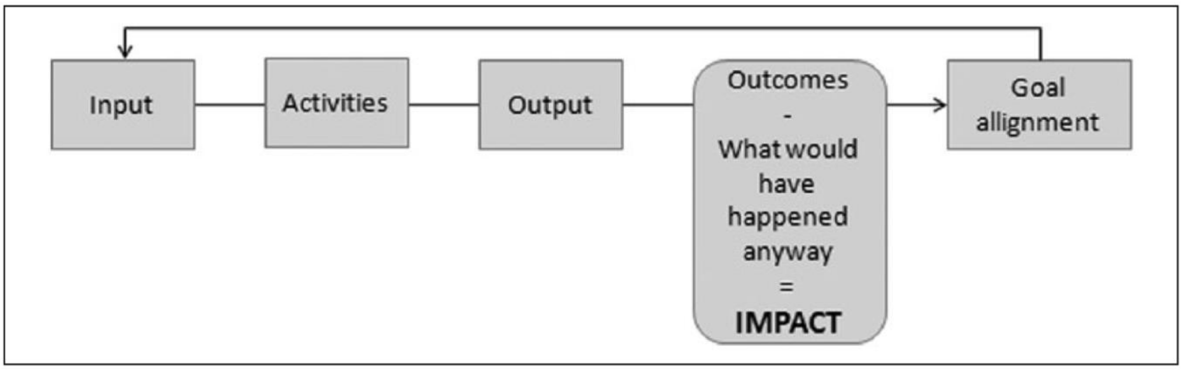

Figure 2: Impact Value Chain (Clark et al. 2004)

So far, social baseline assessment has already taken place in the pilot sites Poznan, Ghent and Segrate. For descriptive analysis, see III.1.1. ,IV.1.2. V.1.2. . From the data collected, social impact was measured. One significant challenge in this process is one of comparing data both between and within Pilot cases. The varying contexts and pre-conditions of each pilot case, such as the presence of an established community in Ghent compared to the absence of such in Segrate or Poznan, make it difficult to draw meaningful comparisons between pilots. However, evaluating overlapping KPIs between the Pilots can provide insights into the social KPIs that play a key role across communities.

When considering individual Pilot cases, the challenge of within-subject comparison is a hindrance in some contexts. In Ghent, granular level comparisons between time points are possible due to the access to a specific community and the use of personal codes in surveys. However, this is not feasible in Poznan and Segrate, where a convenience sample was collected through public events and networks. Nevertheless, in these cases, it will still be possible to compare mean values and distributions of social KPIs.

Two inherent challenges in self-reported surveys are self-selection bias and social desirability bias. To mitigate these challenges, the project aimed to offer multiple and diverse methods of participating in the KPI surveys and utilized a combination of different types of scales and reverse-coded items to reduce the potential for methodological biases.

III. IMPACT ASSESSMENT OF RENERGETIC PILOT ACTIVITIES IN GHENT

The pilot of Ghent is working on the following epics:

Social Campaigning	Heat Supply Optimization	Local Waste Heat Optimization	Heat Demand Response	EV Demand Response	Electricity Supply Optimization	Electricity Demand Response
X			X	X		X

III.1. Baseline Assessment

Intending to reflect the baseline performance (before the implementation of any epics) in the pilot with regards heating and electricity sectors vectors, key performance indicators (KPIs) were identified within D7.2 and partly calculated (heating KPIs for Ghent-New Docks).

III.1.1. Technical baseline assessment

III.1.1.a. New Docks Heat Domain

Heating KPIs can assist in assessing the impact of a heating system in several ways. By tracking energy usage by the heating system, it is feasible to identify the trends and determine the impact of certain technologies or compliance behaviour from a demand-side perspective. As such, the impact can be a certain delta value or a percentage of improvement, or a deterioration of some heat indicators over some time. From an efficiency perspective, the monitoring of the heating system efficiency levels indicates a certain impact on the end users and the technology or behavioural actions on certain indicators. From an environmentally oriented viewpoint, the introduction of more electrified sources of heat together with a balancing heat controller leads to a better ecological impact in an optimistic scenario. This impact is quantifiable by better levels of RES share for the heat sector. Besides, the right control of the heat load and generation side has a positive influence on the CO2 intensity levels through the monitoring of the energy island mix of heat sources. By regularly tracking the defined KPIs, a better understanding of the impact of the heating system on energy usage, comfort, and maintenance costs.

For this baseline assessment, heat data has been collected in the heating network for Ghent-New Docks assisted by the energy island managers. The baseline analysis covers the time period from January 2021 until January 2022 and is based on monthly data values. In detail, the assessment is concerned with the different heating sources available and sinks requiring heat. The heating sources within the energy island are the heat pumps, the recovered heat from the neighbouring factory (Christeyns), and the gas boilers. The heat sinks are the buildings connected to the central district heating system of DuCoop, the office buildings, the water treatment equipment, a sport centre, and a school. This is reported also thoroughly in D4.1. Furthermore, two other figures were required to calculate the approximate emissions quantities for the whole heating system in Ghent-New Docks. These two measures are the CO2 heat coefficient for natural gas (1900 gCO2/m^3) (Innovation Norway, 2021) and CO2 coefficient when consuming from electricity grid (whole portfolio of Belgium) as 143 gCO2/kWh (Our World in Data, 2022).

In Figure 3 , a depiction of the different KPIs calculated above is presented, with their monthly evolution, The left axis is the primary axis dedicated to all the KPIs, except CO2 intensity KPI, while the right-hand axis is the secondary axis and is devoted to the levels of CO2 intensity (in gCO2/kWh thermal). This graph is encompassing all the KPIs to give a holistic overview of the historical performance of New Docks energy island through the evolution of these KPIs in time.

In this current version of KPIs depiction, it should be highlighted that there is an additional KPI on top of the already defined set in D7.2, which is the energy saving KPI (see Appendix VIII.8. This KPI expresses the saved heat energy with regards to the previous period (in this case the period is a month). The utility of this KPI lies in its aptitude to track the difference in energy consumption (delta of heat consumption between two consecutive periods). It is also to be emphasized that this KPI can be generalized to compare two periods of the same year since it does not make a lot of sense to compare two different months of two consecutive seasons which means that the energy saving will yield values that are negative or highly negative because of the average temperature change between the months in the current studied resolution. As such, comparing two similar months of different years can inform about the levels of savings or waste of heat compared to the same period of another year. For example, the impact of the energy reduction campaign can be assessed. Even though this comparison can be more or less fair but there are plenty of other factors that affect the levels of consumption of heat among which are the ambient temperature and insulation performance if a certain insulation upgrading is conducted between the compared periods.

Concerning the added KPI of energy saving percentage represented in Table 18, it is clear that the biggest shift in values occurs when the heat consumption goes back to the upward trend meaning from the month of October 2021 followed by a higher level of consumption consecutively in November and December which explains the energy savings KPI trend indicating that the consumption is more important from that period onwards in comparison to the previous period.

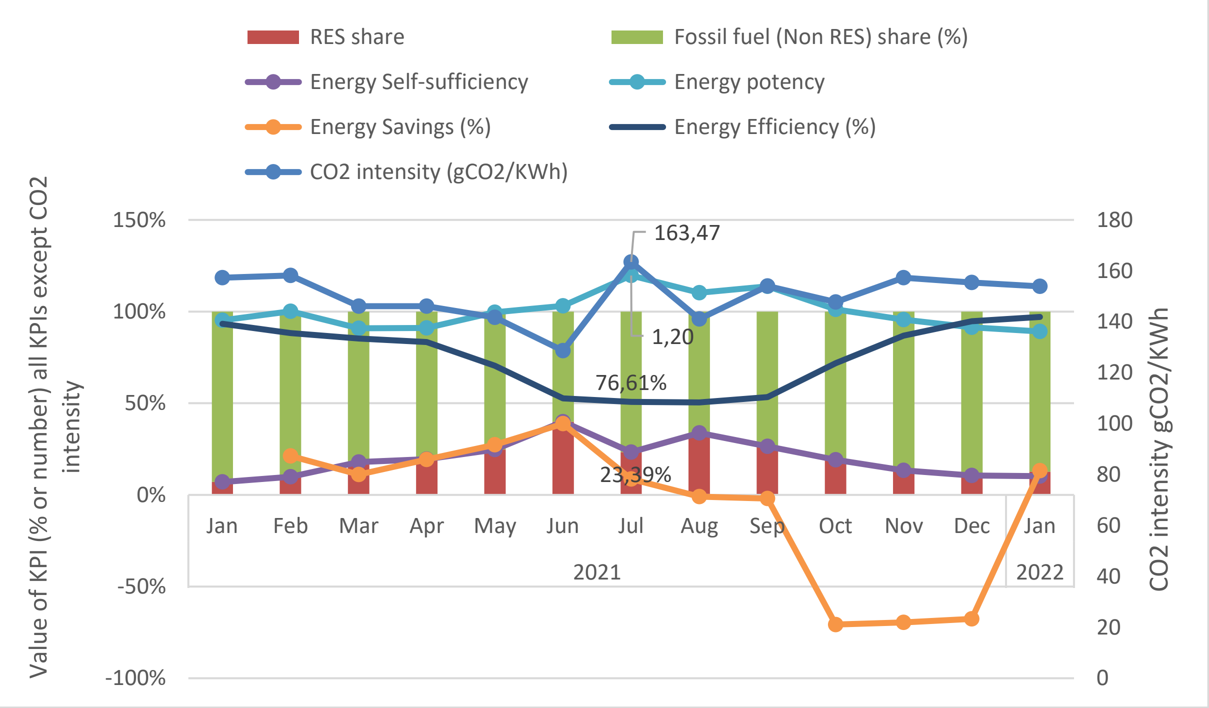

Figure 3: Monthly Technical Heat KPIs Graph (namely Renewable Energy Sources Share, Fossil Fuel (Non-RES) Share, Energy Self-sufficiency indicator, Energy Potency, Energy Savings, Energy Efficiency, and CO2 intensity) Calculated based on Real Data for the Heat Network

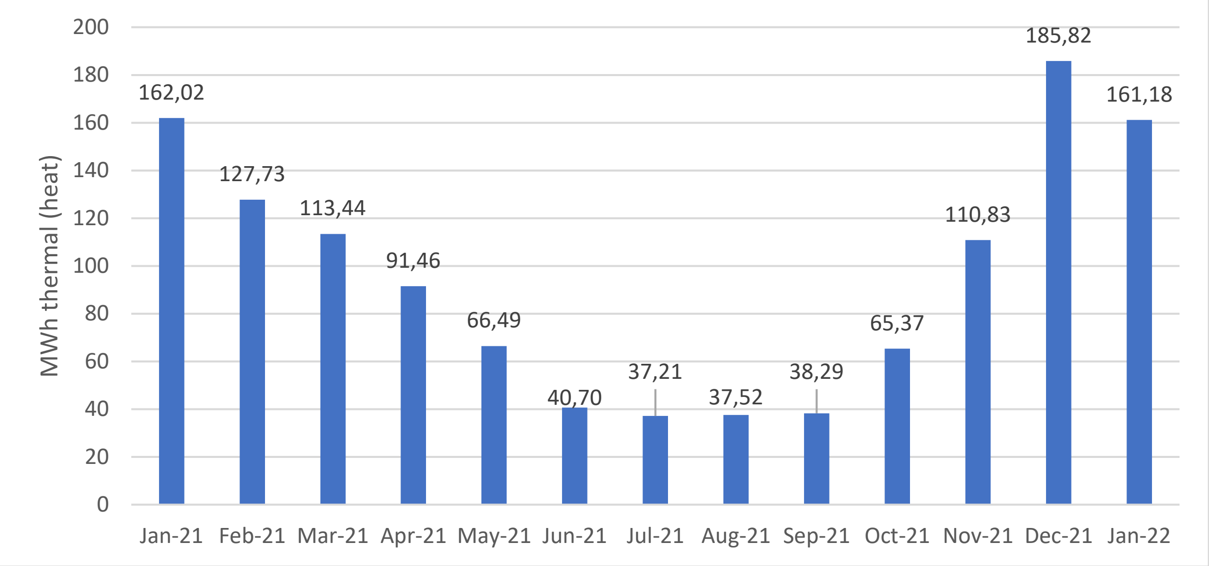

Figure 4: Sum of Heat Consumption and Losses for the Period January 2021 to January 2022

The self-sufficiency[2] levels presented in Table 19 are also impacted by the levels of consumption and Renewable Energy Sources (namely the Photovoltaic installations serving to provide part of the heat of the energy island plus the heat recovery from a neighbouring industrial factory where both of these variables are considered as renewable energy sources for heating the energy island). This KPI can inform the decision makers about the independency situation for the selected time horizon T. Indeed, the self-sufficiency as stated in D7.2 considers also energy sold to an external grid. Thus, aligning demand with availability of excess energy does not change the KPI. Rather, the Energy is shifted from energy excess to cover part of energy missing but the overall sum remains the same.

Concerning the RES KPI value presented in Table 21, it represents the overall percentage of the amount of thermal energy sourcing from RES or re-used heat from external sources. In this regard, the reusability potential is improved. For instance, the rejected thermal energy by the industrial factory in Ghent is exploited for other useful purposes, such as injection into the district heating system, rather than being wasted and unused.

The CO2 intensity indicator presented in in Table 17 depends on the amount of heat consumed by the end-users as well as losses as the overall load received and on the amount of CO2 emissions generated by producing heat based on the heat sources within the energy island (the heat pumps and the gas boilers). The monthly evolution of this KPI showed that it is revolving around the value of 150 gCO2/kWh. It should be highlighted that the heat pump indirectly releases around 143 gCO2/kWh when it consumed from the grid.

Within Figure 5, a depiction of the monthly CO2 emission levels with regards to the different sources of heat is presented and is referring to the Table 23 and the components of the formula. It should be noted that the ranges of values for the different heat generation technologies in terms of CO2 emissions are large. Thus, two axes provide a better view of the CO2 emission amounts for each technology while taking this disparity into account by scaling the axes. The CO2 emissions indirectly released by heat pumps when consuming grid electricity and producing heat from solar energy (45gCO2/kWh) are much lower than the amounts of CO2 emissions released when burning natural gas for heating by gas boilers. The secondary right axis is accounting for the HP emissions in gCO2 and kgCO2 equivalent and the primary left axis is reflecting the total amount of emissions in kgCO2 (the yellow line) together with the emissions coming from the natural gas boilers (blue columns).

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[2] Please not the slight modification of the term “self-sufficiency” as defined in D7.2 to better reflect the objectives of RENergetic. More information can be found in the appendix VIII.7.

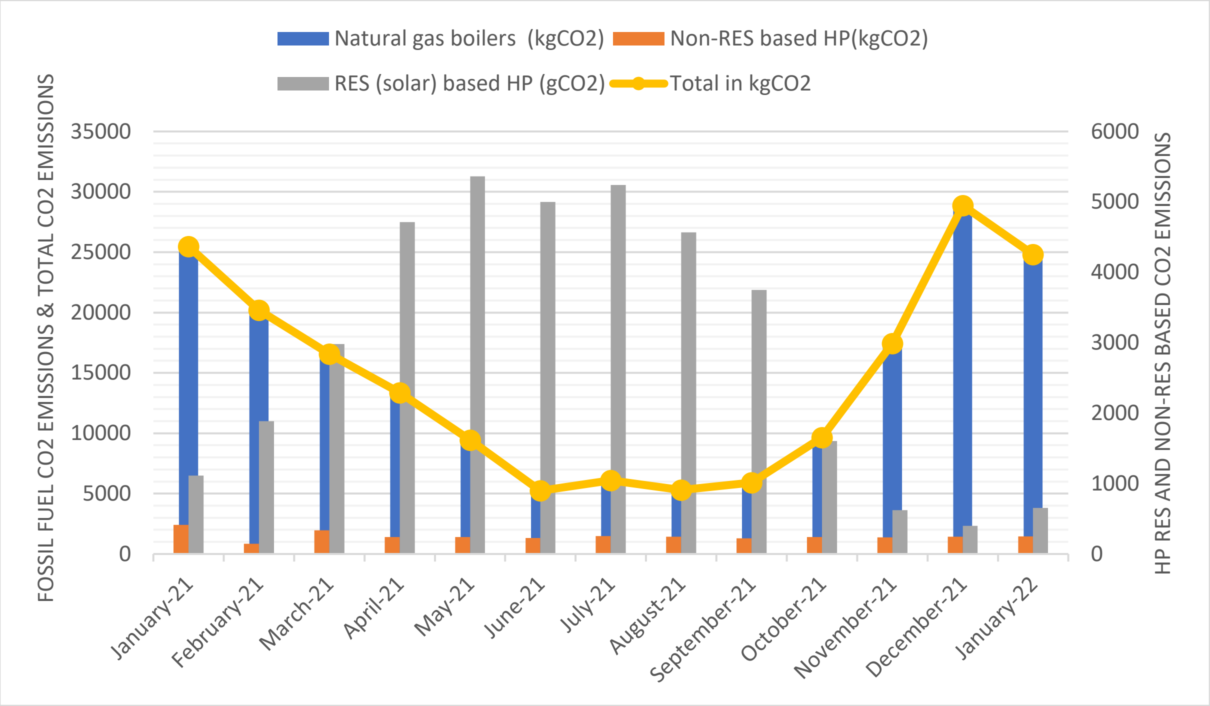
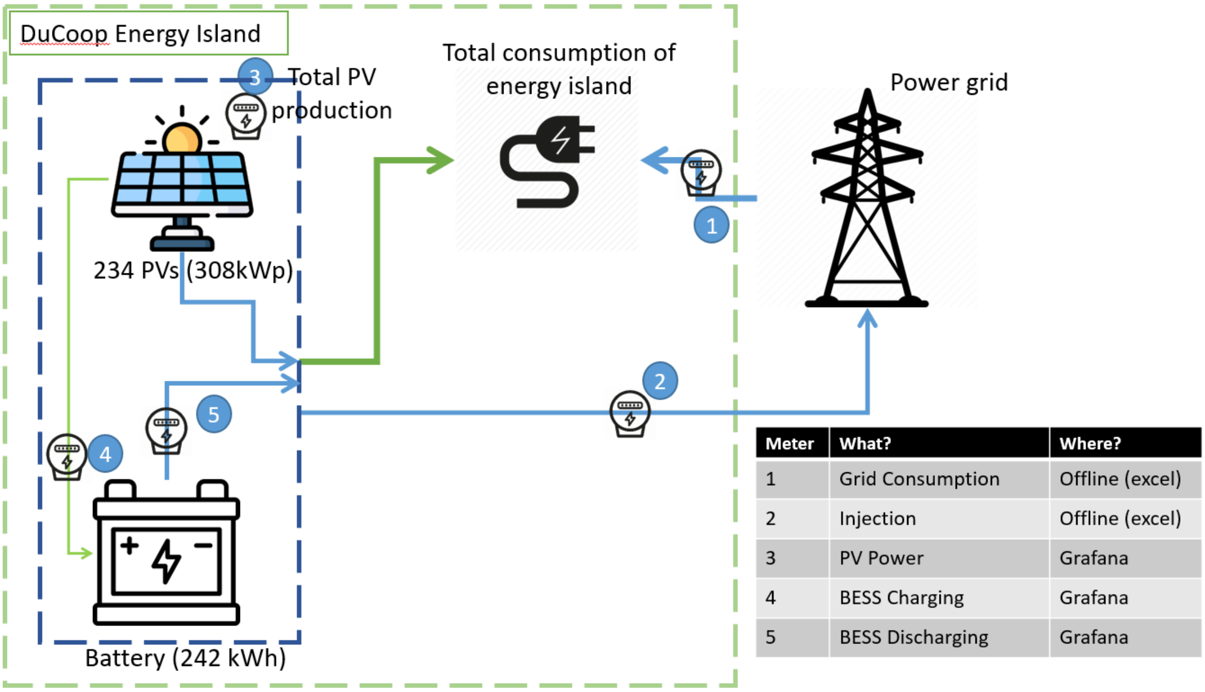


Figure 5: Amounts of CO2 Emissions in gCO2 per heat source (primary axis is for the fossil fuel emissions & secondary axis is for HP RES and non-RES CO2 emissions (note scale difference))

III.1.1.b. New Docks Electricity Domain

In this section, we rely on the different steps in the identified process for technical KPI calculation as described in D7.2. First, the specifics of the electricity network and its design are obtained from the energy managers of the Ghent energy island. Figure 6 shows the most important elements in the New Docks electricity network in a simplified way.



Meter	What?	Where?
1	Grid Consumption	Offline (excel)
2	Injection	Offline (excel)
3	PV Power	Grafana
4	BESS Charging	Grafana
5	BESS Discharging	Grafana

Figure 6: Simplified Electricity Network for Ghent-New Docks Use Case

We have calculated the different KPIs suggested in D7.2 on a, quarterly (15-minute) basis. The required data is collected through Grafana platform in Ghent[3].
In the next subsections, the details of calculation for each of the technical KPIs are shown.

SELF-SUFFICIENCY OR AUTARKY INDICATOR

The self-sufficiency for the electricity energy vector is comparable to the thermal energy self-sufficiency[4]. In the heating energy vector, the values of this KPI were derived from the monthly measures for the different terms constituting the KPI formula. However, in this case, the values of self-sufficiency were calculated quarterly (every 15 minutes) based on the data availability for the electricity network for Ghent-New Docks. By applying the same formula for self-sufficiency, the T values are generalizable and can be transformed from a quarter-hourly to any other target time-resolution (monthly in this case). This granularity is adopted owing to the data availability for the electricity in Ghent-New Docks energy island. The transformation to the monthly fashion of computing the KPIs is the comparability with the heat KPIs.
Table 19 gives an overview of the monthly trend of consumption and imports from the grid in kWh electrical in addition to the injected or excess electricity exported to the grid where from the energy island perspective, the injections can be considered in the sense where it can be a net exporter or importer at some time intervals (15 minutes periods). The losses in electricity systems can be negligeable according (SP Energy Networks, 2022) and (Curt Harting, 2010). As such, for the electricity network baseline assessment, they are considered having zero values. Thoroughly, the losses can be monitored on the BESS level by quantifying the difference between the charging and discharging energy bearing in mind the level of state of charge to make a fair comparison. Based on the electricity data for the BESS in Ghent energy island, if we compare the whole electricity load of 375278,446 kWh versus the battery 851.589 kWh charging and discharging over the studied period taking into account the SoC (beginning of study period 98% to 33,5% around 156 kWh to be subtracted), then we get 695.5 kWh for the whole period of loss which is quite negligible compared to the entire energy island. The

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[3] https://energycollector.openmotics.com/login

[4] Please not the slight modification of the term “self-sufficiency” as defined in D7.2 to better reflect the objectives of RENergetic. More information can be found in the appendix VIII.7.

value is then 0.18% of electricity loss. This value can be converted to a monthly one by assuming the loss is evenly divided between the months of the year then, the monthly loss is around 0.015%.

ELECTRICITY EFFICIENCY INDICATOR

Due to the necessity of extremely sensitive sensors and long-time monitoring, this KPI for the time being is not integrated in the current technical baseline assessment.

ELECTRICITY POTENCY INDICATOR

In this configuration, since losses are not considered but there is electrical energy excess, the value of energy potency is close to $1 - \mathrm{E}_{\mathrm{SS}}^{\mathrm{T}}(\mathrm{Electricity})$. However, when observing closer some registered data rows, this value can be a lot higher than 1 based on the following formula:

$$\mathrm{E}_{\mathrm{Pot}}^{\mathrm{T}} = \frac{\mathrm{E}_{\mathrm{missing}}^{\mathrm{T}} + \mathrm{E}_{\mathrm{excess}}^{\mathrm{T}} + \mathrm{E}_{\mathrm{loss}}^{\mathrm{T}}}{\mathrm{E}_{\mathrm{Consumed}}^{\mathrm{T}} + \mathrm{E}_{\mathrm{loss}}^{\mathrm{T}}}$$

This is the case for the observations of 2021-05-16 14:30 and 2021-05-16 14:45 where the values of energy potency are high because of the injection versus low values of load at these time slots. In other words, the energy island injects more energy into the grid than it withdraws meaning that the energy island is a net exporter due to the existence of PVs and BESS. However, this KPI gets penalized since the objective is to minimize it.

For the calculation of this KPI, the same logic applies where the average values of the 15-minute calculations of the energy potency yield a value different from the holistic monthly value of energy potency KPI.

SHARE OF FOSSIL-FUEL BASED ELECTRICITY (NON-RES SHARE IN ELECTRICITY MIX FOR THE ENERGY ISLAND) AND SHARE OF RES BASED ELECTRICITY

The share of fossil fuel and RES-based electricity is calculated through the data collected on photovoltaics' power generation with comparison to the overall electricity load. It should be highlighted that in the electrical reading of the connection point with the grid, the flow between the energy island and the grid is registered as depicted in Figure 6. This data is available offline in numerous monthly excel spreadsheets on a 15-minute basis. Relying on this data, the actual electricity load within the island is not only the electricity imported (missing) but rather the amount withdrawn from the grid plus the energy generated by the photovoltaics as well as the battery energy storage system (BESS). As a result, the real load of the energy island or its actual consumption is composed of the grid consumption plus the photovoltaics' power generation. As such, it is possible to write the following conclusion:

$$\mathrm{E}_{\mathrm{Consumed}}^{\mathrm{T}} = \mathrm{E}_{\mathrm{grid}}^{\mathrm{T}} + \mathrm{E}_{\mathrm{PVs}}^{\mathrm{T}} = \mathrm{E}_{\mathrm{missing}}^{\mathrm{T}} + \mathrm{E}_{\mathrm{RES}}^{\mathrm{T}}$$

Where:

- $\mathrm{E}_{\mathrm{grid}}^{\mathrm{T}} = \mathrm{E}_{\mathrm{missing}}^{\mathrm{T}}$ represents the energy withdrawn from the external electricity grid or energy missing or energy imported at a certain period T measured in kWh electric.
- $\mathrm{E}_{\mathrm{PVs}}^{\mathrm{T}}$ represents the energy generated by the photovoltaics destined to the consumption of the energy island and it represents the locally generated energy and is also a renewable energy source (RES) at a certain period of time T.

For different $\mathrm{E}_{\mathrm{Consumed}}^{\mathrm{t}}$ values, the $\mathrm{Share}_{\mathrm{RES}}^{\mathrm{T}} = \frac{\mathrm{E}_{\mathrm{Consumed}}^{\mathrm{T}}}{\mathrm{E}_{\mathrm{RES}}^{\mathrm{T}}}$ for the whole period is different from the average of the single periods $\frac{\sum_{t=0}^{t=5} \mathrm{Share}_{\mathrm{RES}}^{\mathrm{t}}}{6}$. Hence, the values of the different KPIs embody the average of the fine-grained periods t within the month T, but not the monthly value of the KPI. It should be noted that the technical KPI values for electricity in the Ghent-New Docks pilot are based on averages of the granular values of the different KPIs per 15 minutes.

CO2 INTENSITY FOR THE ELECTRICITY ENERGY-VECTOR

Similarly to the CO2 intensity value for the heating energy-vector, the assessment of the energy island of Ghent-New Docks is performed through the same formula presented in D7.2 the amount of CO2 emissions calculated based on the assumption that the energy island at some moments withdraws electricity from the grid. In this case, there are indirect CO2 emissions that can be calculated based on the factor used for calculating the CO2 emissions in the heating system when the heat is provided by heat pumps that are consuming electricity from the grid. In this case, the amount of electricity that is procured from the electricity grid is contributing in an emission of CO2 based on the intensity factor of 143 gCO2/kWh el (Our World in Data, 2022) for Belgium. As this depends on the energy mix provision. it is hugely disparate from one country to another. The greener (or nuclear-based) electricity driven countries have low CO2 intensity values per kWh, while other countries with electricity systems that are still driven by coal and fossil fuels (natural gas and oil) have high values of CO2 intensity per kWh. It should be highlighted that there is a time-dependent variation of the CO2 intensity values based on the introduction of more RES (long-term) and on the natural features of the country in terms of availability of these resources along with their intermittency levels(short-term). The value used in these calculations is a constant value taken on an annual basis for 2021 for the Belgian electricity grid. On the other side, for the photovoltaics generation, there is also a number associated with CO2 emissions that is more than 3 times less than the electricity grid CO2 intensity value for Belgium. This value is 45gCO2/kWh[5].

AGGREGATED BASELINE RESULTS OF ELECTRICITY KPIS IN GHENT

Figure 7 shows the different electricity KPIs for Ghent-New Docks energy island. RES share and non-RES share KPIs are complementary and reflect the amount of RES-based, Grid-Based electricity in a monthly trend where the highest fraction of RES is registered for April 2021 owing to a relatively smaller load versus the available RES-based electricity. Similarly for the non-RES, the lowest is for April 2021. Correlatedly, the self-sufficiency and potency are regarded as opposite KPIs and have their best measures also for April 2021 owing to the same reasons (high PV generation with lower load). The CO2 intensity follows the same trend as the energy potency KPI and has its best values for April 2021 as well. This KPIs' behaviour can be explained by the different terms of the individual equations, and they are presented in Table 12. The different monthly values of the KPIs can be directly computed based on the data provided in Table 12. It should be highlighted that the electricity unit in Table 12 is the kWh.

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[5] https://www.nrel.gov/docs/fy13osti/56487.pdf

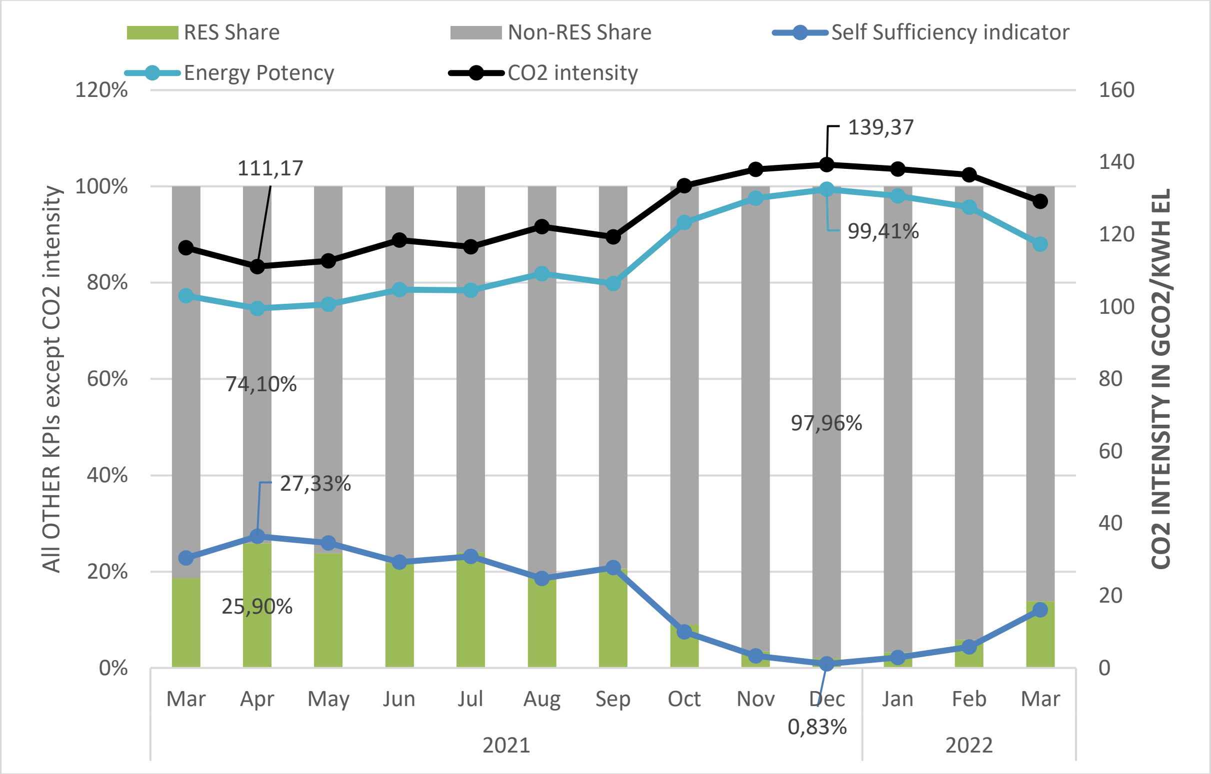

Figure 7: Aggregate Graph of all the Electricity KPIs for Ghent-New Docks

In Table 1, the annual values of the different KPIs are shown and a concise explanation is provided about the reasons for each of the values.

Table 1: Overview of Annual Values of the different KPIs

KPI name	Annual	Interpretation
Self-sufficiency	0.148	• The evolution of self-sufficiency KPI suggests that the levels of dependency on the grid is more important during the fall and winter months (Oct, Nov, Dec, Jan, Feb) where there is a higher probability of having less sun irradiation since the cloudiness is a lot more important than the other months plus the days are shorter compared to the other seasons. Then, this is dependent on the weather conditions in a big part where the PV power is less important season wise. • The energy security in terms of electricity provision for the assessed months is low as seen by the low value of self-sufficiency even when considering the excess power that can be injected into the grid and is counted as extra points. • This KPI expresses an average number for the whole period but according to the analysis, during night-time, the levels of self-sufficiency also decrease which is a consequence of no PV generation during the night.

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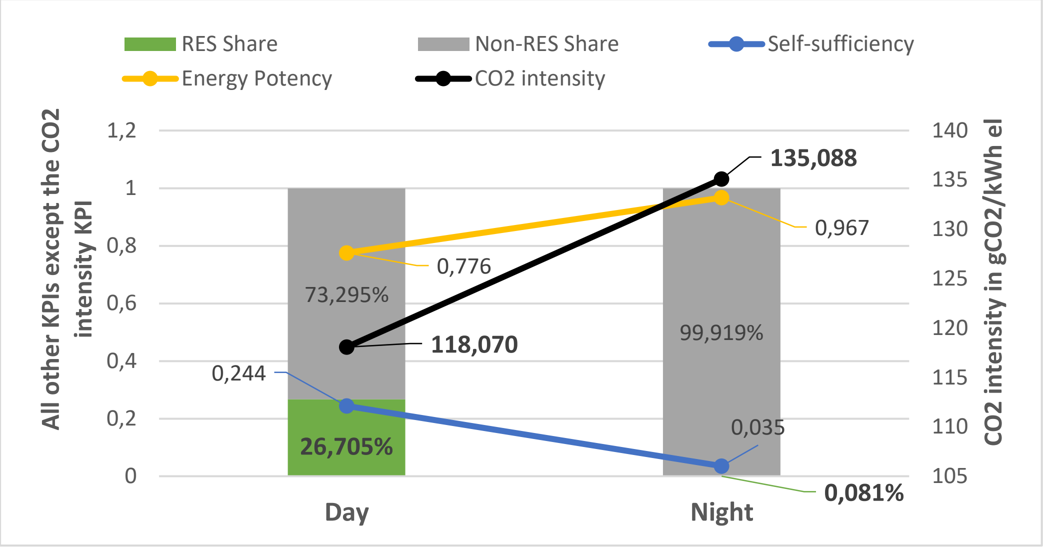

Figure 8: Day Night Influence on KPIs

<table>
<tr><th></th><th>Load</th><th>PV Energy</th><th>Injected Energy</th><th>Grid Import</th><th>Battery Energy</th></tr>
<tr><td>Day</td><td>201781.198</td><td>53884.723</td><td>1974.543</td><td>154519.063</td><td>6622.58</td></tr>
<tr><td>Night</td><td>173497.247</td><td>141.186</td><td>207.940</td><td>167565.063</td><td>-5770.99</td></tr>
<tr><td>Total</td><td>**375278.446**</td><td>**54025.909**</td><td>**2182.483**</td><td>**322084.126**</td><td>**851.58**</td></tr>
</table>
</td>
</tr>
<tr>
<td>Electricity Potency of Energy Island</td>
<td>0.864</td>
<td>

Observing the temporal evolution curve of the energy potency KPI, we notice that it is changing monthly. There is a monthly variation which can be explained by the direct generation of the photovoltaics which provide more power during summer months and can reduce the levels of electricity potency (a value of 0 points is sought) through reducing indirectly the dependence on the grid and adopting the storage system to store the excess energy.
The effect of injection is negligeable since the implementation of a storage system is serving essentially to promote the self-consumption within the energy island over the injection to the grid.
The day-night pattern is similarly explaining the evolution of the KPI value with regards to existence of sun rays or not.

</td>
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<tr>
<td>RES share</td>
<td>14.4%</td>
<td>

Low RES-shares imply directly higher non-RES shares.
It is also influenced by the levels of RES integration in the energy island the magnitude of the electricity load in comparison to the PV installation

</td>
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<tr>
<td>Non-RES Share</td>
<td>85.6%</td>
<td>

Same conclusions can be drawn from the shares of non-RES as the ones for the RES-shares.

</td>
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<tr>
<td>CO2 intensity in gCO2/kWh</td>
<td>125.9</td>
<td>

Based on the formula for CO2 intensity calculation, this value is not that close to the set value by EU for the power plants taxonomy in terms of CO2 emissions (100gCO2/kWh el). (EU Technical Expert Group on Sustainable Finance (TEG), 2020)
In Figure 7, an assumption was adopted concerning the CO2 emissions when generating energy by the PV plants of a value equalling 45 gCO2/kWh and for the electricity consumed from the grid, the value 143 gCO2/kWh is adopted based on (Our World in Data, 2022)
Based on these numbers, the month of December 2021 has the peak value of CO2 intensity with a value (135.088 gCO2/kWh) close to 143 gCO2/kWh (representing the CO2 intensity when consuming from the grid without any backup RES-based electricity). Here, the remaining amount is provided directly by PV power during days or through PV based electricity stored beforehand in the storage system.

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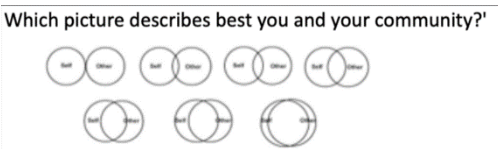
III.1.1. Social baseline assessment

The baseline assessment of the social key performance indicators (KPIs) in Ghent was conducted in conjunction with the implementation of a technical trial for heat demand response, labelled as "smart scheduling." This approach had several benefits. Firstly, it provided the stakeholders with a clear context in which to complete attitude items for the system presented to them, while additionally reinforcing the existing community's salience. Further, it created an organizational framework for participation in the survey, both at the outset of the trial and at its conclusion. This enabled the development of a personalized code for participation, which will allow for a concrete comparison of residents' changes over time on the measured constructs. Given practical constraints and the potential for drop-outs due to lengthy surveys, a shorter version of the KPI survey was administered. Furthermore, some hypothetical items, such as "attitude for participation," are not assessed, but rather translated into real-life behaviours in the New Docks context. Table 2 provides an overview of the constructs included in the KPI baseline assessment in all three pilots. Please note that some items were adapted to the specific context of heat demand response and smart scheduling. To enable comparability, after being designed for Ghent, the same KPI survey was executed in all three pilots, however, with some additional constructs for Poznan and Segrate, as indicated in column three of Table 2.

Table 2: Overview of KPIs assessed in Ghent, Poznan, and Segrate/OSR (note: additional KPIs in Poznan and Segrate)

Construct	Items (Likert)	Pilot
Democratic Participation	In my community everyone can participate in energy transition decisions The majority of the members of my community have the opportunity to participate in decisions on the energy transition.	P, S
Individual Energy awareness	I find it important to be conscious about my energy behaviour. I find it important to save energy.	P, S
Communal Energy Behavior intentions	I want to motivate others in my local community to be more conscious about energy behavior. I want to save energy together with other people in my community.	P, S
Attitude towards participation	I would like to be more involved in decision making regarding the energy transition in my local community. I'm interested in contributing actively to the energy transition in my local community.	P, S
Attitude towards System (self)	I think, smart scheduling of heat through turning off the thermostat at certain time points is a good solution.	G
Attitude towards System (community)	Most people in my community will think, smart scheduling of heat through turning off the thermostat at certain time points is a good solution.	G

Thermal-comfort	Within the last week, I was satisfied with the thermal comfort in my apartment. There are frequent disagreements about heating and thermal comfort in my household. Generally, I am comfortable with the temperature in my living space.	P, S, G
Social identification	I feel a sense of belonging to my local community. I see myself as part of my local community.	P, S, G
Social cohesion	 Which picture describes best you and your community?'	P, S, G
Self-efficacy	I/(We) - as a person/(household) can make a big difference ecologically by being part on the energy transition.	P, S, G
Collective efficacy	We – as a community – can make a big difference ecologically by being part on the energy transition.	P, S, G
Technical efficacy beliefs	Confidence: you can handle new technologies. Confidence: you can successfully adopt new technologies.	P, S, G
Role of politics	I think that public administrations should encourage the creation of communities committed to reducing energy consumption. I think citizens are capable of organizing themselves into energy-conscious communities without any need for public administrations	P, S
Communication of consumption	I - as a member of my community - (would) appreciate knowing about the energy production and consumption of my neighbourhood/community area. I - as a member of my community - am happy with the amount of information I receive about the energy production and consumption of my neighbourhood/community area.	P, S

As previously noted, in Ghent, the survey was conducted at two points in time: prior to the start of the trial and immediately after its conclusion. This approach aimed to provide two benefits. Firstly, it allowed for the inclusion of households that were unable to participate in the trial due to technical constraints. Secondly, it aimed to measure any changes between the first and second sample, at time 2 (T2). However, the small sample size at T2 (N=5) prevented this calculation[6]. As a result, the two samples were combined and duplicates were eliminated, resulting in a final sample of N=29 individuals or households. Figure 9 presents the means of all assessed scales. The results show a positive picture, with participants reporting high levels of thermal comfort, social identification with the New Docks Community, and tech efficacy. Comparing the perceived self-efficacy of individual households and the collective efficacy of the community, the latter showed to be slightly higher. Similarly, for attitude towards the

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[6] Nevertheless, this will enable a comparison at a later point of the project.

system, the difference between the mean attitude of individual households and that of the community was small, but in the opposite direction, with the former slightly higher.

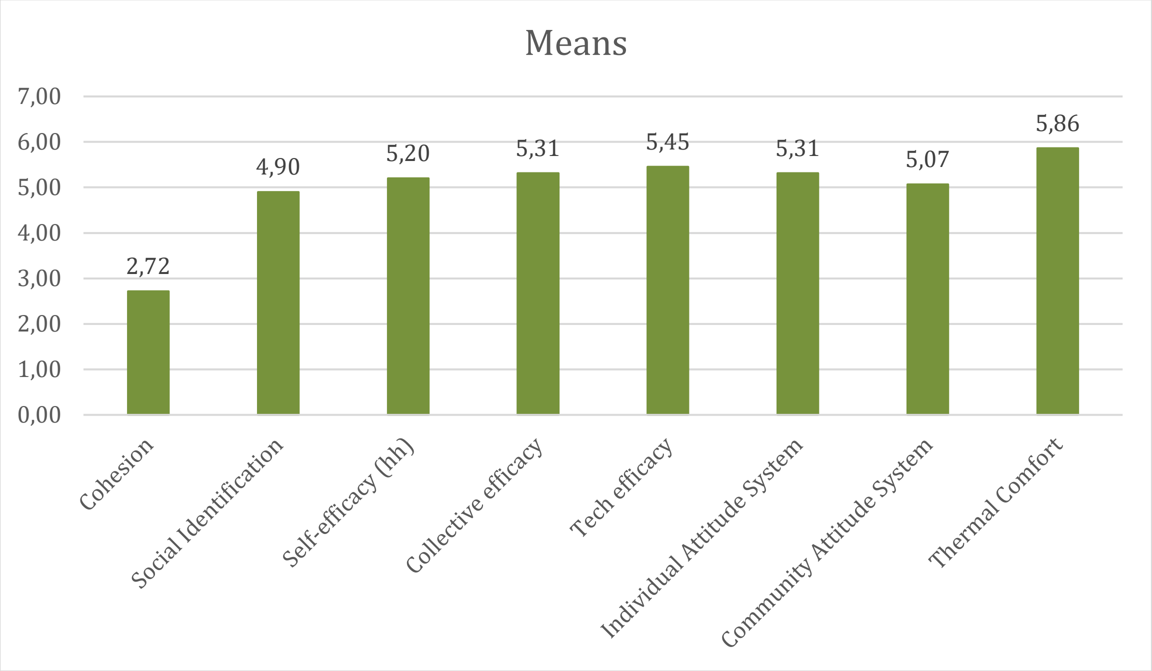

Figure 9: Descriptive Means of all KPIs Assessed, Baseline

** Note: Social cohesion was assessed graphically on a scale from 1 to 5, while all other KPIs were measured on scales from 1-7.

The demographic analysis of the survey participants revealed that a majority of them were men, with the age range being predominantly between 30 and 39 years old. The gender and age distributions are presented in Figure 10. The majority of the participants were residing in households with 2 inhabitants (55%).

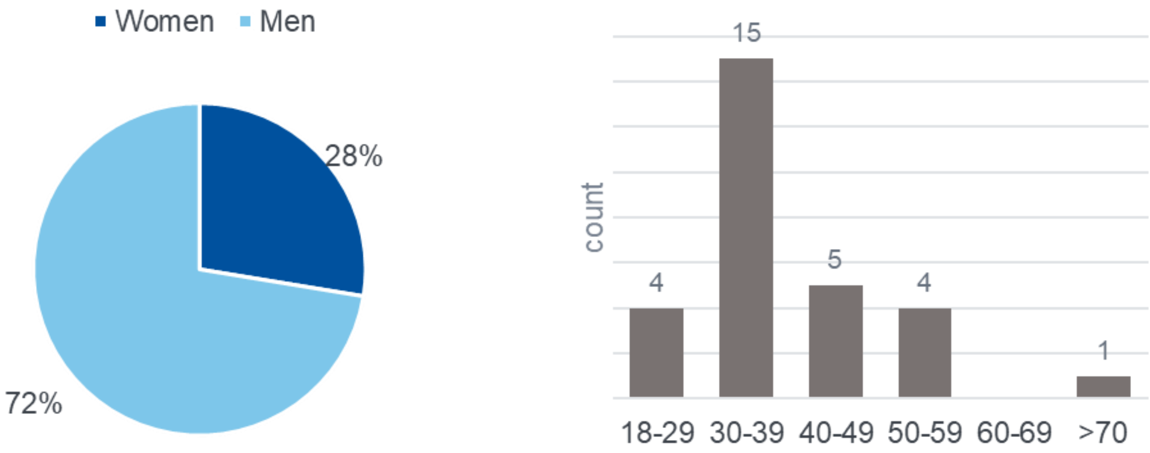

Figure 10: Gender and Age Distribution in Ghent

In order to analyze the distribution of responses for selected scales, particularly those assessed at the baseline across all three Pilot Sites, histograms for distribution of answers were generated. The graphs for social identification, self-efficacy beliefs, and collective efficacy beliefs are presented below. The results indicated that social identification had a close-to-normal distribution, with a slightly positive inclination. Additionally, the distribution of self-efficacy beliefs (related to the own household) and collective efficacy beliefs were observed to be very similar within the New Docks Community.

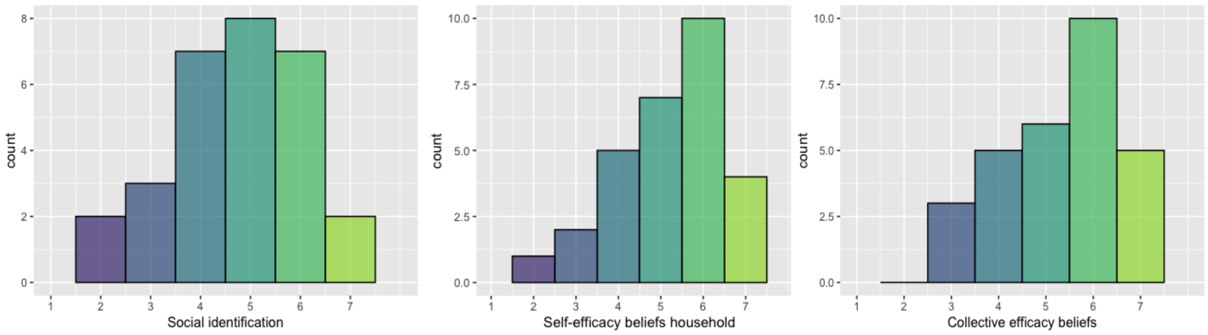

Figure 11: Social Constructs in Ghent: Social Identification, Self- and Collective Efficacy Beliefs

III.2. Social Campaigning in Ghent

III.2.1. Activities & Results

From the beginning, the New Dock project development in Ghent has been engaging the EI inhabitants, mostly owners and tenants of the apartments, but also owners and tenants of a few shops and service companies. So, setting up focus groups, amending the interactive platform or performing surveys as has been initiated by the RENergetic WP2 team, was well received. As described with more detail in D8.1, V.1, the main methods applied in Ghent to increase collaboration and acceptance from the EI inhabitants included interviews (at the beginning of the project), surveys and questionnaires, which were accompanying different epics and the setting-up and continuing discussion through focus group meetings. These actions thus frequently enabled a picture of the social side development in the Ghent community. Additionally, Ghent is aiming to integrate an interactive platform, which is currently under development and implementation.

III.2.2. Expected Impact

The proposed social activities in New Docks are aimed at promoting positive social impact and increased acceptance of newly developed technical solutions within the project. By leveraging participatory formats such as focus groups, we anticipate enhancing efficacy beliefs on both the household and community levels. The interventions in Ghent are designed as a collective approach with an emphasis on community involvement to bolster social identification and cohesion. Through a transparent analysis of potential barriers and motivators for new technical systems, we hope to inform the design and implementation of project Epics and foster a positive attitude towards the developed solutions. Additionally, we aim to mitigate any potential negative effects on comfort, as measured by thermal comfort when implementing the new technical systems through careful consideration of impact.

III.3. Heat Supply Optimization in Ghent

III.3.1. Activities

As a preliminary solution, until the RENergetic solution is completed, the implementation of the epic heat supply optimization in the flavour of the Ghent pilot is done using a simple rule-based engine to optimize the usage of the district heating pump (125 kWh) and planning the optimal integration a cascade of sustainable heat sources (biogas boiler, heat pumps, CHP, etc). The heat source optimization logic has also been integrated in the multi-vector optimizer as described in section III.7. The existing model controls the activation and modulation of the heat pump based on pricing, COP, heat demand and availability of wastewater effluent.

III.3.2. Expected Impact

The expected technical impact is an increase in Share of RES and Self Sufficiency and a decrease in CO2-intensity and share of fossil fuel.

III.4. Heat Demand Response in Ghent

III.4.1. Activities & Results

Ghent was the first pilot to engage in automated HeatDR by carrying out an experiment about the technology acceptance of inhabitants, agreeing to have their floor-heating pre-heated in the very early morning hours, when there is excess waste heat from Christeyns available. At the same time, to reduce the morning peak between 8:00-10:00h, the floor-heating supply was reduced by centrally manipulating the thermostats. The acceptance rate measured in terms of “opt-in acknowledgements of inhabitants” was at 77%, with more than the majority of people opting in due to the personal relationship with the manager. More information of the implementation variant of HeatDR in Ghent can be found in D8.1, V.

III.4.2. Expected Impact

The result of a great share of inhabitants accepting the heat DR motivated manipulation of their room thermostats should have had a technical impact in terms of a) increase of heat demand in the pre-heating period and b) reduction. It was planned to monitor the shifted amount of kWh as well as the overall effect by utilizing as much waste heat as possible. It had been planned to monitor this in terms of room temperature, kWh used for heating, and hot water usage during the trial. Unfortunately, it turned out that the equipment did not work as foreseen. Therefore, a modified version of the trial with a slightly different technical solution is repeated in winter 2022/2023.

However, it could be shown that the main rule-based manipulating of thermostat succeeded to shift the demand peak to later in the morning (see Figure 12).

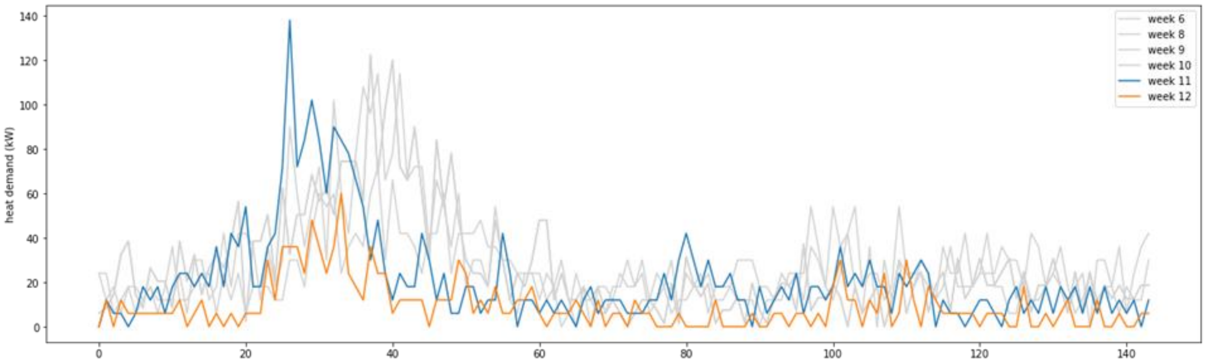

Figure 12: Shift of the Morning Heat Demand Peak in the Building 'Faar' on Wednesday, Before and After the Implementation of a Heat DR Experiment (Week 11/12 vs Week 6-9 2022; DuCoop EAN)

III.5. Electricity Demand Response in Ghent

III.5.1. Activities

The Ghent flavour of the epic Electricity Demand Response will revolve around capacity tariffs. Residents will face higher electricity costs if they exceed an agreed upon maximum electricity capacity. Therefore, for the residents it is key to know when an overconsumption is imminent and what they can do to avoid it. The planned implementation will predict electricity demand and notify the users with the Ducoop app, if a crossing of the agreed upon capacity is expected. Additionally, through the demand prediction users will be able to see to which time frame they should shift their load. Apart from this, the cooperation DuCoop has also a specific capacity tariff for collective loads (DuCoop grid access point).

III.5.2. Expected Impact

Due to the resulting lowered peaks in the form of consumption shifting (as e.g., in Figure 13) as a ***technical impact*** utilization of on-side PV-panels will be higher and therefore there will be a reduced consumption from the grid. The expected impact will then naturally be an improvement in **self-sufficiency**, **CO2-intensity** and **share of RES**.

In line with this technical impact, as an ***economic impact*** an expensive peak can be avoided, therefore a reduction in **levelized cost of energy (LCOE)** will be achieved.

Figure 13: Example of Peak Shaving above 100kW Threshold on the Collective Load Curve (DuCoop EAN)

III.6. Electric Vehicle Demand Response in Ghent

III.6.1. Activities

The experimentation for the epic electric vehicle (EV) demand response for the Ghent pilot is planned to take place in the New Docks parking garage with around 40 reoccurring users. It is going to be implemented as a manual demand response approach. Different to the Segrate's flavour of the epic (V.4) there is a PV installation on-site. Therefore, the goal is to shift loads to timeframes in which PV energy generation is especially high.

In Figure 14 the session flexibility time of the vehicles in Ghent is presented, with departure times linked to arrival times. Blue points are ideal for participating in DR, since they are connected to the charging stations for a long time. Additionally, one can see that the arrival times of most vehicles take place during the evening. So unfortunately, for those vehicles a shift towards hours with high PV generation is not possible. DR would only be able to be carried out by the vehicles which arrive early and leave their car connected to a charging station throughout the day, depicted in the picture as blue points with an early arrival time.

There are two currently two options of communications with users. One is to display a red light on entering the garage signifying if charging at this very moment has a high level of RENs (solar) or not. Another idea is to create a Whatsapp group giving the same information. The corresponding experiment will be carried out in the summer of 2023.

From the technical point of view, another key component for an efficient demand response approach is to predict electricity supply generated by the PV panels. This will be done by AI prediction models, which will also see utilization by the electricity supply optimization epic in Poznan (IV.4).

Alternatively, in Ghent, automated DR is planned to be either simulated or – depending on the access to the charging stations, experimented with in the field. In this case the charging profile (load and time will be managed in function of electricity price, sustainability (degree of renewable energy) and the desires of the clients (using in-app interactions).

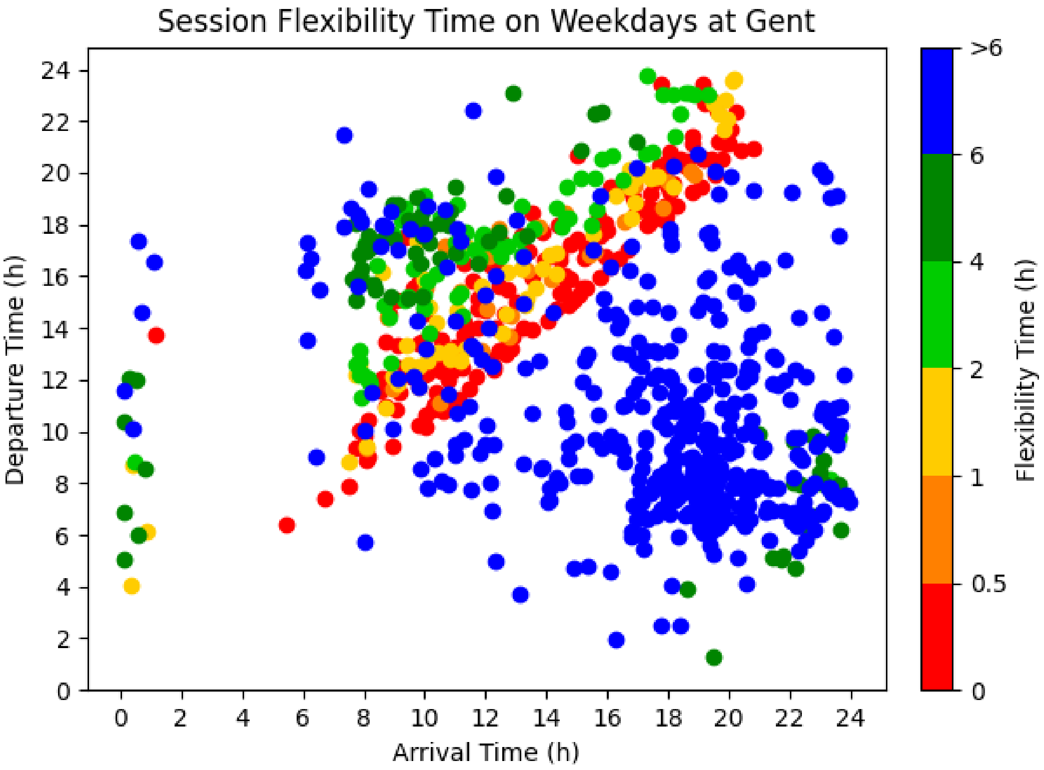

Figure 14: Session Flexibility Times on Weekdays at Ghent, Relating Arrival with Departure Times

III.6.2. Expected Impact

The KPIs affected would be mainly a ***technical impact*** in the form of an increase in **self-sufficiency**, since the loads will be shifted to a higher self-production of energy through PV panels. Also, the **share of RES** will be increased with a similar reasoning, that there will be less need to buy electricity from the grid. By the same assumption **CO2-intensity** will be also decreased.

The ***economic impact*** will be in the form of reduced electricity costs by using the own generated energy instead of the one provided by the grid. Therefore, an improvement is expected in the **levelized cost of energy (LCOE)** and **load purchasing from the grid** KPIs.

III.7. Applying the Multi-vector Optimizer in Ghent

III.7.1. Preliminary Modelling

The multi-vector optimizer optimizes the energy flow between devices and their respective energy domains, in order to increase the share of cheap renewable energy sources, increase self-sufficiency by for example optimizing energy storage control and provide an economic benefit, by exploiting low energy prices during high injection hours. It ignores domain specific constraints and provides a very generalised view of the optimization problem, which means that its results do not need to be met perfectly, but rather provide a guideline for domain specific optimizers, which then, considering their local constraints, try to reach a solution which is as close as possible to the multi-vector optimizers output. This means that the multi-vector optimizer functions as a connection point between multiple domain specific optimizers and, due to its high degree of abstraction, allows for a vast variety of domain specific optimization schemes.

The multi-vector optimizer separates Ghent into multiple domains. As of right now, three major domains were established:

- Electricity
- Heating
- Mobility

These domains a) have different entities in their respective domain (e.g., PV panels, which are modelled as fixed generation) and b) are connected via specific devices such as heat pumps (connecting electricity with the heating domain) or EV charging stations (connecting electricity with the mobility domain). Figure 15 shows a preliminary outline of the local system with example data in order to visualize the used attributes of the respective device modelling. As of right now, the modelling of the multi-vector Ghent case is still in development and additional modelling, such as idle losses of the battery, still need to be evaluated and implemented. Further confirmation from the pilot side is still in progress.

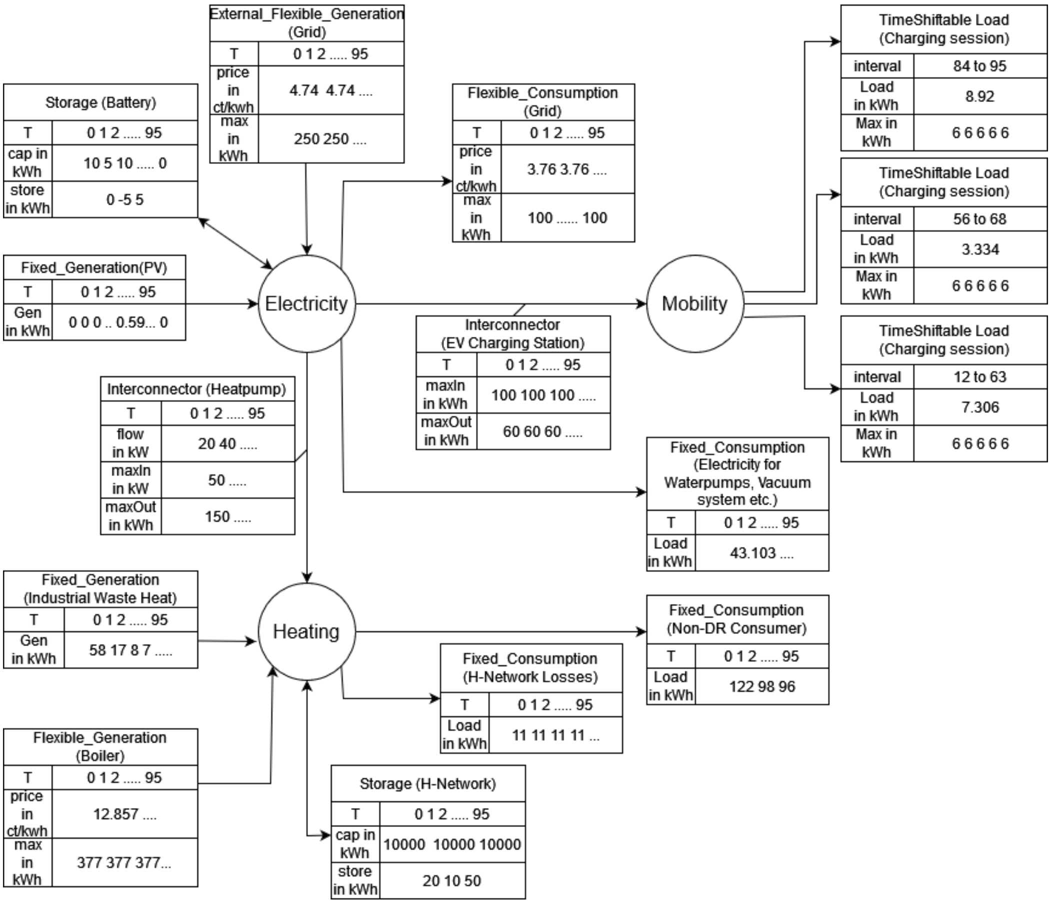

Figure 15: Preliminary Structure of the Multi-Vector Optimizer

III.7.2. Preliminary Results and Impact

In the following, a brief comparison of the Ghent system with and without the optimizer will be shown and evaluated. For this the KPIs “Energy sold to the grid” and “Load purchasing from the grid” are chosen, since they provide a good overview of the differences in consumption and injection behaviour, see Figure 16b). However, since Ghent uses flexible prices on a 15-minute basis, it is worth to look at the overall consumption first, before looking at the cost during the predefined timeframe of the 1st of March 2021 and the 1st of March 2022 (see Figure 16a)). Furthermore, the KPI “Load purchasing from the grid” will be split up into two cases, namely the “from E-grid” and the “from H-grid” cases. This depicts the effects on the KPIs in the respective domain and allows us to get a better overview of the systemwide influence.

Generally speaking, the electricity consumption increases, which can be explained based on two factors. First, the utilization of the heat pump increases dramatically, since the flexible electricity prices are often cheaper than the gas prices and therefore incentivize the heat pump to convert more electricity to heat. Second, these prices allow the battery to store energy and inject it later in order to increase profits. Even though this consumption increases by a bit, there is no increase in costs visible, due to the shifting of electricity consumption from hours with high prices to hours with comparably low prices, which can be explained by the time-shiftable appliance (such as the EV charging station) and the battery. Another interesting observation is that the consumption of gas is reduced drastically. The reason for this is the comparatively high gas prices, which for a high percentage of the timeframe favours electricity over gas imports. Last to note is the increase of injection into the grid, which predominantly is due to the battery being allowed to store energy when prices are low and inject when injection prices are comparatively high.

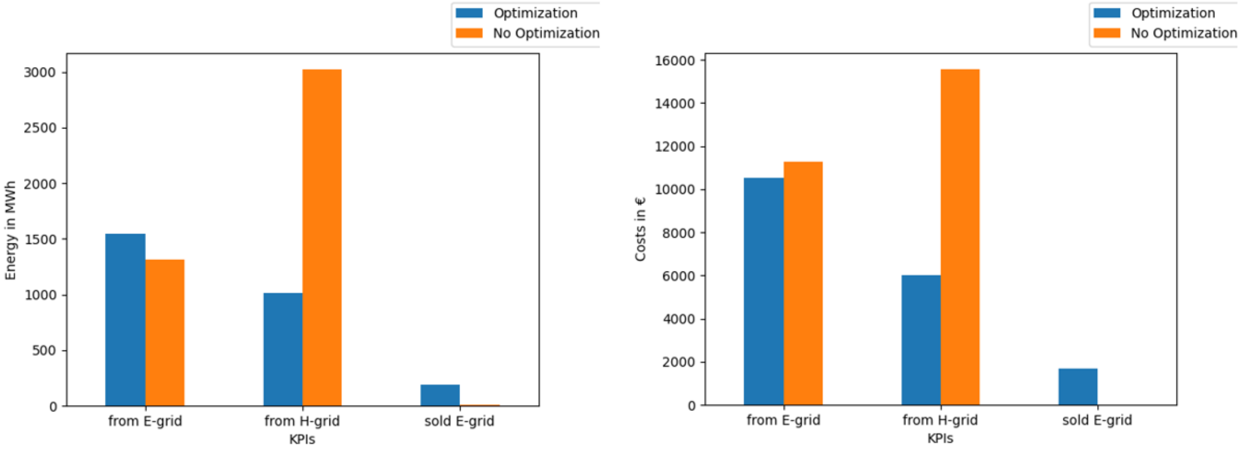

Figure 16: Comparison of Electricity (a) and Cost (b) with and without Optimizer

However, even though the direction of the multi-vector optimizer looks promising, one still has to consider that this model is still a work in progress and for now seems rather optimistic. It is still necessary to revaluate the model depicted in Figure 15 and continuous communication with the pilot site of Ghent is necessary. Furthermore, note that this evaluation is based on the data collected during the 1st of March of 2021 and the 1st of March of 2022 had missing data, which needed to be estimated. Even though for the most part it only effects one to three hours, sometimes the missing data spans even multiple days, which makes both the optimized and the unoptimized case less accurate. It is also worth noting that other issues, such as the idle losses of the battery or EV charging sessions, which are too small to be shifted, are not included in the optimization case and still need to be implemented.

III.8. Extending the Infrastructure via Investment in Photovoltaic and Battery in Ghent

III.8.1. Scenario Description

Throughout this section, two complementary phases are outlined intending to address the inquiry about the viability and positive business case existence for the investment in RES technologies (PVs in particular) together with the smart charging discharging driven battery energy storage system (BESS). The assessment concerns the actual economic settings within the New Docks energy island while comparing it to the case of basing the electricity load on the grid financially. The current design comprehends the multi-sourced electricity consumption (either from the PVs or from BESS). The goal of this analysis is to benchmark certain economic KPIs and then compare them to the actual electricity grid pricing profile, either historically or in the future. Afterward, the financial appraisal is generalized to upscale the number of PVs and conclude the viability of the endeavour.

The analysis focuses on the incurred costs and the potential income streams for the energy island by quantifying the already incurred costs by investing in PVs and BESS. Costs are measured over the long run based on some electricity-specific metrics (LCOE and LCOS). This permits the computation of the expected costs over the long run. Moreover, this analysis allows for an extension of the case study by simulating the economic PV array upscaling impact in the next stage. This can be quantified based on the calculated KPIs and the grid tariff profile.

The first phase concerns the calculation of the Levelized Cost of Electricity (LCOE) and the Levelized cost of storage (LCOS) KPIs. Thus, the usefulness of these indicators is summarized in their comparability to the unit price when the energy island is withdrawing electricity from the grid, especially, in the case of peak and valley electricity prices in a variable pricing fashion. In the second phase, two scenarios are identified concerning business as usual (BAU) and where no technologies exist and full dependence upon the grid is assumed. For coherence reasons, the naming of the scenarios will be as follows:

1. Scenario 1 represents the grid-tied and non-existence of any technology. This scenario does not represent the business as usual (BAU) since the BAU consists of multi-source electricity consumption.
2. Scenario 2 represents the BAU composed of joint electricity provision sources (on-grid, PVs, and BESS), together with the smart charging-discharging techniques for the BESS.

III.8.2. Expected Economic Impact

Throughout this section, the economic impact of the electricity technologies is addressed through specific techno-economic KPIs followed by simulation results. Given that LCOE and LCOS values are calculated in an initial phase, the comparability of both scenarios defined becomes fair and relevant by considering the base year (15/03/2021 – 15/03/2022), and the current data collected on that specific year while keeping in mind that certain assumptions are adopted to render the comparison equitable.

LCOE AND LCOS CALCULATION

In this section, the two concepts of LCOE and LCOS are discussed. These two terms are interchangeable with the term "life cycle cost" in the literature, as discussed in (Jülich, 2016).

The terms LCOS and LCOE both represent discounted costs of electricity per unit, but they have different meanings. LCOS is specific to battery energy storage systems (BESS) and factors in the cost of storage, the energy source, and charging decisions. LCOE represents the levelized cost of electricity produced by photovoltaic (PV) technology. Both LCOS and LCOE are levelized over the lifetime of the technology, allowing for direct comparison between different projects or parameters.

LCOS Formula and Calculation

Several models exist to calculate the LCOS. The following equation was adopted for the calculation of LCOS inspired by (Mayr, 2016) and is including the charging costs over the lifetime of the BESS.

$$\mathrm{LCOS_{Ch}} = \frac{\mathrm{Capex + O\&M - V_{residual}}}{\sum_{n=1}^{N} \mathrm{E_{out}^{n}} * \frac{(1-\mathrm{DEG}*n)}{(1+r)^{n}}} + \frac{\mathrm{Charging}}{\sum_{n=1}^{N} \mathrm{E_{out}^{n}} * \frac{(1-\mathrm{DEG}*n)}{(1+r)^{n}}} = \mathrm{LCOS_{NoCharging}} + \mathrm{Charging_{Cost}}$$

Where:

$$\mathrm{Capex} = \sum_{i\in\{0,10,20\}} \frac{\mathrm{Capex_{ref}} * (1-d)^{i}}{(1+r)^{i}} \qquad \mathrm{O\&M} = \sum_{n=0}^{N} \frac{\mathrm{O\&M_{ref}}}{(1+r)^{n}} \qquad \mathrm{V_{residual}} = \sum_{i\in\{0,10,20\}} \frac{\mathrm{res\%} * \mathrm{Capex_{i}}}{(1+r)^{i+10}}$$

$$\mathrm{Charging} = \sum_{n=0}^{N} \frac{E_{\mathrm{charging}}^{n} * \frac{P_{\mathrm{elec-in}}^{n}(1+t)}{\eta(\mathrm{DoD})}}{(1+r)^{n}} \qquad P_{\mathrm{elec-in}}^{n} = \frac{\sum_i C_{\mathrm{el}}^{i} * \mathrm{Power}_i}{\sum_i \mathrm{Power}_i}$$

- Capex: upfront costs in the BESS (acquisition, installation, DC/AC inverters, safety engineering, shipping, other specific tasks for BESS acquisition and installation).
- $\mathrm{Capex}_{\mathrm{ref}}$ the given initial investment figure for the current installation of BESS.$\mathrm{Capex}_{\mathrm{i}}$: the capex of BESS in year i
- $\mathrm{O\&M}$: operation and maintenance expenditures.
- $\mathrm{O\&M}_{\mathrm{ref}}$ the given O&M figure for the current installation of BESS per year
- r : discount rate (e.g., the Weighted Average Cost of Capital (WACC), or Minimum Accepted rate of Return (MARR)).
- E_{out}^{n} is the energy discharged by the battery system in year n
- DEG represents the degradation rate of the BESS.
- $\eta(\mathrm{DoD})$ represents the round-trip efficiency at DoD (assumed to be constant)
- $P_{\mathrm{elec-in}}$ the charging electricity tariff
- V_{residual} represents the residual value or the salvage value of the BESS.
- d represents the average cost drop in BESS modules.
- t represents the percentage of VAT and other charges.
- $\mathrm{res\%}$: percentage of capex investment in the BESS.
- $E_{\mathrm{charging}}^{n}$ is the energy charged by the BESS in year n.

In the next overview Table 3, the input data for calculating the LCOS is shown.

Table 3: Input Data for LCOS Calculation

Item	Value	Source
$\mathbf{Capex_{ref}}$	€102,602.00	DuCoop
$\mathbf{N}$ $(\mathbf{SP})$	30 years	DuCoop
$\mathbf{d}$	17.46%[7]	(BloombergNEF (BNEF), 2021),
$\mathbf{r}$	7.5%	(Frank Meinke-Hubeny et al., 2017)
$\mathbf{O\&M_{ref}}$	€800/year	DuCoop
$\mathbf{E_{charging}^{n}}$	18684.86	Grafana (collected via OpenMotics 2022)
$\mathbf{DEG}$	2%	(Lazard, 2022),
$\mathbf{P_{elec-in}}$	7.86 c€	Grafana (collected via OpenMotics 2022) and DuCoop Pricing (Contract) (15/03/2021-15/03/2022)
$\boldsymbol{\eta}(\mathbf{DoD})$	92.7%	Battery Datasheet
$\mathbf{E_{out}^{n}}$	36272.43	Grafana (collected via OpenMotics 2022)
$\mathbf{res\%}$	5%	(Stephan and Stephan, 2016),
$\mathbf{t}$	38%	Flanders (VAT and other charges)

In Table 4, the calculated intermediate and final numbers are represented.

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[7] This value is obtained through (BloombergNEF (BNEF), 2021) considering the cell price (in 2013, 469$ and in 2021, 101$) through the formula $average\ drop\ per\ year = 1 - \sqrt[\#\ of\ years]{\frac{469-101}{469}} = 17.46\%$

Table 4: LCOS Value and Other Details

Item	Value
Present Worth of O&M $(€_{2021})$	€12,841.577
Discounted Investment Cost $(€_{2021})$	€137,234.679
Discounted Amount of Energy Discharged (kWh)	533736.90
Real Charging Cost = $\frac{P_{elec-in}}{\eta(DoD)}$ **(ct€/KWh)**	12.96
LCOS (Capital) $(€_{2021})$	€0.2107
LCOS (O&M) $(€_{2021})$	€0.0241
LCOS (Residual) $(€_{2021})$	-€0.0064
$\boldsymbol{Charging_{Cost}}$ $(€_{2021})$	€0.0786
$\mathbf{LCOS_{NoCharging}}(€_{2021})$	€0.2285
$\mathbf{LCOS_{Ch}}(€_{2021})$	€0.3070

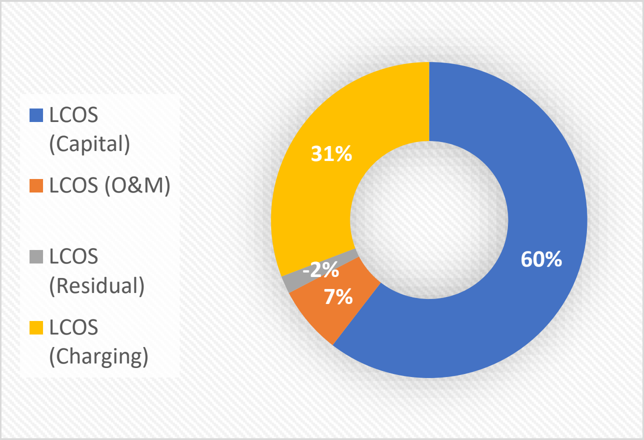

Figure 17: LCOS Breakdown

The comparison can be conducted on the electricity grid prices level and is further explained in the Appendix VIII.3.

LCOE CALCULATION

According to (CFI Team, 2022), the levelized cost of energy (LCOE) is a metric used to examine and compare various energy production systems. The LCOE of an energy-generating asset is the average total cost of building and operating the equipment per unit of total electricity generated over an expected lifespan. Otherwise, the LCOE can be regarded as the average (levelized) minimum price at which the electricity generated by the power plant is required to be sold (really or fictively) in order to offset the total costs of production over its lifetime. Calculating the LCOE is related to the concept of assessing a project's net present value. Similar to using NPV, the LCOE can be used to resolve whether a project will be a profitable venture.

The LCOE formula can be written as follows and is based on (CFI Team, 2022).

$$\mathrm{LCOE_{generated}} = \frac{\mathrm{Capex} + \mathrm{C_{Inverters}} + \mathrm{O\&M} + \mathrm{Repl_{inverters}}}{\sum_{n=1}^{N} \mathrm{E_n} * \frac{(1 - \mathrm{DEG} * n)}{(1 + r)^n}}$$

Such that:

- Capex overall capital expenditure in all the PVs during the study period (SP)
- $\mathrm{C_{Inverters}}$ cost of inverters during the study period
- $\mathrm{O\&M}$ overall operational expenditure in all the PVs during the study period (SP)
- $\mathrm{Repl_{inverters}}$ the cost of replacing the inverters during the study period (SP)
- $\mathrm{E_n}$ the amount of energy generated in year n of the study period (SP)
- DEG the annual degradation factor of the PVs generation.
- r the real discount rate.
- $\mathrm{Capex_{ref}}$ given initial investment figure for the current installation for the 234 PVs.

Table 5: LCOE Overview Calculation

Item	Value	Item
Discount rate r	7.5%	(Frank Meinke-Hubeny et al., 2017)
$\mathbf{E_{2021}}$ **(KWh)**	54025.91	Grafana (collected via OpenMotics 2022)
CAPEX (for 234 PVs)	€79,779.21	DuCoop
Batches	5	DuCoop
O&M (for 234 PVs)/year	€800	
Capex per PV panel	€340.9	Calculated

# PVs /inverter	46	Calculated
# Inverters	5	DuCoop
O&M /PV/year	€3.41	Calculated
Inverter's Cost	€2,393.38	15% of Capex (for all the inverters)
Inverter's replacement	€2,393.38	15% of Capex (for all the inverters)
$V_{residual}$ (Salvage value of PVs)	€ 0	Assumed based on (Lindahl, 2017)
Degradation rate (DEG)	0.5%	Assumed based on (Jordan and Kurtz, 2015)

Table 6: LCOS Value and Other Details

Item	**Value**
Present Worth Investment Structure ($€_{2021}$)	366,381.40
Present Worth O&M Structure ($€_{2021}$)	70,181.88
Present Worth Inverters' Structure ($€_{2021}$)	68,210.29
Discounted Investment Cost ($€_{2021}$)	540,124.55
Discounted Amount of Energy Generated (KWh)	4497520.32
Present Worth Inverters' Replacement Structure ($€_{2021}$)	35,350.98
LCOE (ct€/KWh)	12.01

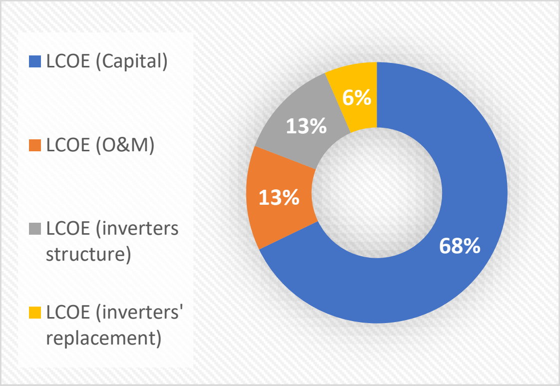

Figure 18: LCOE Breakdown

COMPARISON OF LCOE AND LCOS TO GRID PRICES VARIATION

Intending to address a certain comparison between the daily average energy price with the values of LCOS and LCOE, it is practical to place the fluctuating electricity price curve together with the LCOS and LCOE linear values (since they are both levelized meaning they keep their value constant over the whole year and the study period duration).

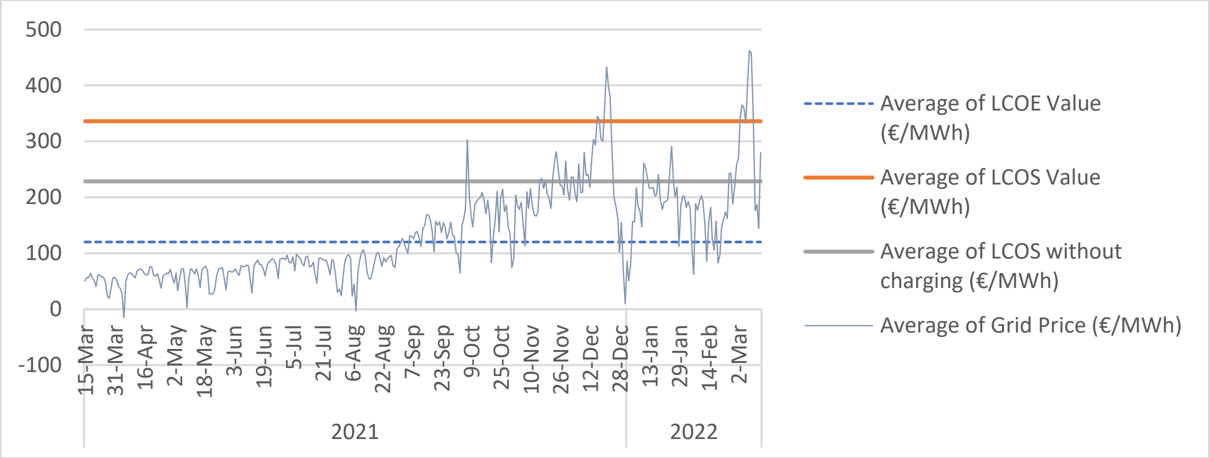

Figure 19: Average Grid Price, LCOE, and LCOS without Charging and with Charging Values

As the BESS is intended to perform peak saving, i.e., to buy cheap energy from the grid when a certain threshold is reached. This amount of electricity is consumed later when grid costs are higher. Similarly, the BESS can play a role in storing solar energy that is generated for free by PV panels without being forced to inject it into the grid at a lower price since the injection pricing profile follows the production trend (prices are higher during the night on average because there is no solar energy production during that period, even though the grid can also be fed by wind power plants). Once the injection has been completed and no solar power is available to meet the need, the energy island will have to withdraw from the grid again at likely higher prices. In this context, the LCOS must be put in perspective with the daily fluctuations in grid costs and/or the difference between the average grid cost (or even lower grid costs because grid costs tend to decrease when solar energy is abundant) and the injection rate. Based on Figure 21, the grid electricity rate, at least for the study base year (03/15/2021 to 03/15/2022), during the day on average is cheaper than during the night due to the availability of solar energy.

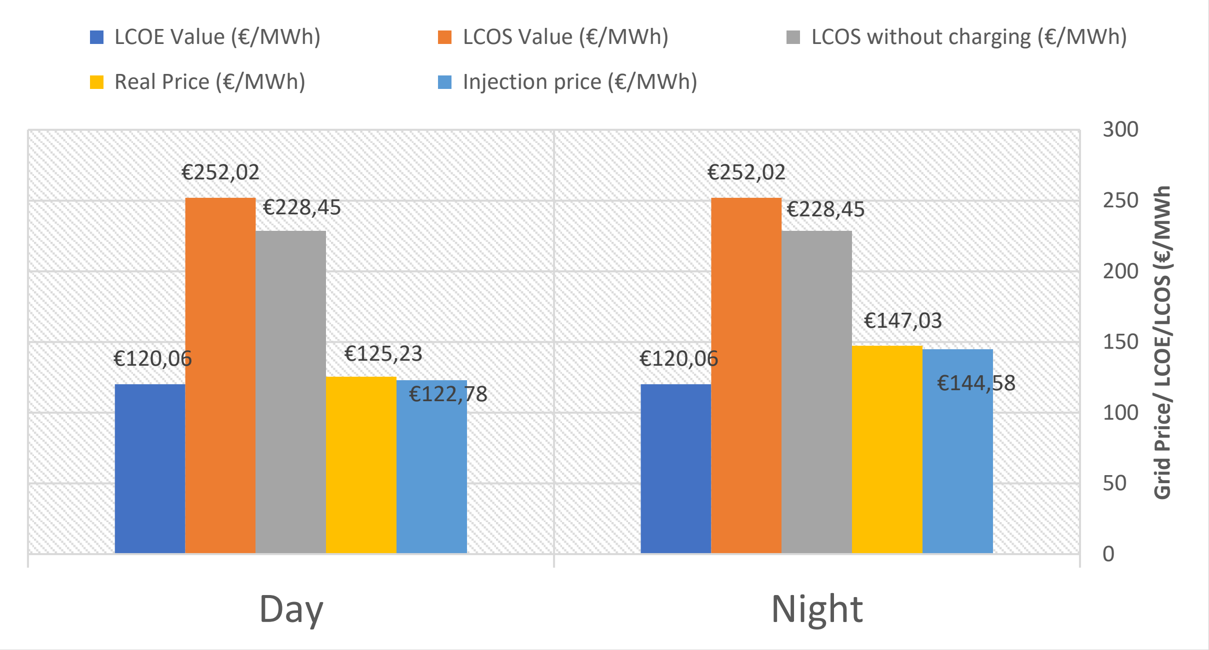

Figure 20: Comparison of the Day versus Night Prices with LCOE and LCOS (with and without Charging)

For the LCOE value, it turns out to be around 12 ct€/kWh. Given the considered average injection tariff of 13.34 cents though should be highlighted during the daytime, this average is less for the injection (12.27 cents/kWh), thus the sale of any excess energy to the grid does barely compensate for the costs associated with local PV-based electricity consumption since only 0.27 ct€/kWh of earnings is received. On the other hand, using the average grid cost of about 13.58 cents, the LCOE is considered reasonable when looking at avoiding consuming from the grid and can produce a saving to the energy island (about 1.58 cents/kWh of savings). Storing solar energy for later use when prices are even higher than the calculated average (during the night for example) is a viable approach to avoid consuming for super high prices. In this context, BESS can act as a buffer when prices are between the LCOS without charging KPI and the LCOE that will save the energy island (high energy values at night - low prices in the morning = 14.45-12.27= 2.18 ct€/kWh consumed). However, putting the difference between day and night electricity grid tariff with the LCOS without charging, the latter (22.84 ct€/kWh) is way larger than the calculated difference of 2.18 ct€. This observation indicates that investing in a BESS uniquely to compensate for the grid price difference between day and night is not a viable one. Looking at the potential of the BESS as an electricity provision unit instead of the grid has a saving capability as well. An opportunistic discharging method can make use of the LCOS without charging as a comparison metric to the grid prices and discharge in those times.

Electricity Cost Function Behaviour in Function of Number of PVs

In this section, the electricity cost function is defined while sizing the PV array based on the base year selected for the simulation. It should be mentioned that there are two cases for this evaluation. The first case concerns the effect of the PV dimensioning on the electricity cost without BESS consideration and the second case regards the simulation of the impact of increasing the PV array while considering the current battery size as well as the applied algorithm based on the charge and discharge rules for the reference year. The electricity cost function is defined according to the two studied cases in the following sections.

1- No BESS is considered:

$$Electricity_{Cost}(n) = Cost\ of\ Imported\ Energy + Cost\ of\ Consumption\ of\ Local\ Electric + Cost\ of Export\ of\ Electricity$$

$$Electricity^{T}_{Cost}(n) = \sum_{t=1}^{t=35040} \max\left(0, (E^{t}_{load} - E^{t}_{PV}(n)\right) * (Pr^{t}_{grid} + \alpha) + \min\left(E^{t}_{load}, E^{t}_{PV}(n)\right) * LCOE + \max(0, E^{t}_{PV}(n) - E^{t}_{load}) * (LCOE - Pr^{t}_{grid} + \alpha)$$

- E^{t}_{load} electricity load at t
- E^{t}_{PV}(n) electricity generation by n PVs at t
- $(E^{t}_{load} - E^{t}_{PV}(n))$ the delta value between the electricity load and the electricity production at t
- Pr^{t}_{grid}represents the price of consuming electricity from the grid where in this case is a dynamic pricing changing on an hourly basis.
- α represents the commission cost which is defined as a constant.
- $LCOE$ is the levelized cost of electricity generated and is calculated above in section 0

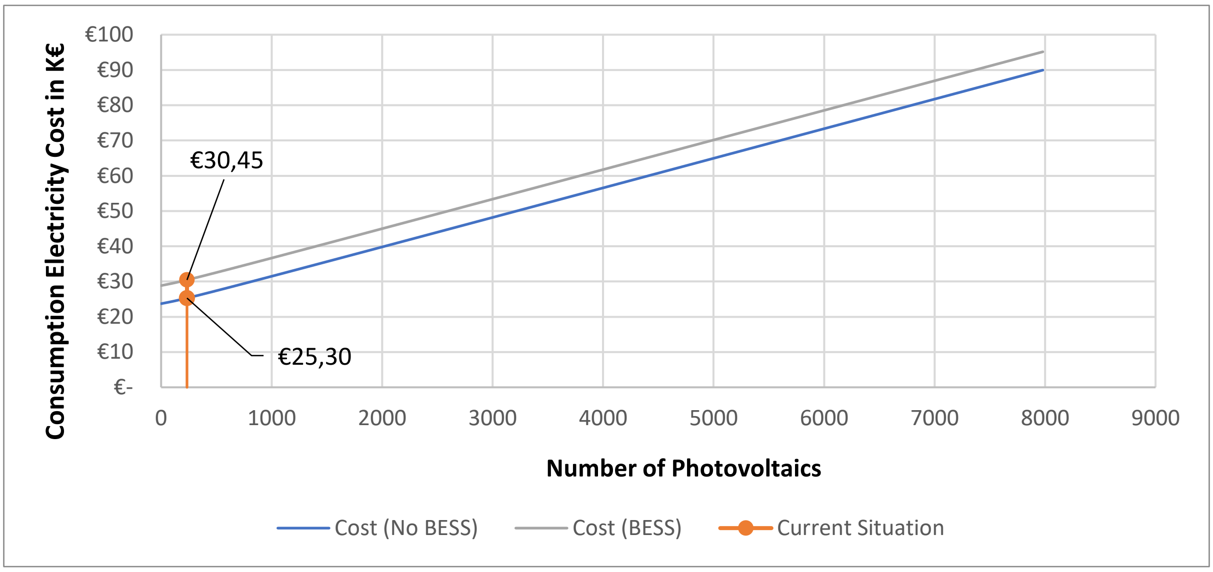

Figure 21: Impact of Increasing the Number of PVs on the Electricity Cost Function (with and without Battery) (Pricing Profile from 15/03/2021 until 15/03/2022)

Figure 22 illustrates the evolution of electricity cost when scaling up the PV array in a simulation to observe the impact based on the electricity price from the base year 15-03-2021 to 15-03-2022. It is found that the electricity cost function curve is linearly correlated with the number of PVs, as it is assumed that the electricity produced by the PVs is correlated with the number of PVs and that they produce the same amount of energy when used. This assumption implies that the increasing number of PVs will be reflected in the electricity production per 15-minute increment. This trend can be explained by the fact that the injection benefit does not compensate for the investment in more PVs since by increasing the PV array, a large electricity generation is expected and since there is no consideration for BESS, then the excess electricity will be re-injected to the grid.

2- A BESS with the current charging - discharging control is considered

$$Electricity_{Cost}^{T} = \sum_{t=1}^{t=35040} E_{Disch}^{t} * \mathrm{LCOS}_{\mathrm{NoCharg}} + E_{PV}^{t}(n) * \mathrm{LCOE} - \max\left(0, \left(E_{PV}^{t}(n) - E_{load'}^{t}\right) * (Pr_{grid}^{t} - \alpha) + \max\left(0, \left(E_{load'}^{t} - E_{PV}^{t}(n)\right) * (Pr_{grid}^{t} + \alpha)\right.\right.$$

- E_{Disch}^{t} is the discharged amount of electricity by the BESS at a certain timeframe of 15 minutes.
- $\mathrm{LCOS}_{\mathrm{NoCharg}}$ is the levelized cost of storage calculated above in section 0
- $E_{PV}^{t}(n)$ is the upscaled electricity generation when considering the number n of PVs.
- $E_{load'}^{t}$=$E_{load}^{t} + E_{Charg}^{t} - E_{Disch}^{t}$ where:
    - E_{load}^{t}represents the electricity load by the energy island.
    - $E_{Charg}^{t}$is the amount of electricity charged by the BESS from the grid
    - E_{Disch}^{t} is the amount of electricity discharged by the BESS to the energy island

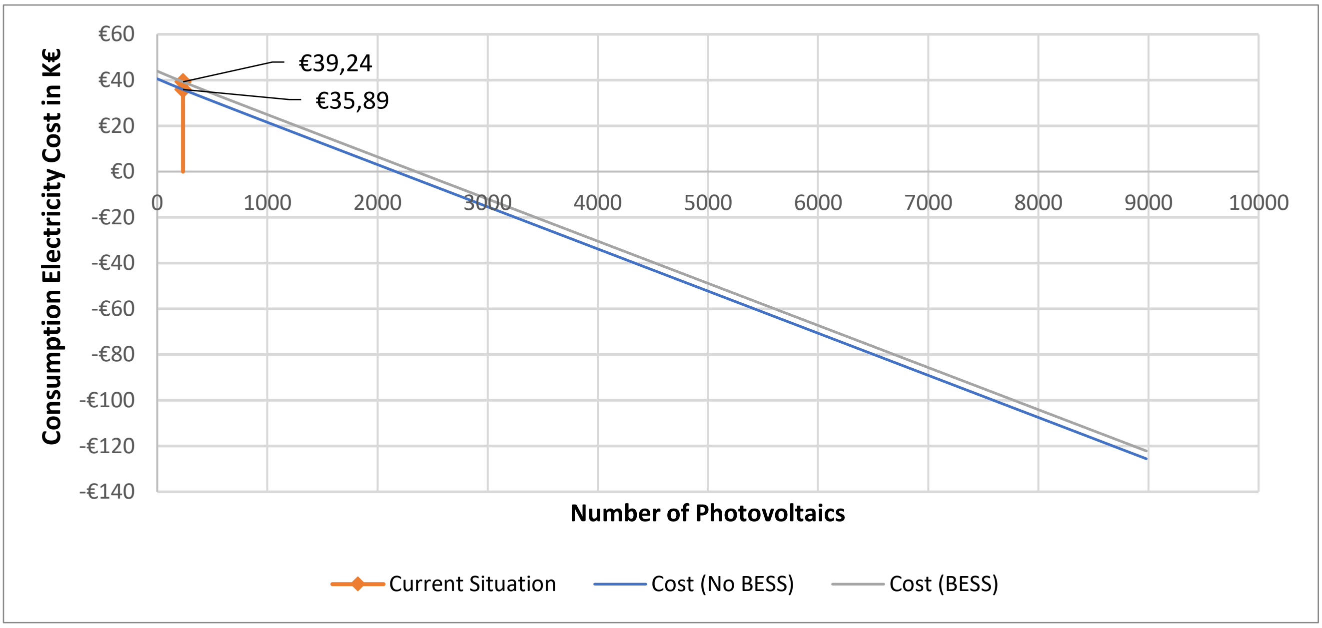

Figure 22: Impact of Increasing the Number of PVs on the Cost Function (with and without Battery)

Regarding Figure 22, the impact of the dimensioning of the PV array with and without BESS together with the smart charging discharging techniques are shown while adopting the case of the grid tariff profile of the period running from 15/01/2022 to 15/01/2023 while keeping the load pattern as for the period (15/03/2021-15/03/2022). The curve reveals a downward trendline which is explained by the fact that the cost of electricity will decrease when the upscaling process is adopted, and more PVs are installed. This is due to the significant increase in the average grid price throughout this period owing to some geopolitical reasons for the European area. In terms of numbers, the average price between these two considered periods has undergone a substantial increase from 135.88 €/MWh to around 241.49 €/MWh (around +78% increase in price).

RES Share Behaviour in function of PVs and BESS

The adopted formulae to compute the levels of RES Share within the energy island for Ghent-New Docks can be written as follows:

$$Share_{RES}^{T}(\text{No BESS}) = \frac{E_{PV}^{T}(n)}{E_{load}^{T}} = \frac{\sum_{t=1}^{t=35040} E_{PV}^{t}(n)}{\sum_{t=1}^{t=35040} E_{load}^{t}}$$

$$Share_{RES}^{T}(\text{BESS}) = \frac{E_{PV}^{T}(n) - E_{Charg}^{T}}{E_{load}^{T}} = \frac{\sum_{t=1}^{t=35040}(E_{PV}^{t}(n) - E_{Charg}^{t})}{\sum_{t=1}^{t=35040} E_{load}^{t}}$$

Where:

- T represents the study period between 15/03/2021 and 15/03/2022.
- E_{Charg}^{T} is the energy charged by the BESS during period T

For the RES assessment, the fraction of renewable energy resources is calculated by varying the number of photovoltaic panels and is shown in Figure 23 for the cases where a BESS is adopted with the charging discharging techniques and without BESS. Based on the curve presented, the increase in the number of PV panels to infinity implies a 100% RES share within the energy island since all the load is expected to be met by the significant amount of electricity provided by the PVs.

Regarding the impact of the BESS within the energy island, the levels of the RES share have the same pattern as well since less grid consumption will be recorded with the increase of the number of PV and the excess PV electricity that will be used to improve the RES fraction when more PV units are installed and thus, for a large number of PVs, the entire battery charge will be based on PV. The charging figure is responsible for the RES share values as indicated for the case of BESS where the not only the electricity load requires to be met but also the charging load of the BESS to meet the electricity load at a later stage.

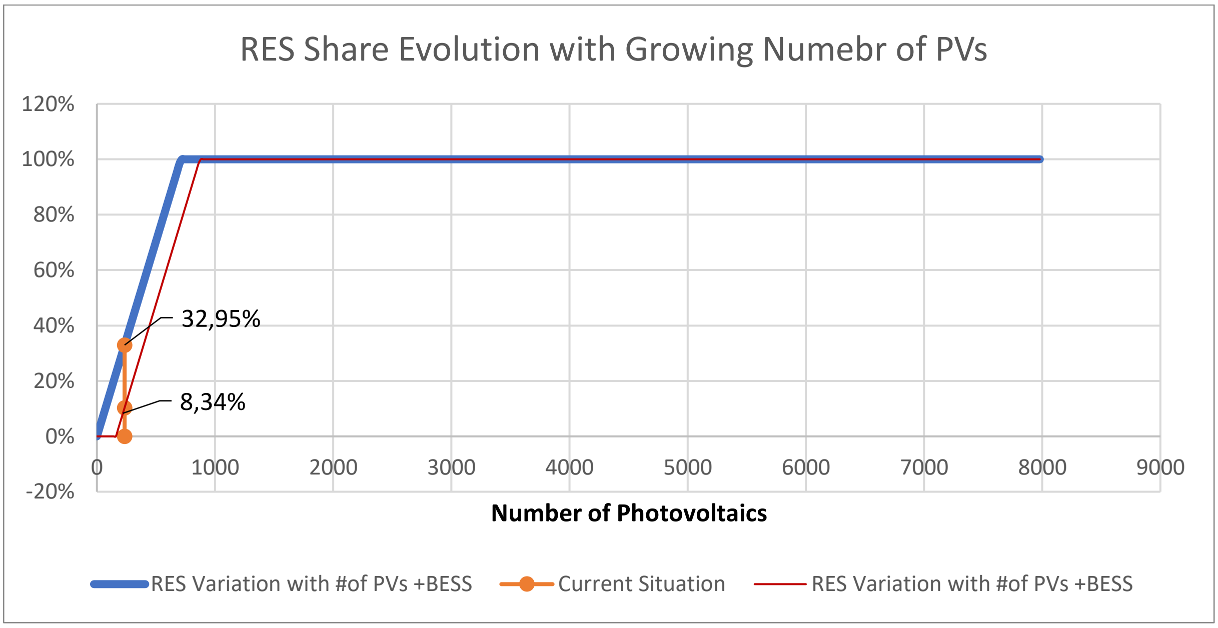

Figure 23: RES Share when increasing the Number of PVs for Ghent-New Docks Energy Island

IV. IMPACT ASSESSMENT OF RENERGETIC PILOT ACTIVITIES IN POZNAN

The Pilot of Poznan is working on the following Epics:

Social Campaigning	Heat Supply Optimization	Local Waste Heat Optimization	Heat Demand Response	EV Demand Response	Electricity Supply Optimization	Electricity Demand Response
X		X	X		X	

IV.1. Baseline Assessment

IV.1.1. Technical Baseline Assessment

IV.1.1.a. Poznan Heat Domain

For the Polish Pilot site and more exactly Poznan Warta Campus Energy Island, an assessment of a single building named CDWTCh is conducted. The different KPIs for the heating energy vector are calculated based on the definitions from the previous deliverable D7.2. The data required to proceed with the calculations was provided manually through the collection of the monthly terms needed for each of the technical heat KPIs by the energy managers. This included assisting in inputting the heating data for a single building within the energy island. Therefore, the assessment can be regarded as temporally on a monthly basis and geographically focussed on evaluating one building which is used as laboratory, office and lecture halls.

In Figure 24, a depiction of the different KPIs is revealed with a monthly evolution trend where the left axis is the primary axis dedicated to all the KPIs except CO2 intensity KPI while the right-hand axis is the secondary axis and is devoted to the levels of CO2 intensity (in gCO2/kWh thermal) due to scaling issues where the ranges of the KPIs are not comparable when looking at the CO2 intensity.

SELF-SUFFICIENCY INDICATOR

The self-sufficiency indicator[8] is defined as a technical performance indicator insofar as the energy island of the Poznan-Warta Campus is secured in terms of heating independence from the external network (Veolia as a heating supplier). In this context, the focus is on the monthly autarky levels of the availability of thermal energy quantities meeting the heating load by the assessed building. The monthly assessment is a high-level calculation of the overall thermal energy self-sufficiency levels which may differ considerably if the assessment is more refined or based on real-time values, as the exact balance between demand load and heat supply may cause some inefficiencies in the system by increasing losses or excess heat that is either dissipated to the atmosphere. The heat is most likely lost or stored in the ground if the system allows. Heat storage technology is available in the Poznan-Warta campus energy island by transferring heat into bore pits in the ground through the action of ground source heat pumps that act accordingly to minimize losses and make the most of the optimal storage techniques available.

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[8] Please not the slight modification of the term “self-sufficiency” as defined in D7.2 to better reflect the objectives of RENergetic. More information can be found in the appendix VIII.7.

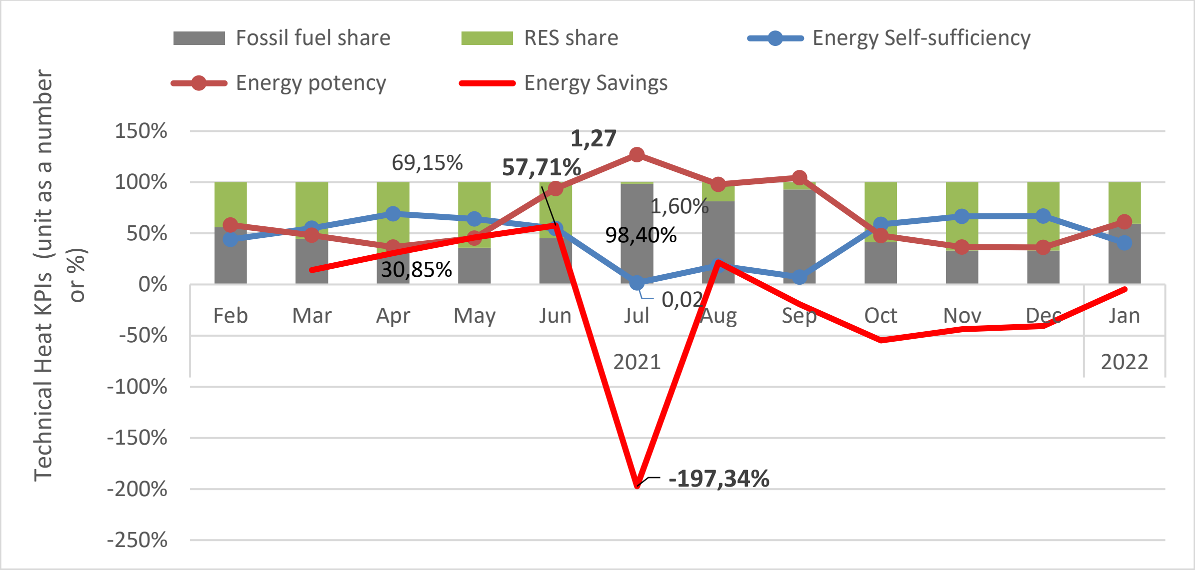

Figure 24: Aggregated Plot of the Technical KPIs of the CDWTCh Heating System Except CO2 Intensity (Monthly Data)

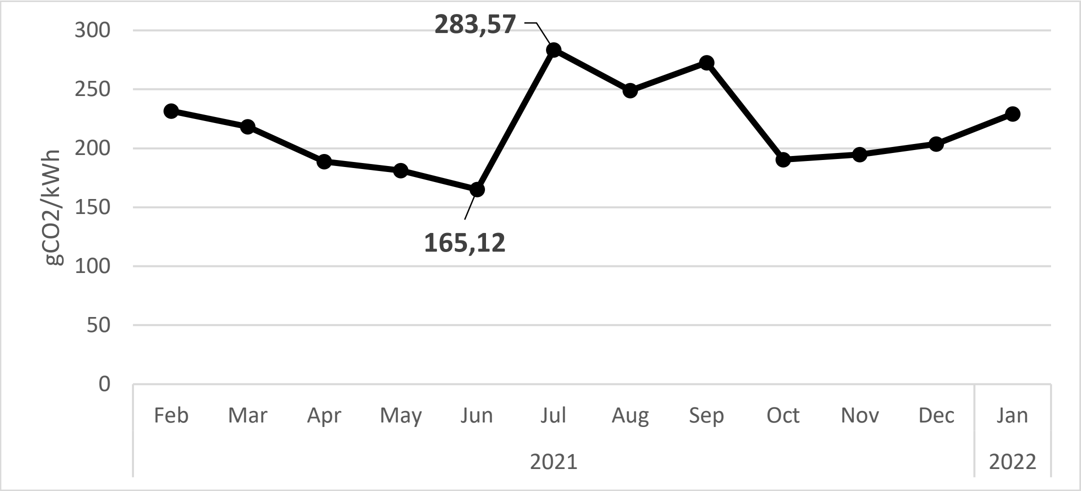

Figure 25: Monthly CO2 Intensity KPI Graph for CDWTCh Building

Figure 24 shows the monthly evolution of the energy self-sufficiency KPI. Analyzing the graph, it can be said that during the spring and fall months, the value of self-sufficiency is the highest, which indicates that the dependence on the external heating network is minimal in the total monthly heat load. This may also imply that the amount of renewable energy available in the ground is greater during these seasons, which can be explained in the fall when we have stored significant amounts of heat from the summer months in the ground, increasing RES-based heat availability and reducing heat imports during this period. For the spring self-sufficiency levels, minimal heat supply is withdrawn externally in addition to the lower electricity imported by the HP. However, the minimum self-sufficiency values observed during the summer months can be explained by the large amount of heat imported in the summer relative to the total heat demand, where for example in July 2021, imports constituted almost the entire heat load. According to the managers of the Poznan-Warta campus energy island, the heat imported in summer is mainly used to control humidity, which is particularly high at this time of year. Another reason, stated as well regarding the reason for this heat consumption, may be maintaining a certain temperature in domestic water in the building where the control algorithms tend to keep the water temperature at a certain level during the summer for domestic water use, resulting in large amounts of heat from the external grid, with a significant impact on the self-sufficiency KPI, especially as the magnitude of the heat load is significantly less during these months.

Figure 27 represents the levels of heat supply per month through the line with triangles, and through the stacked columns it represents the missing heat either directly consumed from the heating grid or generated by the action of the heat pumps. Lumping both values within this graph permits the comparison between the total amount of heat consumed versus the one missing which is clearly observable where the magnitude of heat load is expressed through the line with triangles indicating a significant decline of demand owing to the occupancy of the building plus the natural weather conditions that tend to be less demand for heating during the warm months. On contrast, by comparing the closeness of the line with triangles to the stacked columns, it is clear that the distance is a lot shorter in summer months meaning that the imports are more significant with comparison to the actual heat load during these months. This observation can explain the deterioration of the self-sufficiency values even though that we consume a lot less thermal energy.

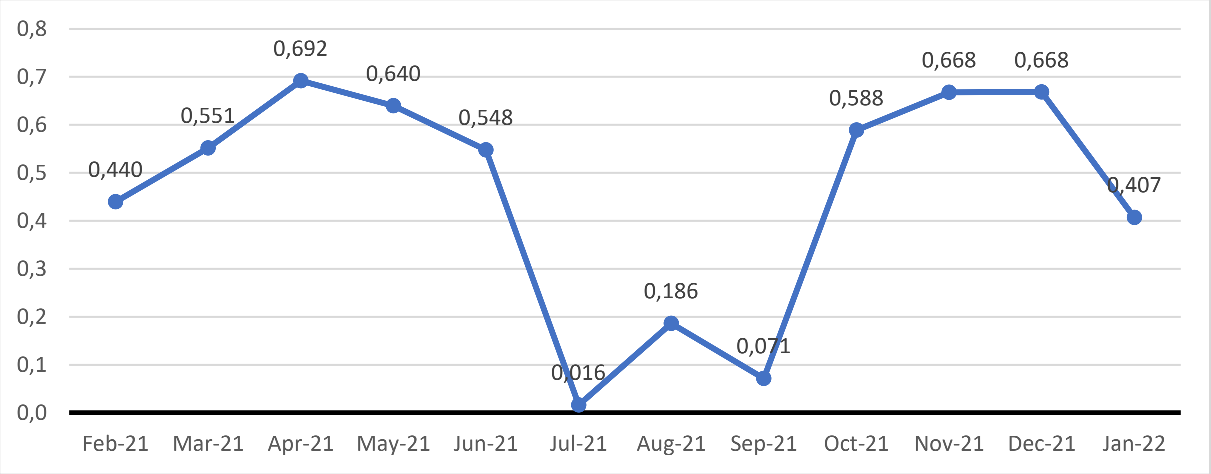

Figure 26: Self-Sufficiency KPI for CDWTCh Building

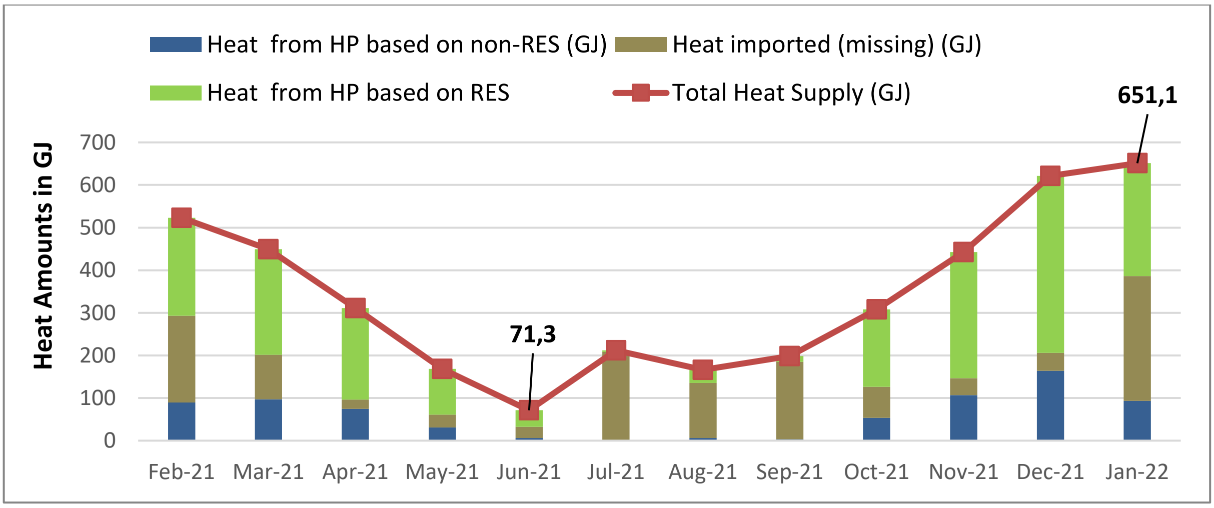

Figure 27: Explaining Factors for Heat Energy Self-Sufficiency Indicator for Poznan

ENERGY POTENCY INDICATOR

The energy potency indicator is a better idea about the aptitude of the energy island to be improved through investing more in balancing its demand and supply in terms of thermal energy in the case where the assessment is fine-grained. It is also representing the capacity of avoiding the provision from the external grid and controlling efficiently the excesses and losses identified in the heating system which can be responsible for significantly degrading the values of this KPI even though the levels of consumption are minimal. The idea behind adopting this KPI is to translate the extent to which the energy island is close to its ideal status of striving towards equalling this KPI to a zero value through being totally independent from any external heat supply, by eliminating the losses in the system, and by perfectly matching the heat supply and demand through using the excess heat to be re-injected through the storage system.

For the studied case of Poznan-Warta Campus, the values of thermal energy losses and excess are not reported by the energy islands or are challenging to obtain because it is requiring a heating system screening and maybe further investment in calorimeters installations all over the buildings. Based on this fact, the utility of both KPIs of self-sufficiency and energy potency in this case can be merged where through applying simple mathematical equivalence, both KPIs can be written as follows when adapting the KPI to the existing terms in Poznan pilot based on the assumption that $(\mathrm{E}^{\mathrm{T}}_{\mathrm{excess}} + \mathrm{E}^{\mathrm{T}}_{\mathrm{loss}} = 0)$:

$$\mathrm{E}^{\mathrm{T}}_{\mathrm{Pot}} = \frac{\mathrm{E}^{\mathrm{T}}_{\mathrm{missing}} + \mathrm{E}^{\mathrm{T}}_{\mathrm{excess}} + \mathrm{E}^{\mathrm{T}}_{\mathrm{loss}}}{\mathrm{E}^{\mathrm{T}}_{\mathrm{Consumed}} + \mathrm{E}^{\mathrm{T}}_{\mathrm{loss}}} = \frac{\mathrm{E}^{\mathrm{T}}_{\mathrm{missing}}}{\mathrm{E}^{\mathrm{T}}_{\mathrm{Consumed}} + \mathrm{E}^{\mathrm{T}}_{\mathrm{loss}}} = \frac{\mathrm{E}^{\mathrm{T}}_{\mathrm{imported}} + \mathrm{E}^{\mathrm{T}}_{\mathrm{HP\ NonRES}}}{\mathrm{E}^{\mathrm{T}}_{\mathrm{Consumed}} + \mathrm{E}^{\mathrm{T}}_{\mathrm{loss}}} \quad (1)$$

$$\mathrm{E}^{\mathrm{T}}_{\mathrm{SS}} = \frac{\mathrm{E}^{\mathrm{T}}_{\mathrm{Consumed}} + \mathrm{E}^{\mathrm{T}}_{\mathrm{loss}} - \mathrm{E}^{\mathrm{T}}_{\mathrm{missing}} + \mathrm{E}^{\mathrm{T}}_{\mathrm{excess}}}{\mathrm{E}^{\mathrm{T}}_{\mathrm{Consumed}} + \mathrm{E}^{\mathrm{T}}_{\mathrm{loss}}} = 1 - \frac{\mathrm{E}^{\mathrm{T}}_{\mathrm{missing}} - \mathrm{E}^{\mathrm{T}}_{\mathrm{excess}}}{\mathrm{E}^{\mathrm{T}}_{\mathrm{Consumed}} + \mathrm{E}^{\mathrm{T}}_{\mathrm{loss}}} \quad (2)$$

$$\mathrm{E}^{\mathrm{T}}_{\mathrm{SS}} = 1 - \mathrm{E}^{\mathrm{T}}_{\mathrm{Pot}}$$

Thus, the values can be easily deducted the one from the other. However, for the purpose of genericity, the formulation is kept as it is to comprehend a future improvement of the system in which we can be sure with certainty about the different values of losses and excesses in the heating network.

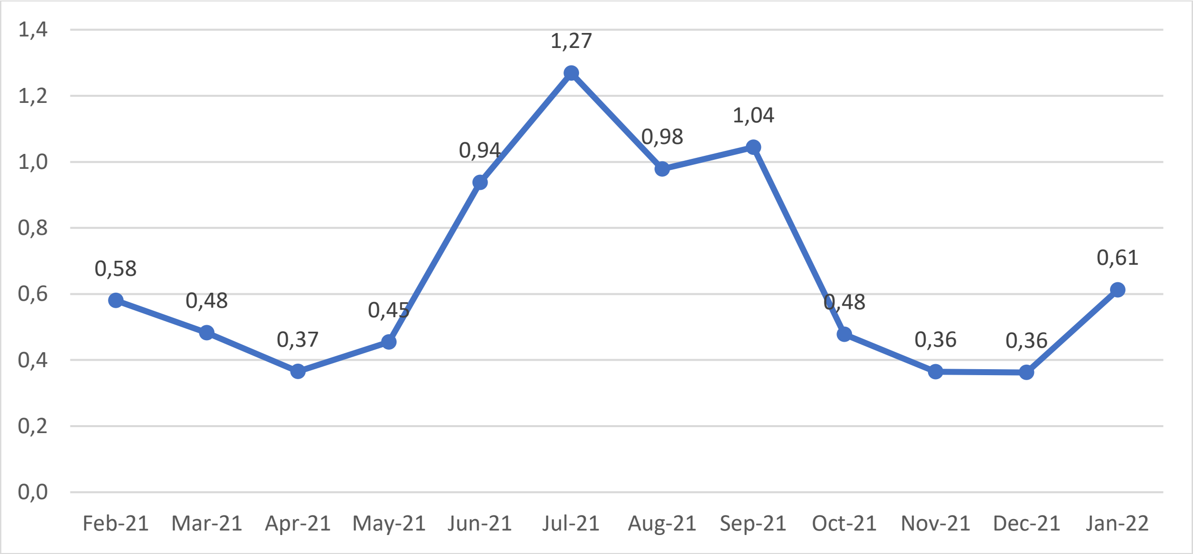

Figure 28: Energy Potency Values for 2021-2022 in CDWTCh Building in Poznan-Warta Campus Energy Island

RES AND NON-RES SHARES

The share of renewable energy sources for Poznan-Warta Campus is based essentially on the performance of the ground source heat pumps. Those latter use the relatively constant temperature of the earth as the exchange medium instead of the outside air temperature. This method of heating and cooling is adopted in order to hedge against the extreme weather conditions intending to yield better efficiency of both heating and cooling operations. This performance can be reflected in the coefficient of performance of the heat pumps where their action of reversing the heat flow in the direction of the warmer medium from the colder medium.

In fact, heat pumps use electricity to transfer heat from a cooler source to a warmer source, making the cool space cooler and the warm space warmer. As such, ground source heat pumps are able to heat, cool, and, if so installed, can supply hot water. Among the benefits of setting up this kind of heat pump, relative to air-source heat pumps, they are quieter, last longer, need little maintenance, and do not depend on the temperature of the outside air. Along with the technical advantages, there can be also several economic pros for setting up a ground source heat pump instead of air-based heat pump. Among the financial benefits on the long-run, its useful lifetime is longer and saves a lot more energy than the air-based heat pumps.

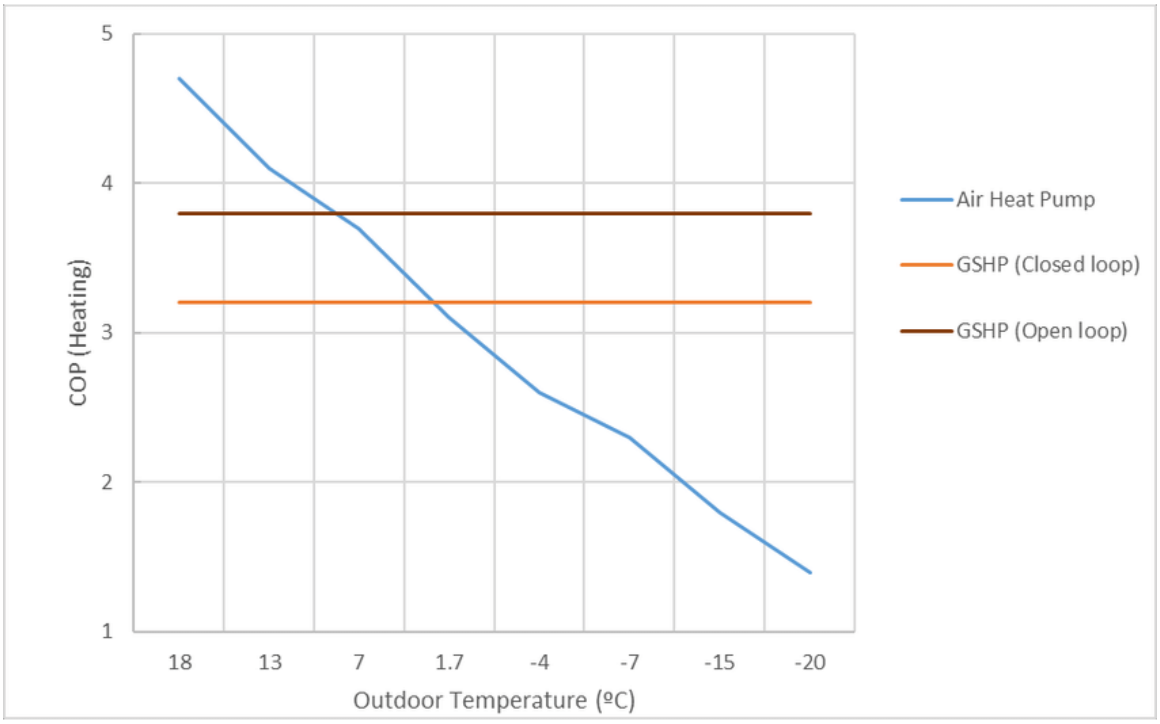

Figure 29: Energy Potency Values for 2021-2022 in CDWTCh Building in Poznan-Warta Campus Energy Island

It should also be highlighted that the values of the COP for the geothermal heat pumps depend on the inlet and outlet temperatures (also called source and compressor off temperature). Particularly the summer/winter difference is high; Figure 66 and Figure 67 showing this dependency can be found in Annex VIII.4.

Both figures show that the inlet and outlet temperatures levels variation is responsible for the coefficient of performance (COP) of the heat pumps and in particular the ground source heat pumps. Based on the previous figure showing that the temperature in the ground is stable throughout the year since the holes in the ground for heating and cooling provision are dug deep and therefore endowed with this constant level of temperature, then the variable defining the COP value will be mainly the output temperature that needs to be fulfilled. Indeed, the higher the outlet temperature of the heat pump required, the more work the compressor must exert to achieve this temperature. Therefore, the more electric power the heat pump requires and the lower COP.

As a conclusion, during the summer months, the COP value for the ground source heat pumps in Poznan present a significant increase shown in Figure 30. This can be explained by the constant intake temperature from the ground (to a certain extent) together with the availability of heat waste stemming from the cooling operation of the building where it can be fed to the heat pumps as a low heat source to boost the action of the heat pumps. This suggests that the levels of heat provided would be very important with less amounts of electricity required (reflected in the high values of COP). However, by observing the figures Figure 31, Figure 32, and Figure 33, the values of the share of RES and non-RES KPIs indicate the opposite where the amounts of imported heat from the district heating network (DHN) of Veolia is a lot larger than the amount fed by the heat coming from the heat pumps. In this regards, two different assumptions are likely to be considered as confirmed by the energy managers of Poznan-Warta Campus Energy Island. The first one states that there is a substantial heat loss due to connection work for a second building neighbouring the CDWTCh. The second one is that heat meter readings done by the BMS as well as by the heat district operator Veolia (and appearing on their invoices) show heavy summer heat consumption; however, the final utilization of this heat cannot be monitored.

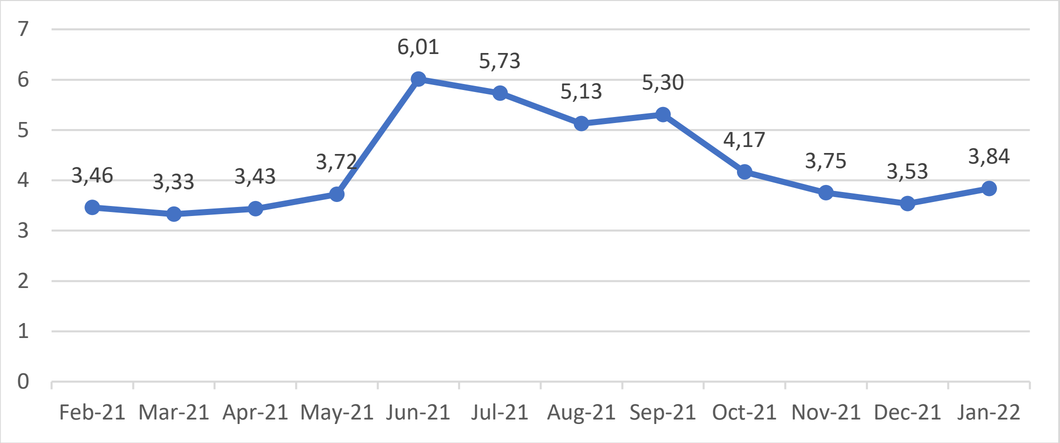

Figure 30: COP Values for the Ground Source Heat Pumps for CDWTCh Building

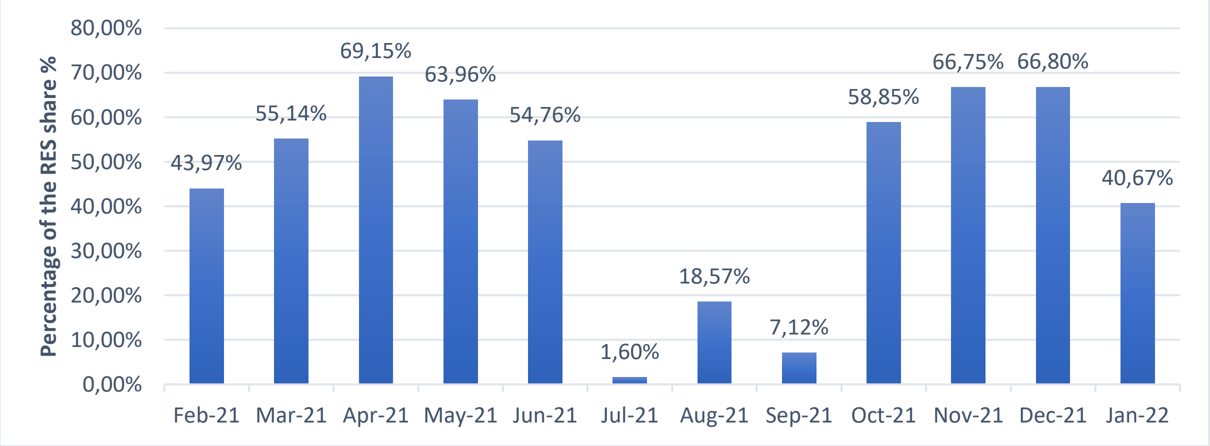

Figure 31: Share of Renewable Energy Sources 2021-2022

In Table 26 in Appendix VIII.4. the different terms of the share of RES and non-RES are revealed for the study period from Feb-21 until Jan-22. The general formula of the KPI as described in D7.2 is applied with a certain modification. This change concerns the way of measuring heat from renewable energy sources. In the case of Poznan Warta Campus, the value of heat supplied by RES-based heat pumps is important since the heat is taken from the ground that was stored during the warm season to be reused by the energy island in winter. This source is called a low heat source (LHS). More details on the adaptation of the RES-Share KPI calculation can be found in Appendix VIII.7.

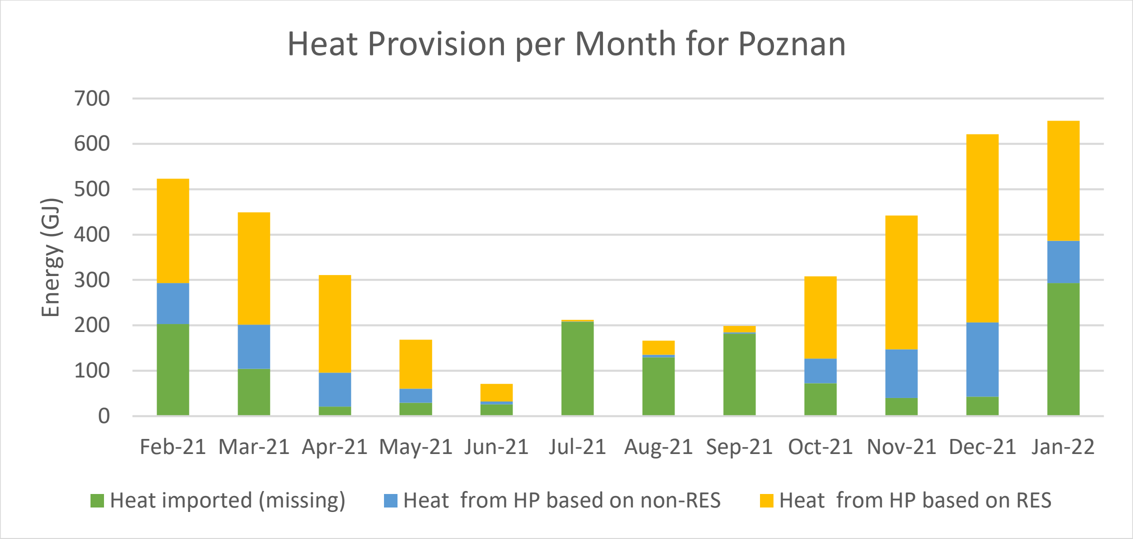

Figure 32: Explaining Factors for RES Share KPI for Poznan

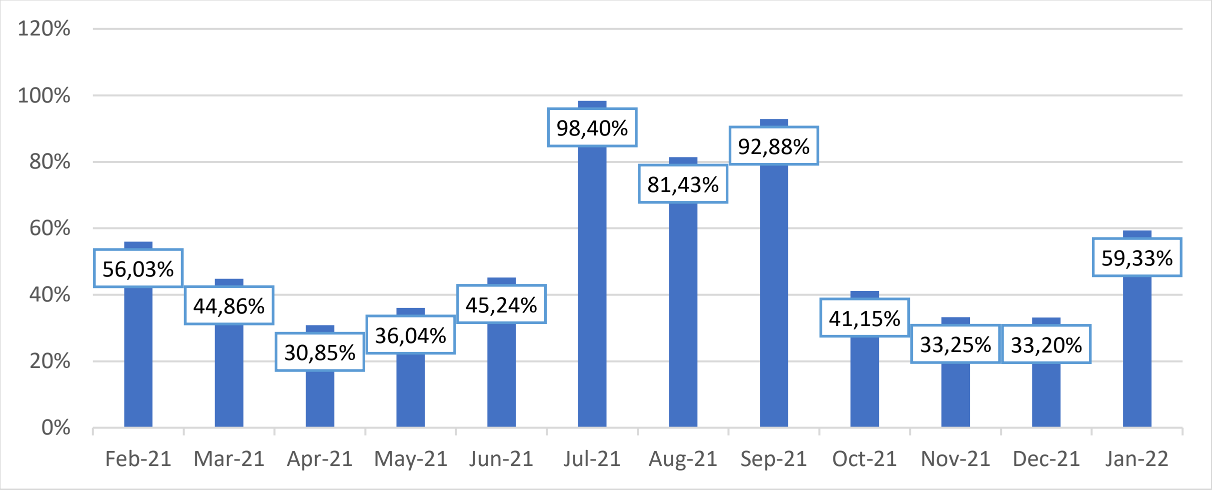

Figure 33: Share of Fossil Fuel in Relation to Consumption of Energy 2021-2022

CO2 INTENSITY FOR THE HEAT NETWORK

The intensity of CO2 KPI is an indicator expressing the heat mix or portfolio of production in comparison with the final heat load. It represents the value of CO2 emissions per consumed thermal unit (kWh thermal) that depends on the heating sources and the corresponding CO2 intensity levels. In this regard, the numbers used for the current assessment are given either by the energy island of Poznan-Warta Campus through Veolia in the case of imported heat from the DHN of Veolia (the given number is 287 gCO2/kWh in 2021). Similarly, the obtained number of the electricity imported intensity for Poland is given as 698 gCO2/kWh based on (KOBIZE, 2020). Concerning the PV emissions intensity in terms of gCO2/kWh, the number adopted is 45 gCO2/kWh[9].

The different factors responsible for these outputs are listed monthly in Table 27 and are depicted in figures Figure 33 and Figure 34 namely the figure of the values of CO2 intensity per month and the mix of heat sources.

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[9] Based on http://electricitymap.tmrow.co (Accessed 25 January 2023)

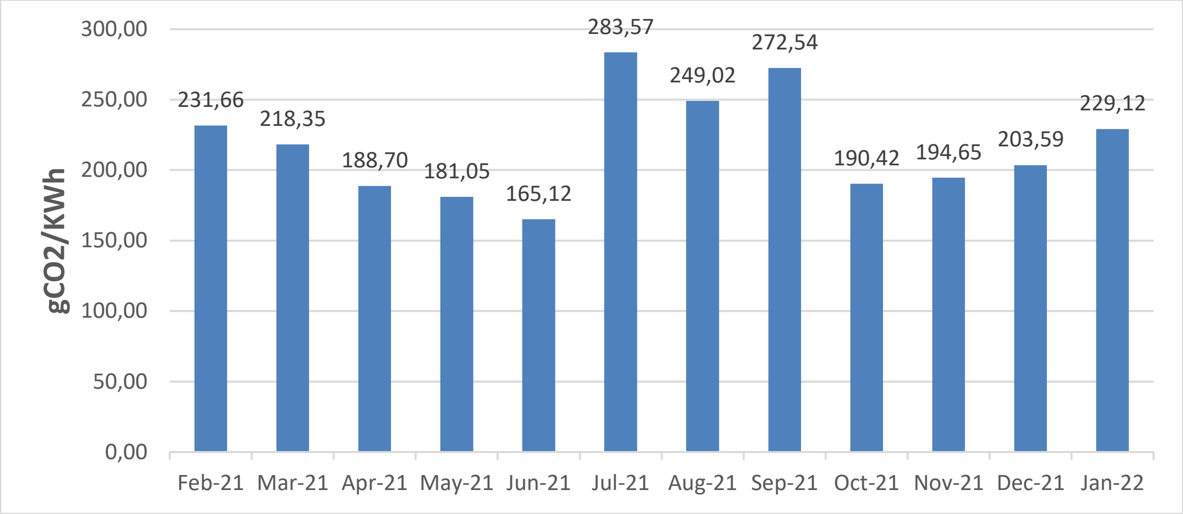

Figure 34: CO2 Intensity 2021-2022

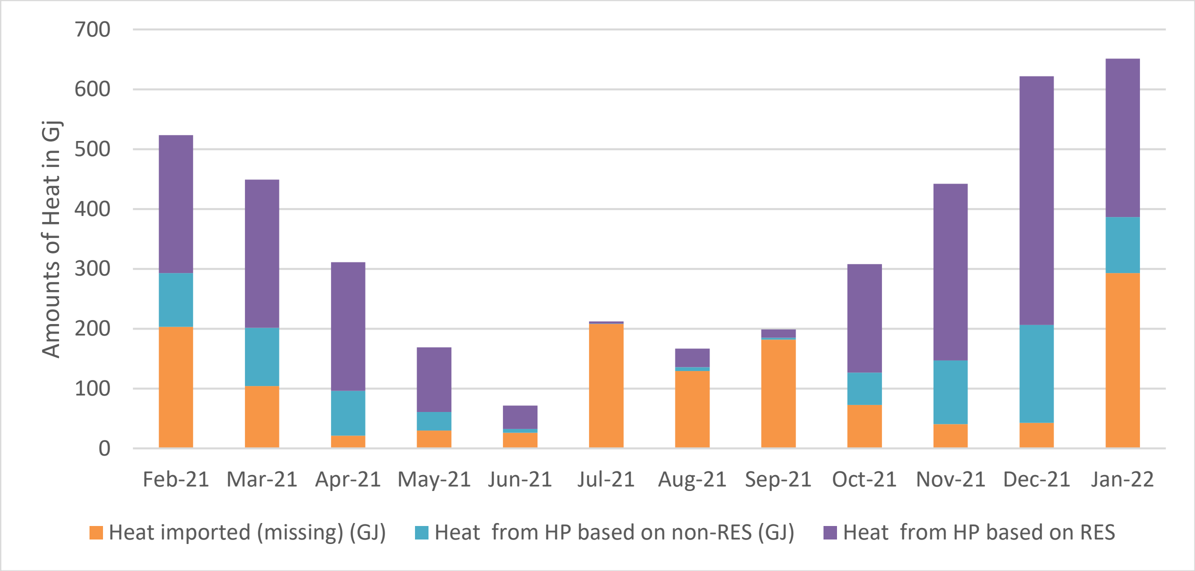

Figure 35: Heat Provision per Month for Poznan

ENERGY SAVINGS FOR THE HEAT NETWORK

As described in the Appendix VIII.7. , energy savings in the context of heating are explained by the presented formula whose main purpose is to evaluate the consumption pattern from month to month. This KPI can be useful if we focus on months of the same season where the numbers can indicate the difference in end-user behaviour with respect to weather conditions. However, looking at Figure 36, there is a negative jump in the energy savings values between June 2021 and July 2021, which shows that there is a sudden increase in the required heat load between these 2 months of the same season. This is easily demonstrated by the negative value of the energy savings KPI where the value deteriorates to about -200%, which means that the level of consumption in July is about 3 times higher than that of June.

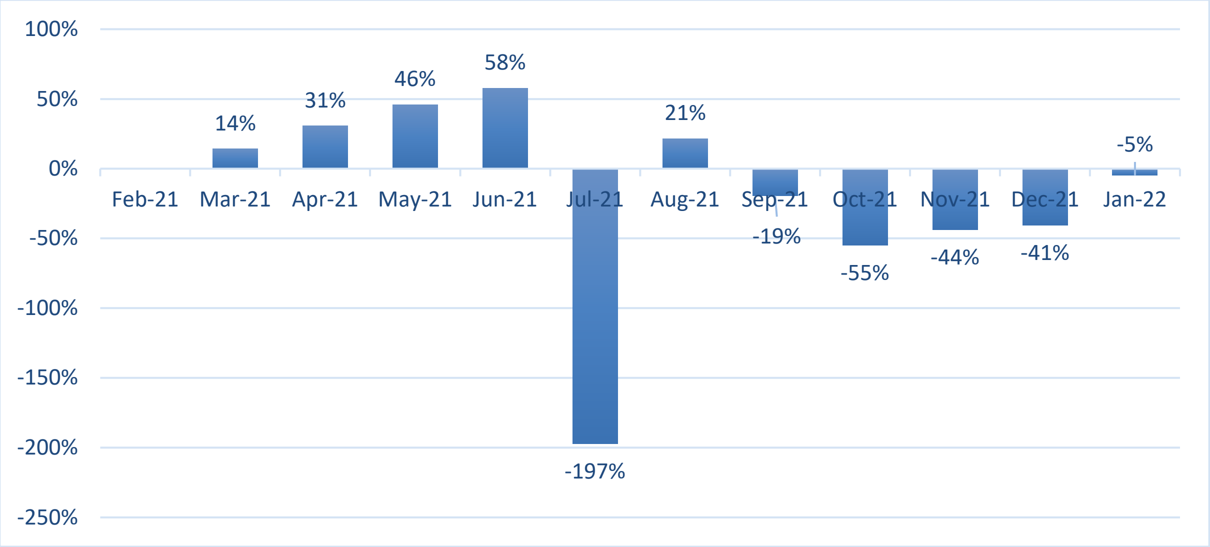

Figure 36: Monthly Energy Savings in % for 2021 and 2022

Table 7: Annual Average Values for the Technical Heat KPIs for Poznan-Warta Campus (CDWTch Building) and Interpretation

KPI name	Annual Average Calculated	Interpretation
Electricity Self-sufficiency for the Energy Island	0.456	• The evolution of the self-sufficiency KPI suggests that the levels of dependence on the external heat network for heating operation are moving towards a more rational use of heat supplied by the Veolia heat network, where the Poznan energy island in terms of heat self-sufficiency is more characterized by a lower dependence on external resources. • Furthermore, the observed monthly trend suggests that the levels of heat supply from external thermal energy and local thermal energy are disparate from month to month, depending on the idea of the efficiency of the ground source heat pumps installed on the Poznan-Warta campus. These heat pumps can provide substantial amounts of heat to meet the increasing demand during the winter months (cold season). It is also observed that the COP value is high during the summer months, resulting in better results in terms of electricity consumption to provide heat, as the performance of the heat pumps is enhanced during the summer by the waste heat from the cooling process. In this scenario, the heat quantities can be sufficient to meet the overall heat demand of building heat system.
Electricity Potency of Energy Island	0.661	• The energy output value suggests that there is still room for improvement in the energy island by investing more in RES-based thermal technologies (more electric ground source heat pumps). • Replacing the current heat source (Veolia) for DHW, with heat pumps. • Some matching of heat demand and supply needs to be implemented to ensure that heat pump operation is cost-effective and that no heat is lost, re-injected or simply rejected to the air.
RES share	45.61%	• The RES share for Poznan is based on geothermal heat stored by the operation of heat pumps. • By using the ground as a natural heat storage medium during the summer, this seasonal storage allows the heat pumps to operate at higher efficiency.
Non-RES Share	54.39%	

		• The stored heat is extracted by electric heat pumps that draw heat from the ground when needed to meet the heat load of the winter months. • This seasonal storage has an impact on the RES share levels for Poznan and pushes towards higher values for the energy island, which is an advantage since the installation is convenient for such storage with which the heat pumps are connected and then their produced heat is distributed to the energy island. • The reasonable values of the non-RES shares prove that the dependence on the heat network is avoided to a certain extent and that only the part not satisfied by the heat generated by the heat pumps has to be fulfilled by an external supply from the DHN. • The same reasons apply to the KPI of the non-RES share, as underground storage serves as a reliable resource for heat through the operation of electric heat pumps (a high COP is also an influential variable in the equation), as they provide a significant portion of the heat demand.
CO2 intensity	217.32 gCO2/kWh	• Based on the previously discussed formula for the calculation of CO2 intensity, the CO2 intensity values are higher than those found for Ghent-New Docks. This can be easily explained by the penalizing CO2 intensity coefficient for the energy island when consuming from the Veolia district heating network (287gCO2/kWh thermal). • The same penalizing value applies to electricity consumption where the CO2 intensity coefficient when drawing from the public grid is 698 gCO2/kWh el. • These values penalize the CO2 intensity values obtained for the CDWTCh building but are considered favourable compared to the grid CO2 intensity levels which are more than 3 times higher than the calculated value, meaning that the COP factors of the heat pumps are significant and help to reduce the effect of the high CO2 intensity of the public grid. • It is also worth mentioning that some photovoltaic installations contribute to significantly reduce CO2 intensity levels as they can provide clean electricity for use by heat pumps, which can then extract clean heat to meet the thermal load of the end users.
Energy Savings (%)	-17.34%	• The annual value obtained indicates an average of the additional heat expenditure for the period under study, observed on a monthly basis., Due to weather sensitivity, on the yearly values are relevant. • This value is most useful if energy savings are compared annually (between years) or between the same periods in different years, for example, assuming some basis for comparison.

IV.1.1.b. Poznan Electricity Domain

In this section, like what was done for Ghent-New Docks, we build on the different steps of the process identified for the calculation of the technical KPIs, as described in D7.2. A bilateral knowledge exchange took place to understand the specifics of the electrical system to be evaluated. This step resulted in one building (CDWTCh_RG1) being considered as the laboratory, office and lecture halls building to be evaluated as not all buildings are equipped with fine-granular sensor equipment. Unlike the Ghent-New Docks pilot, the data is reported monthly through an Excel spreadsheet where each of the items defined for future use for KPI evaluation was entered directly into the Excel sheet shared with the energy managers of the Poznan-Warta campus energy island.

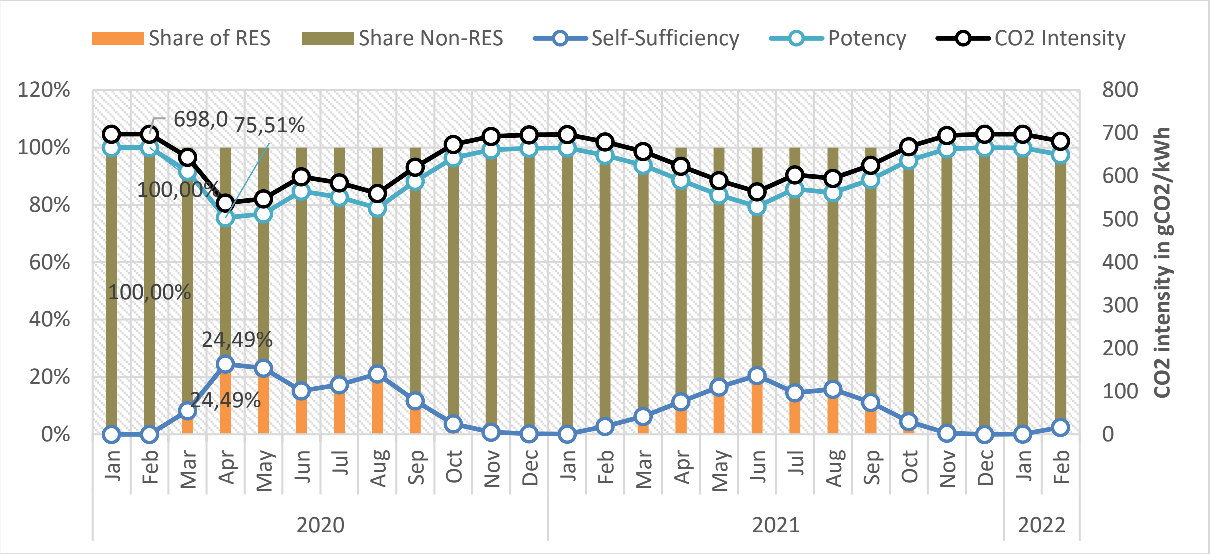

Figure 37: Graphical Representation of the Monthly Technical Electricity KPIs for the Period from January 2020 until February 2022

Based on Table 29 in the annex and Figure 37, the first remark is the dependence of the KPIs and their evolution on the RES availability within the month or the quarter where we can observe that the months with a lot of sun radiation amounts yield better values in terms of all the KPIs meaning better share of RES, more important self-sufficiency[10], and less CO2 intensity together with less important share of fossil-fuel share in the electricity provision mix and less energy potency.

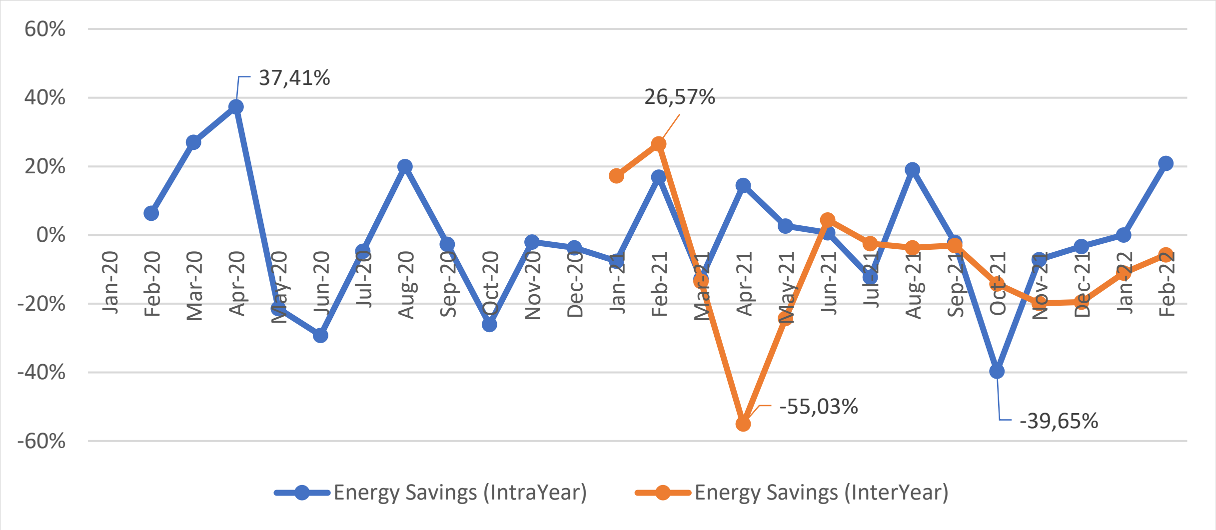

Figure 38: Electricity Saving KPI Intra-annually and Inter-annually

The added KPI reflecting the saving can be computed on different levels and adapted accordingly to compare between two different periods to observe the difference of consumption levels of electricity. Based on Figure 37, the monthly electricity consumption saving KPI indicates that levels of consumption dropped between 2020 and 2021 for February but a significant increase of consumption is recorded between April 2020 and April 2021 as the KPI deteriorates to -55%. Regarding, the interannual fluctuations, these are a result of the season

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[10] Please not the slight modification of the term “self-sufficiency” as defined in D7.2 to better reflect the objectives of RENergetic. More information can be found in the appendix VIII.7.

changing where we note that the lowest values of electricity saving is recorded for October 2021 where typically more heating is required.

IV.1.2. Social Baseline Assessment

The baseline data for the social Key Performance Indicators (KPIs) in Poznan was collected through two methods. The first method involved offering an on-site opportunity to participate in the survey using both paper and pencil and an iPad, in conjunction with the Energy Vision Game. This was made available to passing students within the architecture and technical building. In addition, a link to the survey was distributed via the university network, resulting in a final sample size of N = 52 participants.

The participants completed the extended Social KPI questionnaire, which included questions on their current level of participation opportunities and attitudes towards actively participating in the community's energy transition. These questions were particularly relevant as, at the time of the survey and up to date, there is no established energy-related community but rather the project is building on the existing student community.

As shown in Figure 39, the gender distribution of the sample within Poznan University was balanced, while the age distribution was heavily skewed. The age distribution depicted is consistent with the expected university context, where the vast majority of participants were students.

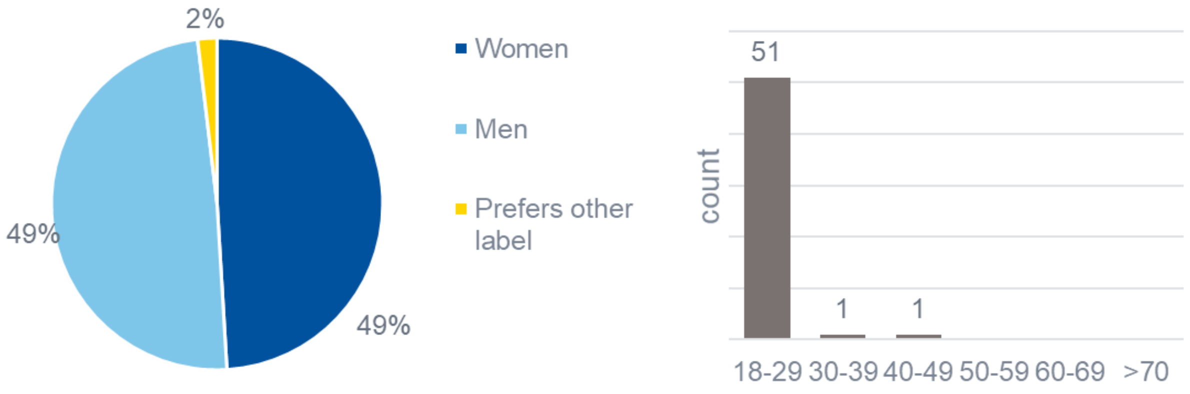

Figure 39: Gender and Age Distribution in Social KPI Sample, Poznan

The means across all assessed constructs show that individual energy behaviour was rated highly, with a mean greater than 6. Additionally, satisfaction with the current communication of energy production and consumption in the neighbourhood/community was low, but the desire to learn more was slightly higher. The perceived opportunities for democratic participation were average, with a higher positive attitude towards getting involved in decision-making regarding the local energy transition. Notably, self-efficacy beliefs were rated significantly lower than collective efficacy beliefs, as demonstrated in more detail in the distribution graphs. Figure 40 summarizes all means for the assessed constructs.

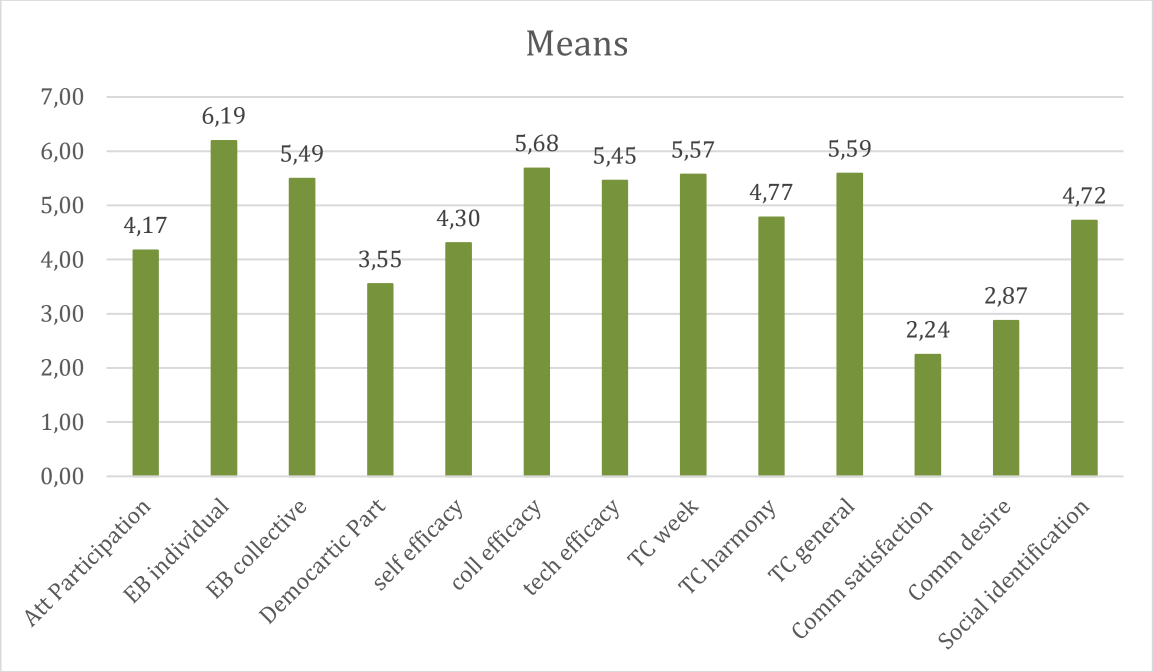

Figure 40: Descriptive Means of all KPIs assessed, Baseline

Distribution graphs for the KPIs assessed in all Pilots are provided, which are related to the Epic of social campaigning. These KPIs include social identification, self-efficacy beliefs compared to collective efficacy beliefs, and, in the case of Poznan, attitude towards more active participation in the local energy transition. Social identification showed a distribution across the scale, with a slightly positive tendency. The attitude towards participation was close to a normal distribution. As previously mentioned, the distribution of self-efficacy beliefs differed significantly from the distribution of collective efficacy beliefs, with the latter showing a stronger positive skewness and a higher tendency for people to agree more.

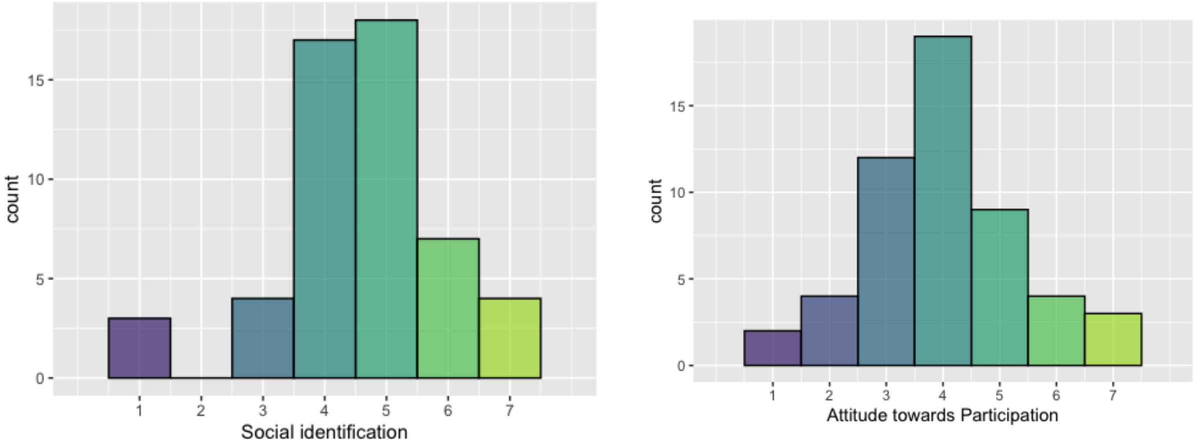

Figure 41: Distribution of Social Identification and Participation Attitude in Poznan

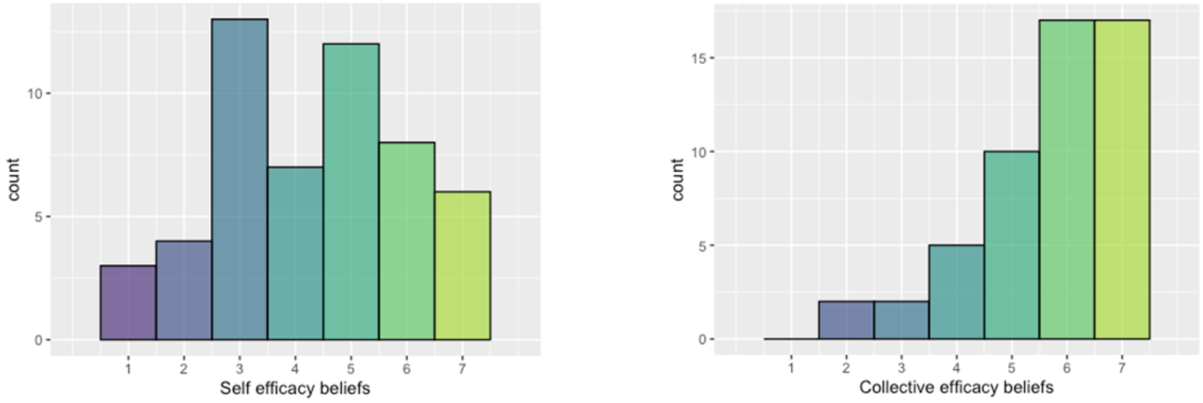

Figure 42: Distribution of Self- and Collective Efficacy Beliefs, Poznan

Finally, we investigated attitude towards participation to determine which other constructs correlate and could influence the individual's willingness to actively engage in the local energy transition. Our analysis highlighted the significant strong correlation between both communal energy behaviour intentions and social identification with attitude towards participation: a strong positive relationship was observed between the willingness to conserve energy collaboratively with others in the community and the motivation to inspire collective action, and social identification on an individual's willingness to participate.

IV.2. Social Campaigning in Poznan

IV.2.1. Social Activities & Results

Since the start of the project, the social activities in Poznan have been focused on involving students and leveraging the existing community within the University to drive engagement in the energy transition. Through early interviews with university representatives from different social groups, the project aimed to learn about potential motivators, barriers, and constraints to increased involvement in energy-related topics and acceptance of technical solutions. To gather further insights, a broader survey was conducted to assess specific learnings for heat demand response, and the Energy Vision Game was utilized to gauge current ideas and awareness about the local energy transition. The social activities in Poznan will continue to concentrate on establishing an interactive platform for communication of energy production and consumption, aimed at further fostering engagement and understanding of energy-related issues.

IV.2.2. Expected Impact

Based on the results of the baseline assessment in Poznan, our objective is to drive a positive social impact through increased social identification and the perception of opportunities for active engagement in the local energy transition. We aim to leverage the existing collective efficacy belief among the community to foster a more proactive attitude towards energy issues. In addition, the implementation of an interactive platform is expected to enhance the communication of energy production and consumption and increase the knowledge and satisfaction with the same. The technical optimizations carried out as part of the project are expected to bolster self-efficacy while ensuring that the comfort levels are not negatively impacted.

IV.3. Local Waste Heat Reuse in Poznan

IV.3.1. Activities and Scenarios

In this section, the scenarios of Warta Campus - Poznan to be evaluated are described. This step allows drawing viable conclusions about what possible alternative should be selected. This can be achieved by assessing technically and economically different key performance indicators (KPIs) based on data availability and interest for the energy island. Three main scenarios are identified related to the investment decision for the campus energy island based on Figure 43. In this figure, we can see that there are two alternatives for the waste heat valorisation (re-use). Another intermediate solution is designed based on some technical considerations of heat conveyance.

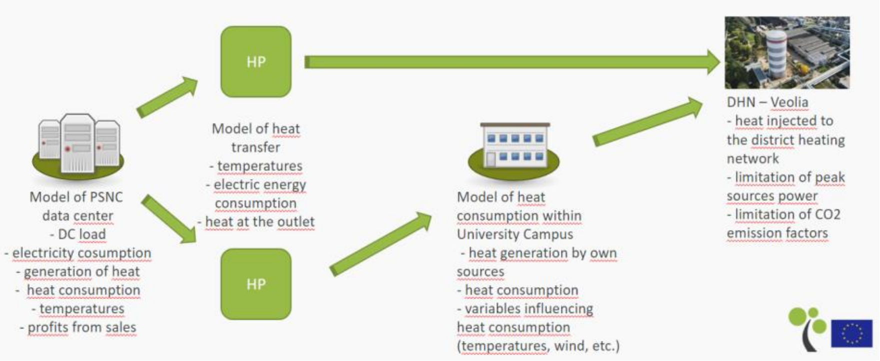

Figure 43: Different Possible Configurations for Waste Heat Valorization

In Figure 44, an illustration of the different heat loops to be implemented and the existing ones in the energy island of Poznan are exhibited together with the different temperature levels where each of the scenarios can be a subset of the pipelines respecting the thermal values of temperature while taking into account the buildings characteristics (the suitable ones and well insulated can be fed with the medium temperature heating system and the old buildings with non-sufficient insulation can be fed with the DHN network).

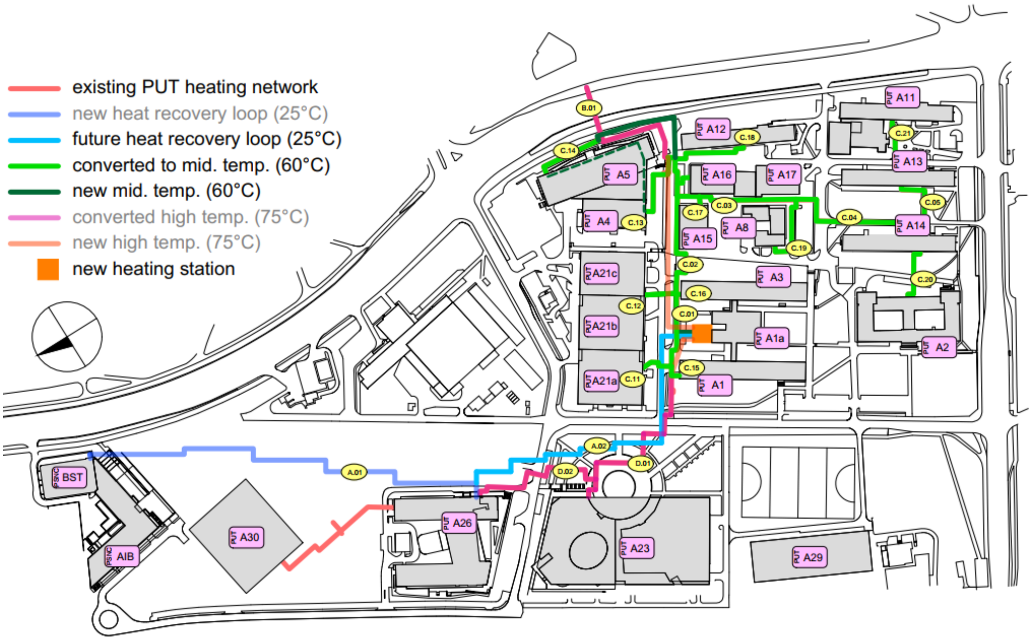

Figure 44: Energy Map of Poznan Energy Island

SHORT WATER LOOP SCENARIO

In the first alternative, the waste heat is injected from PSNC to Veolia district heating network while as a profit the amount of energy injected to Veolia is accounted as a benefit for the energy island (more specifically for PSNC). In this context, there are legal restrictions on the flow of the waste heat to the DHN of Veolia (legal framework needs to be defined). However, in this scenario, the heat consumption when withdrawing from Veolia District Heating Network (DHN) is still billed, indeed, higher than what the waste heat was sold for. Here, some indicators are going to improve a bit but not on the energy island level but rather for Veolia perspective since the waste heat to be injected is going to be considered as lower CO2 intensity since it is a second use heat and is originally electricity-based heat (less CO2 footprint). For the energy island also, this can imply a better indirect way to reduce the CO2 intensity for the heat import from DHN. For other indicators concerning the self-sufficiency it will be less concerned since the heat will be purely imported from Veolia which is still dependent on its heat provision in terms of fossil-based and non-RES based heat generation. However, this is probably influenced by acting on the export of heat to Veolia where the heat balance can be improved with regards to the external provision versus exporting levels since in the energy self-sufficiency indicator this can be reflected for the net heat value as the difference between the exported quantity of heat and the imported (missing) one. On the economic side, the benefits do not seem to be interesting since the most substantial part of the heating costs in terms of direct consumption will remain there and prone to the heat prices volatility stemming from the natural gas or other sources prices volatility without forgetting that the exported amount of heat is also powered by external electricity sources that can be as well vulnerable to prices volatility and unpredictability.

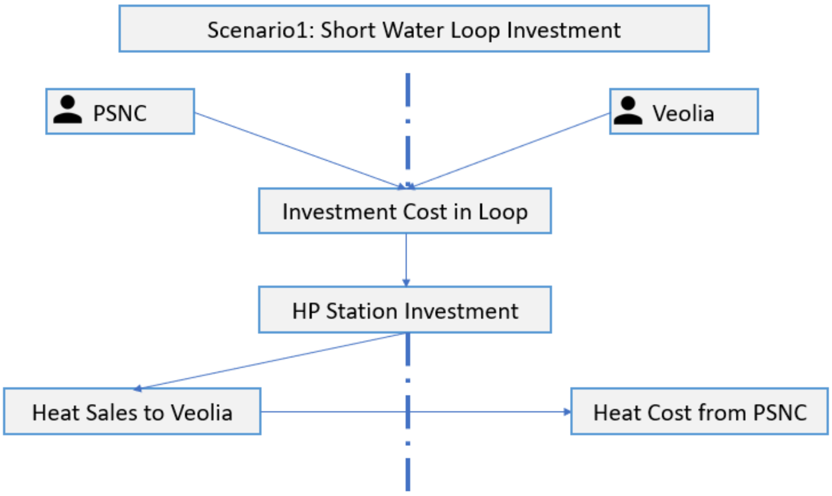

Figure 45: Short Water Loop Scenario - Summary

Table 8: Stakeholder Interests in Short Water Loop Scenario

Actor	Investments	Revenues	Cost
Veolia	- Connection with Veolia (short Water Loop) - Heat Pump Station	- Fees of usage of Water Loop (needs to be defined= monthly/annually or another granularity)	- Electricity for Heat Pumps - Heat imported charged by PSNC (contract terms)
PSNC	- Connection with Veolia (short Water Loop) - Heat Pump Station	- Heat Sales to Veolia (legal framework) depending on the quantity of heat exported	- Electricity for Heat Pumps - Fees of water loop usage

MEDIUM-LENGTH WATER LOOP SCENARIO

For the second scenario, a more in-energy island action is promoted where we prioritize the heat usage and recovery between PSNC and PUT where the investment in the water loop could be the endeavour of PUT or PSNC based on an internal agreement and whether this is a worthwhile investment for the one or the other. This investment will be an added-value generator for PSNC since the implementation of such a water loop connecting the recovered heat to PUT heating system and more specifically to the newest buildings that have the suitable insulation potential by conserving the low-temperature heat efficiently. Those buildings are namely WAWIZ, CDWTCh, and RPP. Then, for this particular scenario, the structure of investment costs is similar to the previous scenario about the short water loop but in this context the length of the water loop will be higher depending on some properties of the water chilling techniques at the level of the data centre. Then, the diameter and the length of this pipeline could be determined based on simulation of the optimal length for this scenario without requiring any extra HPs investment for PUT. The saving structure can be summarized in the fact that avoiding the investment in heat pumps at PUT side will spare it the extra investment expenditure plus the electricity consumption costs. Finally, on the cost level, the low-temperature heat purchase from PSNC is a cost for PUT. However, it is a receipt for PSNC.

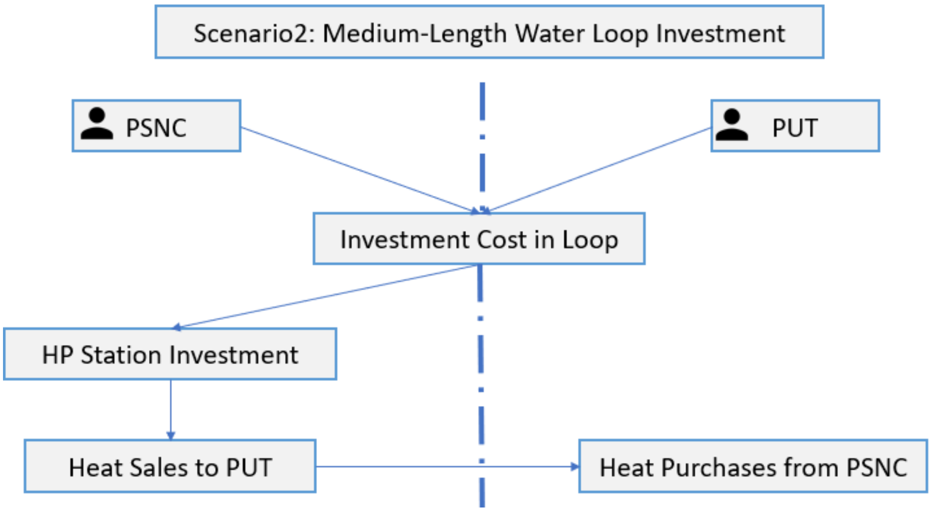

Figure 46: Medium Length Water Loop Scenario - Summary

Table 9: Stakeholder Interests in Medium Water Loop Scenario

Actor	Investments	Revenues	Cost
PSNC	- Water Loop	- Fees of usage of Water Loop (needs to be defined = monthly/annually or another granularity) - Heat Sales to PUT (legal framework)	- Operational costs of water loop maintenance
PUT	- Water Loop	- Heat cost savings (avoiding the import of heat from Veolia) - Electricity cost savings due to a lower electricity consumption (already installed HPs will have higher COPs)	- Payment of fees for water loop usage - Heat purchases from PSNC (price needs to be defined) - Operational costs of water loop maintenance

LONG-LENGTH WATER LOOP SCENARIO

For the third scenario, an upgrade of the heating network within the whole campus by implementing a large in-board e-island heating network to consume the heat produced in-island represents, first, a technical challenge to ensure that the heat reaches all the corners of the energy island (the whole campus). Second, the economic viability of this investment is another question in the sense of to what extent this investment is worth undertaking and would it save us, as an energy island, a comparable amount of energy and money if we are not going to consume from the DHN of Veolia. Another point is critical related to the power generation matching in times of peak demands or production and the calibration of both demand and generation of the waste heat to be able to meet the heat requirements of the entire campus. In this scenario, there are some legal barriers as well to be considered concerning the heat transmission from the data centre as the main source of heat to the different other buildings (offices, dormitories, and others). Here, a comparison between the power heat production of the data centre and the amount of heat demand is needed.

In conclusion, to be completely self-sufficient in heat energy vector, several considerations are to be taken regarding the source of heating, its scope, the intermediate losses by dissipation (hydraulic or air systems), the distance separating the different buildings, the external temperature influence, the balance of heat demand and supply, the effect of electricity consumption and other aspects such as the technical properties of the buildings and their insulation and Energy Performance Certificate (EPC) that measures the energy efficiency of a property at the time it was issued. In this scenario, it seems that there will be a delegation for the self-sufficiency in the heat energy vector to the electricity energy vector since there will be more load on the electricity and more or less depending on the green production of electricity (by PVs) we can define the degree of this self-sufficiency. However, since currently there are not enough PVs installed, the electricity coverage is being withdrawn from the electricity power grid which indirectly leads to another dependency on the electricity level. In addition to that direct consumption by the data centre, all the way there is a re-enhancement of the heat streams from the data centre to other parts of the energy island by the heat pumps, those latter require an electricity load as well to provide that heat flow boosting.

Concerning the heat waste losses concerns, the thermal losses in low-temperature heating systems are significantly lower than the high-temperature heating systems (DHN). In our case, the captured heat from the data centre is at a low temperature of around 25°C.

More in detail, the investment in the long water loop, as well as the central heat pumps’ station, will be the task of PUT where on top of that it purchases the low-temperature heat provided by PSNC on its own built water loop. Thus, PUT can decide to charge PSNC for the water loop usage, or in the terms of the contract between both institutions, the purchase price can be re-adjusted to reflect this investment cost that PUT undertook. After being injected into the PUT water loop, the heat is transported in the long loop to the central HP station, where it will receive a boost to meet different heating or cooling requirements for district heating in wintertime or water chilling in the summertime through storing heat in the ground by the ground-based HPs. Once, the re-intensification is achieved on the captured heat, it can be dispatched to the different buildings and even to Veolia DHN when there is an excess of heat production.

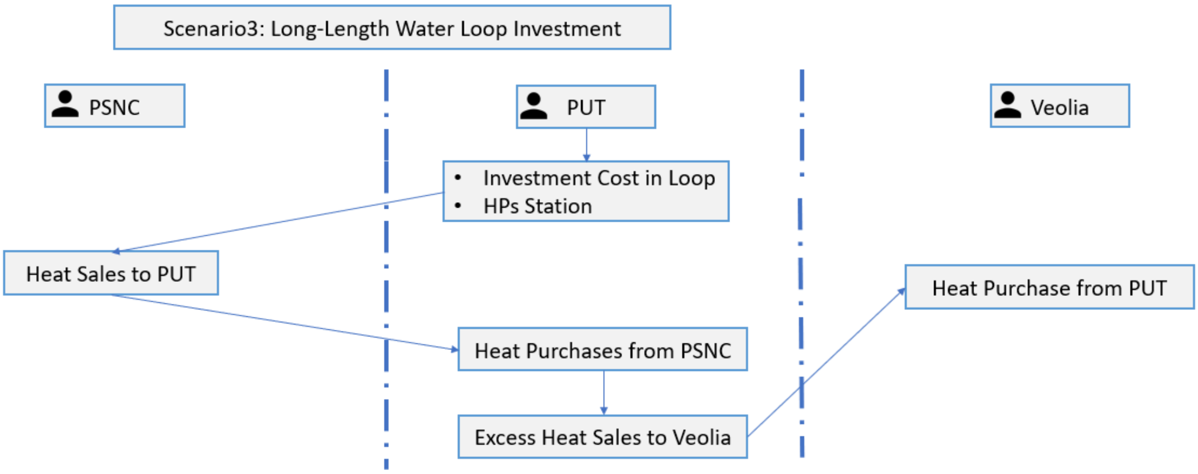

Figure 47: Long-length Water Loop Scenario - Summary

Table 10: Stakeholder Interests in Long-length Water Loop Scenario

	Investments	Revenues	Cost
PSNC	- No extra investment	- Low-temperature heat sales to PUT	- Payment of fees for water loop usage
PUT	- Water Loop - HP station	- Heat cost savings (avoiding the import of heat from Veolia) - Excess heat sales to Veolia	- Heat purchases from PSNC (price needs to be defined) - More electricity consumption at the station of HPs
Veolia	- No investment	- No revenues	- Purchase of excess heat from PUT

IV.3.1. Expected Impact

The various scenarios designed for local waste heat recovery have an impact both on the technical and environmental dimensions as well as on the financial axis. First, the recuperation of the heat released by the data centre will increase on average the heat self-sufficiency and import self-sufficiency KPIs. This is explained by the available amounts of heat locally produced and destined for the end-users within the energy island, especially in both sub-scenarios of medium and long-length water loops. However, the impact on the energy potency indicator is not straightforwardly observable. This is due to the potential imbalance within the heating system to align the heat load with the heat supply. Fortunately, within the heating sector matching these parameters can be performed with freedom degree owing to the storage potential within the ground. The heating potency can be decreased thanks to the storage capacity in addition to the substantial expected decrease of the heat export.

On the level of renewability or greenness dimension, the levels of RES and non-RES will respectively increase and decrease due to the classification of the heat source as entirely renewable. Another KPI reflecting greenness is the CO2 intensity. This KPI will be as well affected and eventually decrease due to the CO2 neutrality of the heat stemming from the data centre.

On the financial axis, several KPIs assess the cost of heat and several facets of the investment. Those KPIs are expected to reflect the viability of the water loop project concerning several configurations as described in the scenarios and their characteristics.

IV.4. Heat Demand Response in Poznan

IV.4.1. Activities

For the epic heat demand response, a semi-automated approach with communication between Veolia (the heating provider) and the Poznan pilot side will take place. Veolia will make demands on a reduction of peaks at a specific time frame and Poznan must fulfil that request and will get monetary compensation. In order to reduce the needed heating energy there is a pre-heating step needed. This is the interesting part from the point of view of the project, since it requires an accurate prediction of heating demand an optimization of pre-heating temperature, time and duration. And the ICT tools developed by the project will help energy managers to find those optimal set points, which they can then enter manually. Thus, the name semi-automated.

Additionally, another automated demand response experiment is planned which will take place in dormitory DS4 in PUT. The idea is to control the temperature set point inside the thermostats when students leave the room and thus and allow for fine grained demand shift.

IV.4.2. Expected Impact

Regarding the expected ***technical impact***, there will likely be a reduction in CO2-Intensity from the part of Veolia, because they will be able to reduce the need of extra boilers, due to mitigated peak demand periods, but the project does not have access to that data and the CO2 reduction will not take place inside of the energy island. In fact, total energy demand will be higher, since heat from the pre-heating step dissipates throughout the time period after pre-heating. Also, the pre-heating temperature/duration must be higher than an in-time heating otherwise would have required.

The ***economic impact*** for the semi-automated demand response will only be in the reimbursement from Veolia for HDR readiness and therefore will affect the KPI levelized cost of energy (LCOE). Aggregating several such entities as PUTs in HDR will avoid demand peaks and the need to run more coal-consuming power units in Veolia. This will translate into reduced CO2 emissions. The contract between Veolia and Poznan has still to be finalized so a quantitative assessment on cost savings cannot be made.

IV.5. Electricity Supply Optimization in Poznan

IV.5.1. Activities

For the Poznan pilot a new installation of PV panels and a battery energy storage system (BESS) is planned. For this flavour of the epic the project will implement a supply and demand prediction model for the PV panel generation and electricity demand. The prediction models will support energy managers with an estimation about how the new installations will affect the electricity demand and supply fit and thus they can make an informed decision on the correct size of the PV panel and the BESS. Therefore, with the help of the ICT tools developed by the project pilot sites, aspiring a higher level of self-sufficiency, like Poznan, will have a concrete justification and reasoning to install renewable energy infrastructure.

IV.5.2. Expected Impact

The ***technical impact*** will be a higher percentage of **self-sufficiency** and a higher **share of RES**, due to the new on-site installations of PV-panels. For the ***economic impact*** a reduction of **load purchasing from the grid** is expected, due to the lowered electricity supply needed from the national grid. And since the self-generated electricity will be at a lower cost and grid electricity a decrease in **LCOE** is also expected.

V. IMPACT ASSESSMENT OF RENERGETIC PILOT ACTIVITIES IN SEGRATE

The Pilot of Segrate is working on the following Epics: Social Campaigning	Heat Supply Optimization	Local Waste Heat Optimization	Head Demand Response	EV Demand Response	Electricity Supply Optimization	Electricity Demand Response
X	X			X	X	

V.1. Baseline Assessment

V.1.1. Technical Baseline Assessment

V.1.1.a. OSR/Segrate Electricity Domain

Regarding the evaluation of the different KPIs listed in D7.3, in the case of OSR's energy system, the measurement of the terms for each of the listed KPIs is straightforward since based on D6.1, the sources of heat and electricity for OSR and Segrate are provided entirely (100%) by the co-generator that is an entity owned by OSR. This plant is located nearby, which ensures a continuous supply of energy. This is therefore reflected in the self-sufficiency KPI which is at its highest level (100%) since the energy supplied is produced locally by the co-generator for both energy vectors. Regarding power and energy efficiency, calorimeter readings are not available for OSR and therefore no accurate values for these KPIs can be measured for heat essentially. Referring to the same deliverable D6.1, the co-generator operates entirely with natural gas combustion engines, resulting in RES and non-RES fractions as 100% non-RES electricity and heat production. Regarding the CO2 intensity KPI, its value can be determined by the performance of the gas and the nature of the combustion that takes place at certain times. Due to the data unavailability on natural gas performance and the amounts of heat consumed, the value of CO2 intensity could be calculated.

Since the usual list of key performance indicators cannot be reported, this section addresses the basic use case of electric vehicle demand response (EVDR) and for which 2 performance indicators are adopted. For this, it is necessary to define the components of the charging system at Segrate-OSR. The charging poles are 10 in number and are placed in front of the OSR hospital. These charging stations are mainly intended for the employees of the San Rafaele Hospital (OSR). Thus, half of the stations are permanently reserved for OSR employees. However, the other half can also be used by other EV users (e.g., incoming parents/friends of patients, occasional commuters at OSR or OSR University students, researchers).

In the following, we focus on evaluating the baseline for calculating the peak energy value.

ELECTRIC VEHICLE ELECTRICITY CONSUMPTION

Based on the very limited amount of data available, the only KPI that we can report on is the peak power (which is not included the list of D7.2). This KPI is an indication for the maxim um power consumed within a period T and can be written as follows:

$$\mathrm{Peak}^{\mathrm{T}} = \max_{\mathrm{i}}\{\mathrm{d}_{\mathrm{i}}\}^{\mathrm{T}}$$

Where:

- $\mathrm{Peak}^{\mathrm{T}}$ represents a peak value of electric power within a period T.

- $\max_i\{d_i\}^T$ represents the maximum power of the granular demands d_i registered within a period T

The idea behind the peak consumption KPI is that this is the value on which the utility operators implement the cabling and power grid and therefore it should be reduced as much as possible so that it is not exceeded, causing damage to the system. In addition, by reducing consumption at peak times, when the power grid is heavily loaded at certain times (peak load times), there is the slight chance for some mitigation of CO2 intensity levels, especially when the power grid is heavily loaded at times when no renewable energy is available in the national grid, which will ultimately result in more non-RES power plants being triggered in the system to meet the load and indirectly contribute to releasing more CO2 into the air.

1- Calculation of peak value for Segrate-OSR Energy Island (EV stations)

Based on the different records of EV charging sessions in the Segrate-OSR energy island shared by the energy managers, about 13 months of charging data are collected through direct communication of an Excel spreadsheet containing the details of the load and power input of each session. In total, about 2114 sessions are available based on which the maximum or peak power value is calculated. The sessions are spanning from 01-09-2021 until 20-10-2022. Appendix 0 Figure 48, and Figure 49 represent the different calculations realized on different granularities.

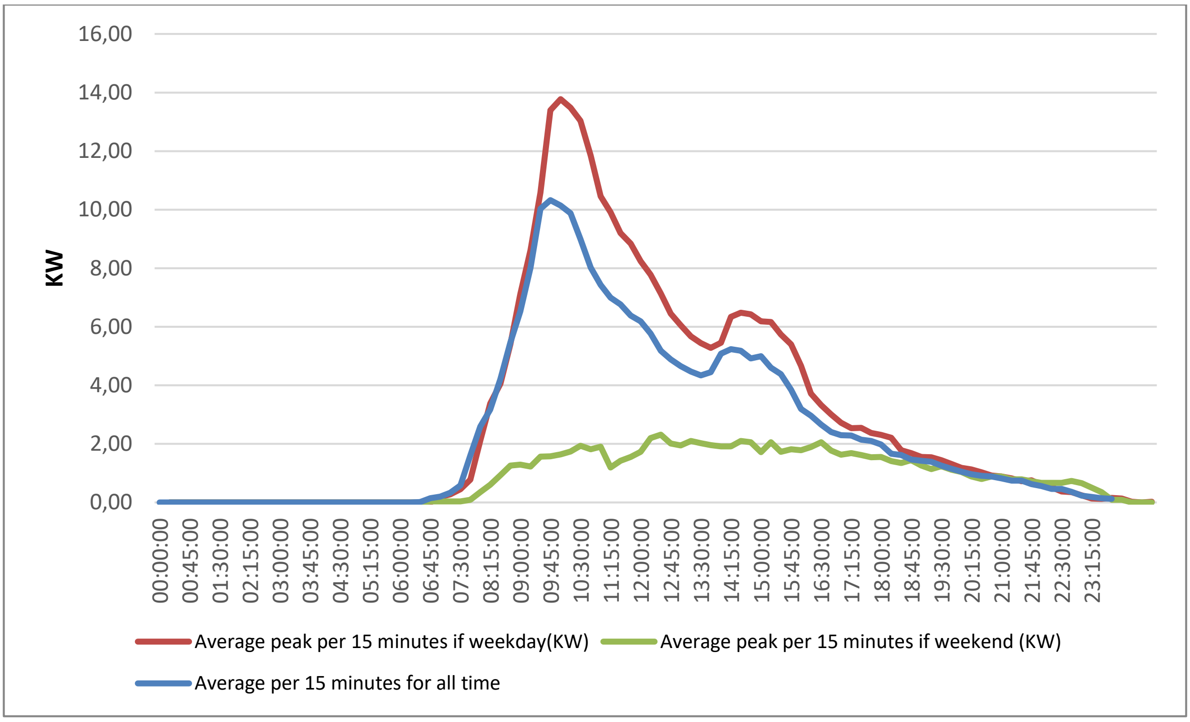

Figure 48: Average Peak Value per 15 Minutes

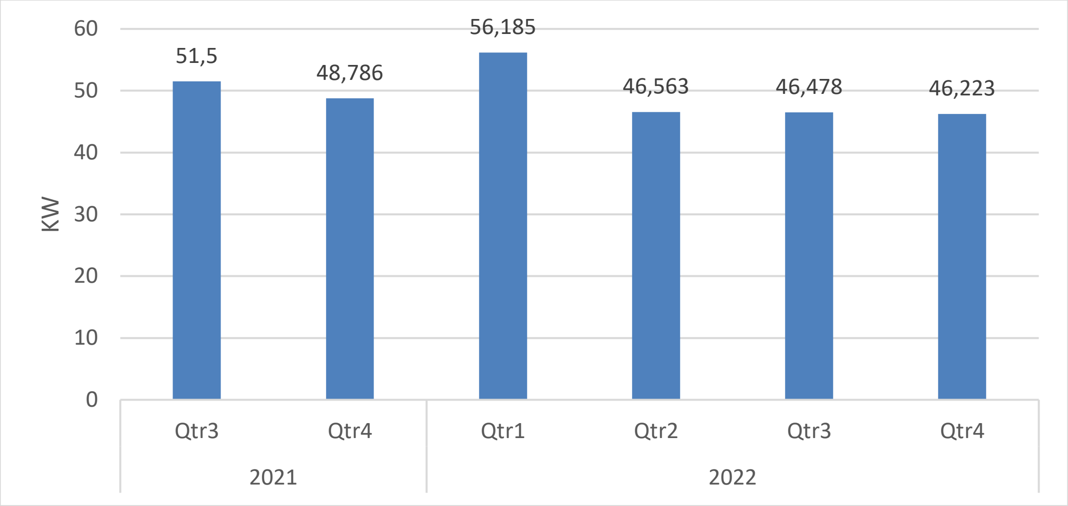

Figure 49: Quarterly Peak Value for EVs Charging Stations for Segrate-OSR Energy Island

Looking at Figure 48, the average compressed peak value in a day shows some typical patterns for EV users at OSR. Considering that this is a non-residential facility, the difference between the weekly patterns is evident, with the weekday pattern being much more pronounced than the weekend pattern. In numbers, based on the different sessions considered, the average peak value is about 13.77 KW for the period 10:00-10:15, which explains the peak arrival time of EV users (the morning shift). Another smaller peak is also recorded, averaging 6.48 KW for the 14:15-14:30 time slot over the 13-month period. This mini-peak may indicate a second shift for a second group of employees. However, on weekends, this value is only 2.31 KW, meaning that the number of EVs coming to charge on weekends is much lower than on weekdays.

Figure 49 reports the Kilowattage values for the aggregate EVs consumption on a quarterly basis (each quarter a year).

V.1.2. Social Baseline Assessment

For the baseline data of the social KPIs in Segrate, we collected data through an online survey distributed during a city and municipality-related event, where people from the area and Segrate were invited to participate. A total of 563 individuals participated in the survey, with 149 of them being residents of Segrate and therefore considered as relevant subsample.

The participants were asked to complete an extended version of the Social KPI questionnaire, which included questions related to their current level of participation possibilities and their attitude towards more active participation in the energy transition. Additionally, they were asked to imagine how a local community-based energy transition would be organized and whether it would be self-organized or organized by the local government. This information was collected to gain insight into the organization of a potential energy groups and projects within RENergetic. The items assessed are the same as in Poznan.

We report demographic data and statistics for both the overall sample and the Segrate citizen subsample. Note that some constructs, such as social identification and cohesion, were only assessed in the Segrate subsample.
The demographic data showed that approximately two-thirds of the overall sample were women, with a wide distribution across age categories. A similar trend was observed in the Segrate subsample, where there was a higher proportion of women, and most participants were middle-aged (between 40-59).

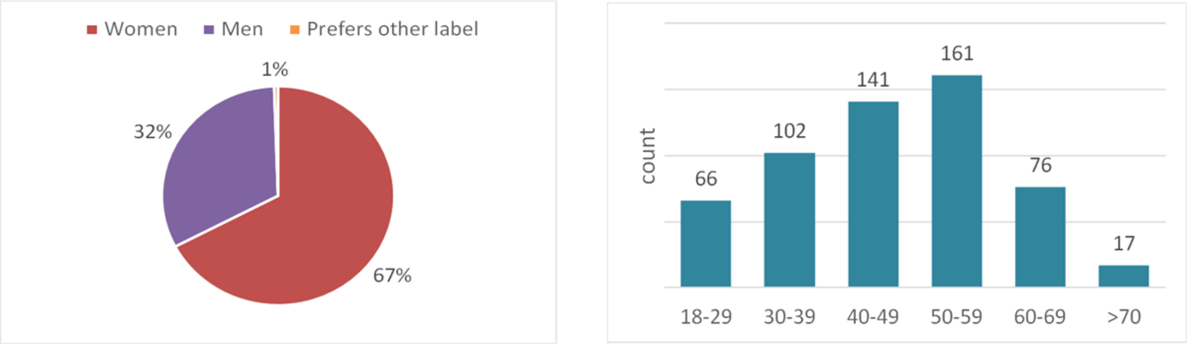

Figure 50: Gender and Age Distribution in the Overall Social KPI Sample, Segrate

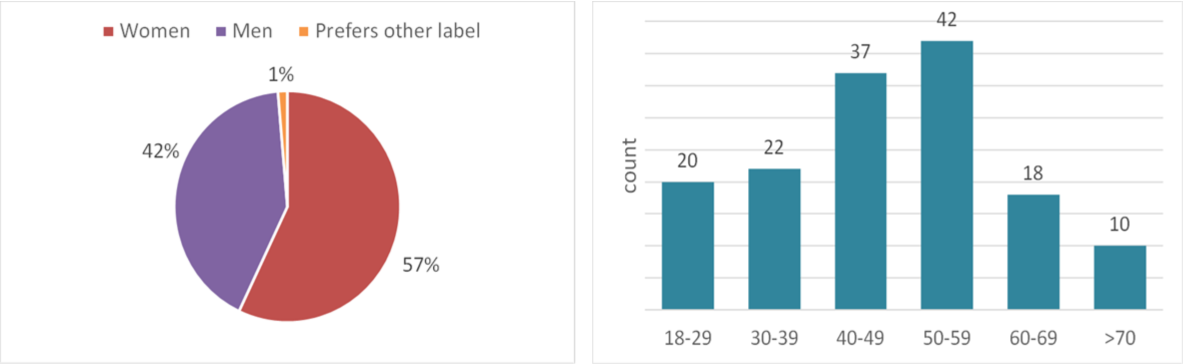

Figure 51: Gender and Age Distribution in the Social KPI Sample, only Segrate Citizens

The survey results showed high intentions for saving energy at both an individual and communal level. A positive attitude towards active participation was also observed, although participants reported low perception of current participation possibilities. There was a low level of satisfaction with the current communication of energy consumption, but a high desire to learn more about energy production and consumption in their neighbourhood or community. For the formation of energy-related groups and potential energy communities, participants expected support from public bodies, while the attitude towards self-organization was lower. The Segrate subsample showed a similar pattern to the overall sample, with a slightly higher perception of democratic participation.

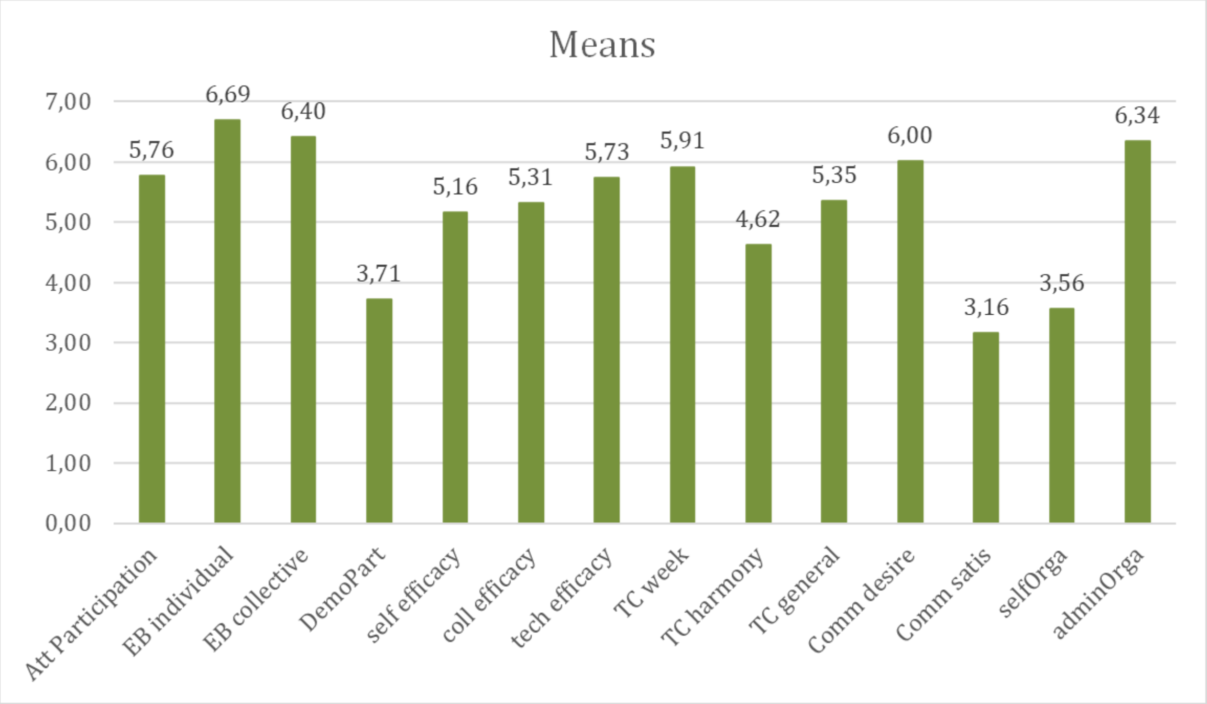

Figure 52: Descriptive Means of all KPIs Assessed, Baseline in Overall Sample

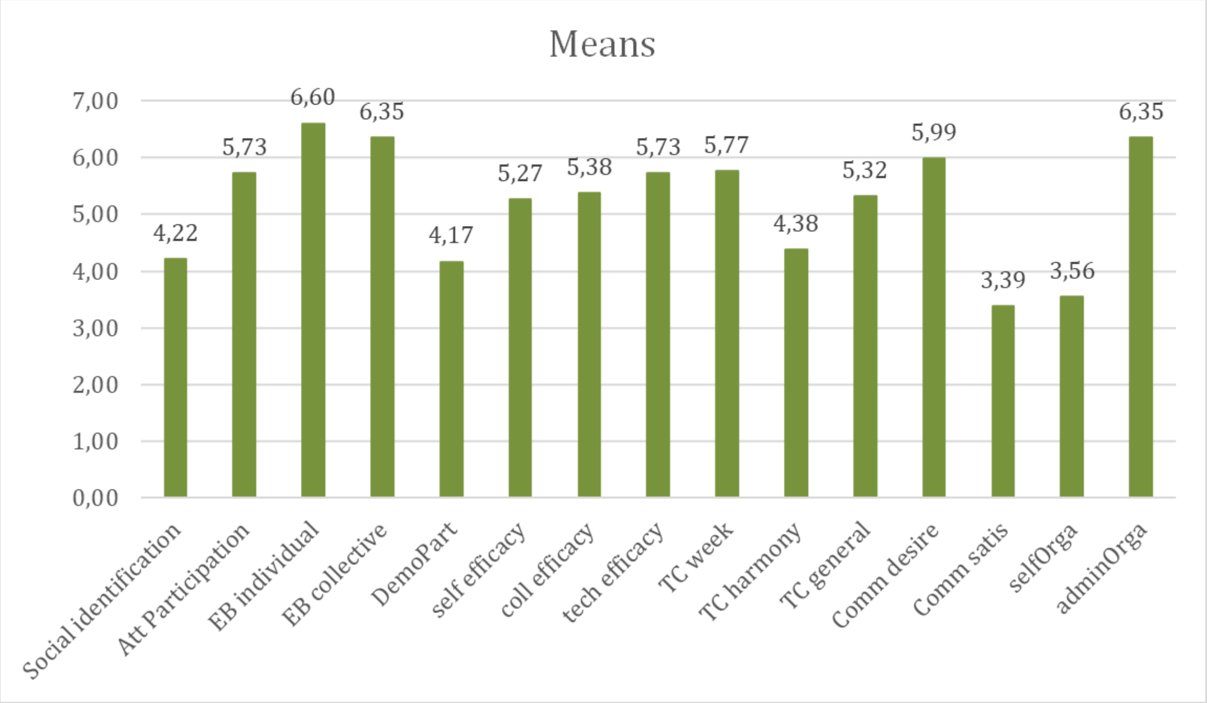

Figure 53: Descriptive Means of all KPIs assessed, Subsample Baseline

The following charts present the social Key Performance Indicators (KPIs) for both the entire sample and the sub-sample of Segrate citizens (with the exception of social identification, which was only recorded for the sub-sample). The distribution of social identification is relatively average, while the overall sample and the sub-sample exhibit a clear positive trend in self-efficacy beliefs and collective efficacy beliefs. Additionally, the attitude towards active participation is skewed towards the positive end of the spectrum. The patterns observed in the overall sample and the sub-sample of Segrate citizens are nearly identical.

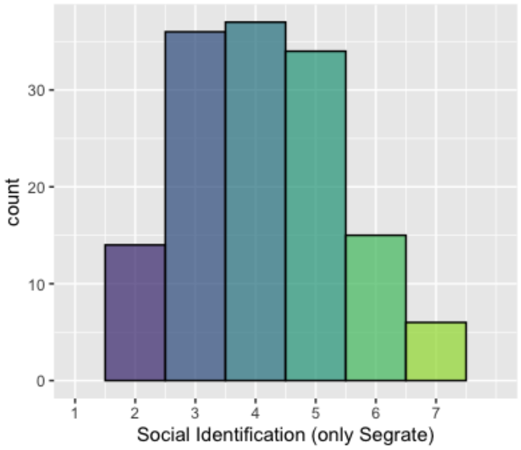

Figure 54: Social Identification Distribution, Segrate Subsample

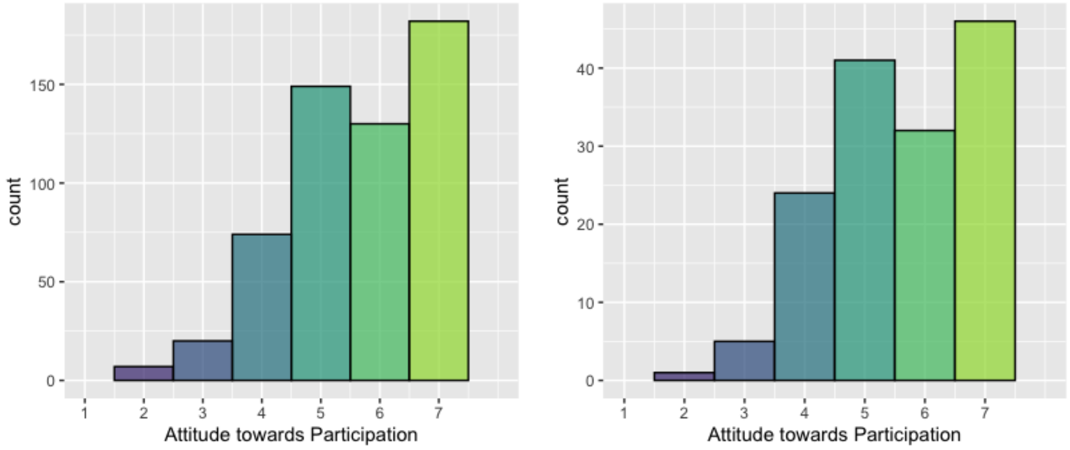

Figure 55: Distribution of Attitude towards Active Participation; Overall sample: left - Subsample: right.

Additionally, we again checked which constructs correlate with a positive attitude towards active participation in the local energy transition. Again, we find a high relevance of communal energy behaviour intentions and social identification with the local community on attitude towards participation, fitting to prior results and underlining the relevance of social concepts for driving the local energy transition and active involvement.

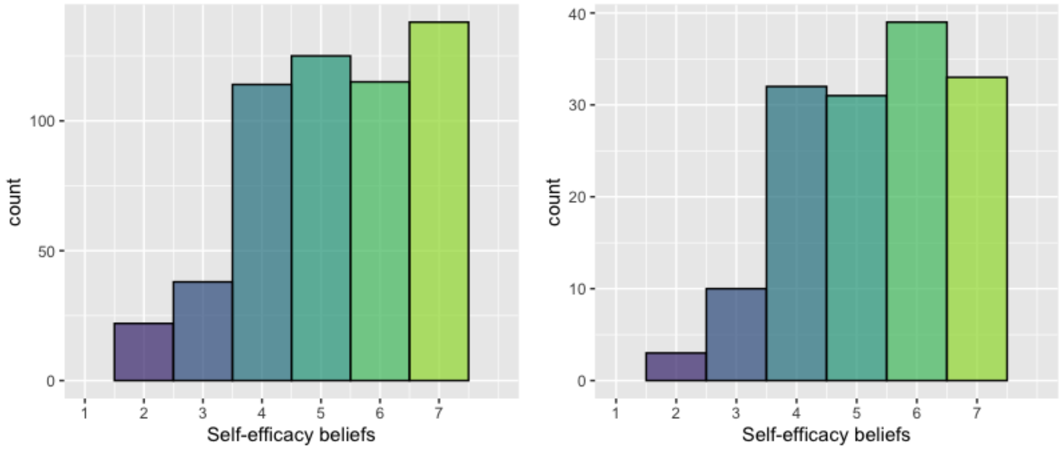

Figure 56: Distribution of Self-efficacy Beliefs in Segrate; Overall Sample: left - Subsample: right

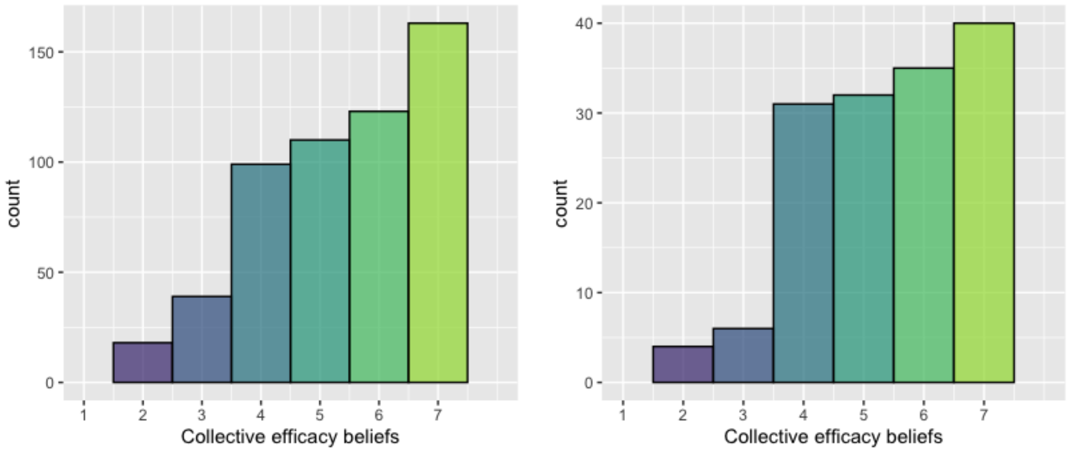

Figure 57: Distribution of Collective Efficacy Beliefs; Overall sample: left - Subsample: right.

V.2. Social Campaigning in OSR/Segrate

V.2.1. Activities and Results

The social epic activities in Segrate have primarily focused on creating awareness among citizens about the project, renewable energy technologies, and opportunities for participation in the energy transition. The activities have also aimed to identify motivators and barriers that can inform the technical design and future social actions within the project. Early interviews with representatives from OSR and Milano 2 helped to gain insights into the motivators and barriers for the Epics developed within RENergetic. To create a widespread awareness and engage a large group of people, open and public formats were utilized, such as the Energy Vision Game in front of the municipality and an information and interaction stand at a local town event. Workshops were also organized in collaboration with the municipality to facilitate participation and awareness, providing a platform for exchange and future project planning with interested citizens and companies.

V.2.2. Expected Impact

The baseline assessment of Segrate and OSR reveals a high level of importance placed on individual and collective energy behaviour by both citizens and OSR stakeholders. There is a clear inclination towards increased involvement and participation in the local energy transition, however, a low perception of the current opportunities to do so. One of the main objectives of the project is to raise the perception of opportunities for active engagement in the energy transition. The assessment also shows a high level of interest in learning more about energy consumption and production, with a low level of satisfaction with current communication of this information. To address this, communication efforts in the project are aimed at increasing satisfaction with communication and enhancing energy awareness. Additionally, community-oriented approaches and collective framing of actions are expected to strengthen social identification and collective efficacy beliefs within the Pilot site. As with the other Pilot sites, efforts will be made to ensure that the implementation of technical optimizations does not result in negative impacts on comfort, such as thermal comfort.

V.3. Heat Supply Optimization in OSR/Segrate

V.3.1. Activities

The Segrate (Milano 2) and OSR heat supply is 100% covered by the OSR co-generator plant, so in this case self-sufficiency is at a 100%. The co-generator operates on gas engines and there is 0% Share in RES. However, there is still room for improvement since the OSR co-generator often overproduces excess heat due to uncertainties in heat demand. By minimizing this overproduction, a technical and economic impact is expected. This will be reached by correctly predicting heat supply of OSR and Segrate with machine learning models and afterward feeding the outputs of the models into an optimization (linear programming) algorithm to correctly plan and therefore minimize the activation times and load of the co-generator.

V.3.2. Expected Impact

There is an expectation of a 2% reduction in **CO2 intensity** as one component of the ***technical impact***, due to the reduced gas consumption on the co-generator's methane engines and the co-generator's auxiliary services, which produce superheated water (steam) and are therefore very energy intensive. Similarly, the **energy potency** and **energy efficiency** will see an increase of 5%. Based on Energy Manager expert judgment in OSR the 2% reduction in CO2 intensity would affect in particular the Dibit 2 and Iceberg New building separately in OSR. This is where machine learning forecasts and linear programming are expected to impact most. The very same energy managers already know that the uncertainty in heat demand unbalance supply production of an estimated 2 to 5 % overall. Furthermore, it is estimated that energy potency and energy efficiency would increase of an estimated 5% in the total OSR buildings overall (i.e., Dibit1, Dibit2, Dimer, Iceberg buildings together). This estimate is based on OSR energy managers understanding of the RENergetic services.

It is expected that a perfect fit of heat supply and demand will not be reached, because of the multi energy vector nature (heat and electricity) of the co-generator. The predictive capacity to right-fit the OSR heat supply to the best expected OSR heat demand (via forecasting) is key to minimise unnecessary heat overproduction and costly gas consumption by the co-generator itself. Also, this optimisation to supply a quantity of heat that is fit to the OSR consumption does maximise indirectly the planned volume of MWh heat to be given to Milano 2 with no imbalances as well, especially in winter times. Therefore, the ***economic impact*** affects the KPI **energy sold to the grid** with an increase of 2-6%, depending on the heat and electricity demand.

V.4. Electricity Supply Optimization in OSR-Segrate

V.4.1. Activities

The epic electricity supply optimization for Segrate is similar to the epic heat supply optimization, since the co-generator is responsible for supplying both heat and electricity. One key difference is though that if the co-generator underestimates electricity demand, it is forced to buy electricity from the national grid. On the other hand, the co-generator is able to sell excess electricity to the grid. Therefore, there is a technical and economic impact expected.

V.4.2. Expected Impact

According to the OSR energy managers the expected technical impact to properly forecast the total OSR demand will be translated into a reduction CO2-intensity by an estimated 2% overall in energy production. This is due to a minimization of imbalances between the planned electricity supplies for OSR and grid and the real OSR demands. On the technical side this will be reached by a week ahead prediction and planning. This estimate refers to the total OSR consumption prediction. With the same reasoning there is an expected increase of 5% of the energy efficiency indicator and possibly an increase in the energy potency indicator. All estimates are in need for experimentations and verifications according to the OSR Energy Managers. It is an estimate suggested by them considering a possible energy efficiency improvement by the RENergetic technical solution.

According to the OSR Energy Managers, selling to the grid the planned amount of electricity (according to the weekly-ahead trading plan), would result in an increased (2-6%) of energy sold (per quarter). This is possible by avoiding imbalances in the weekly selling plans mainly due to incorrect OSR demand predictions. Even in this case, AI Machine Learning methods add values to the process. This is due to the following situation: In case the planning to sell electricity to the national grid is met every week at 100%, it directly translates into planned revenues by billing the national grid. Currently, on average, the plan is reliable by 95% only with and approximately 5% deviation from the plan to sell electricity. This is called "unbalance" and the Energy managers trust that the RENergetic AI models can help prevent such unbalance and return said economic benefit. This is based on the assumption that the AI forecasting models will allow a better prediction of the real energy demand in OSR and thus they improve the plan to sell to the grid with less "unbalances".

V.5. Electric Vehicle Demand Response in OSR-Segrate

V.5.1. Activities

Since parked electric vehicles are stationary for a longer time than a complete charging process requires, there is an opportunity to reach a supply and demand fit, by shifting the charging to time frames with low demand (peak shifting). This would reduce the need to activate additional gas boilers of the co-generator for electricity production and therefore have a measurable technical impact.

There are two scenarios which will be performed with around 30 recurrent CS users. The first scenario, called manual demand response, will be run by asking charging station users to manually shift their charging times. In particular, OSR has 5 private CS for OSR personnel and 5 public CS. The private CS should be used to supply information about potential occupation for the subsequent 24 hours to the affected staff members, asking them to refrain from charging in order to reduce or avoid power peaks. Again, here the ultimate goal is not to increase REN usage but to reduce CO2 emissions due to an optimized alignment of power production and supply at the CHP.

The second scenario, called automatic demand response will be conducted by controlling the charging stations automatically through ICT infrastructure. For this second method the users are asked to insert a point in time, at which the car will be fully charged. In this scenario, the peak shaving process value will be reached by an AI Reinforcement Learning algorithm. This AI method will deal with data about predicted occupancy rates and with a full reinforcement learning approach to minimize peaks and shift them whenever necessary in time. The smart scheduling algorithms will be tested via real in filed experimentations in mid-2023 onwards.

V.5.2. Expected Impact

The expected technical impact will be a reduction of any unnecessary electricity overproduction for the overall CS grid and therefore a reduction of CO2-Intensity by an estimated 5% (on average per Quarter). This is supposed to be achieved both via the “manual” as well as the “automatic” scenarios, i.e., both the RENergetic solution of peak shaving capacity in combination with social recommendations. In fact, both scenarios (social recommendations and AI intelligence) are designed to force reduction of max and average peak values which, in turn, are estimated to impact reduction of average CO2 emissions. The energy efficiency indicator is estimated by OSR energy managers to be increased by 2%, due to such better utilisation of the co-generators supplied energies. All estimates are conservative estimates based on expert judgement from ESCO energy Managers in OSR about solutions that have never been tested on the CS grid in OSR. It is a qualitative call by informed energy managers by profession.

VI. IMPACT ASSESSMENT OF RENERGETIC VIRTUAL PILOT ACTIVITIES

VI.1. Modeling and other Activities

The virtual pilot is used to run experiments that simulate dynamic behaviour of smart converters or other automatically controllable devices. A schematic representation of the grid scenario is presented in Figure 58. The energy island is sized to have a load of 1.5 MW. This aligns roughly with the off-peak load at the Poznan Pilot in 2021. As this is the off-peak load, a short time increase in consumption is plausible. The primary load supply is modelled to be provided by a synchronous generator outside of the energy island. Its actual power contribution is measured inside the energy island after the transformer and therefore excludes potential conversion losses. An assumption is made that there is no initial power supply from the smart converter-interfaced battery or PV system. Line losses are assumed to be include as part of the 1.5 MW load. As a consequence, the transmission of energy from the synchronous generator resp. the smart converter to the load is modelled to be lossless.

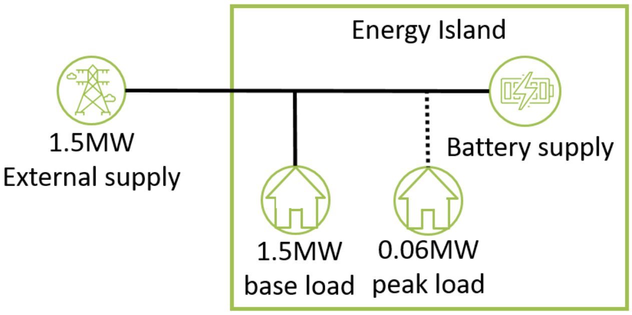

Figure 58: Simplified Schematic Representation of Investigated System in the Virtual Pilot

The goal of this study is to investigate the momentary self-sufficiency KPI when a frequency disturbance occurs[11]. Frequency disturbances occur when the load connected to the grid suddenly increases. Without the contribution of an energy source in the energy island, the synchronous generators in the upstream grid will react to the resulting sudden shift in resistance of the grid. First, the inertia energy stored in their rotating masses will be released and next select synchronous generators will increase their power output proportional to the frequency drop. This will stabilize the grid to an intermediate new stable frequency, which is usually still less than the nominal frequency of 50 Hz. The new settling point is called the transient frequency. After the load normalizes again, the synchronous generator ramps down and the grid can return to its nominal frequency. This process of stabilizing the frequency after the inertial reserves are consumed is done by so-called frequency containment reserves. The proportional ramping needs to be at least linear and reach its maximum value when the frequency reaches a value of 49.8 Hz. Provision of inertial reserves and primary frequency reserves are the most critical for future smart grids due to the fast reaction times they require (ENTSO-E 2021). To focus on these reserves, the time horizon is constrained to the period until frequency containment reserves are replaced by automatic and manual frequency restoration reserves, i.e., to 30 seconds after the disturbance.

If distributed energy resources are sufficiently large or if they are collected into a pool of resources by an aggregator, they may also contribute their share to the frequency containment reserves frequency control process. Part of such a sudden load increase might reside within

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[11] https://www.next-kraftwerke.com/knowledge/frequency-containment-reserve-fcr

an energy island. In that case, the energy island would depend on energy provided by the outside grid and therefore, be less self-sufficient. Providing a contribution to the frequency containment reserves may then improve this short-term self-sufficiency. To evaluate the impact of these reserves a parametric study is presented in this deliverable.

The load increase is 4% of the base load of 1.5 MW or in other words 60kW. The rotational inertia stored in the synchronous generator is set to a sufficiently high value of 5 seconds. The first parameter that is varied in the simulation is the maximum ramping of the synchronous generator. The power of the synchronous generator originates from an external power source supplying a given amount of torque. The base value of this torque is selected to ensure a power output matching the 1.5 MW load. This torque can then, for example, be increased in a water turbine by opening the water valve further or increasing the gas flow in a gas generator. The maximum torque increase is set to 20%, 10% and 5% to model a strong outside grid, a weak outside grid and insufficient outside resources respectively.

The battery is sized proportional again to the size of the load peak. The energy stored in the battery needs to be reserved in two manners. On one hand, there must be sufficient energy stored in the battery at all times. On the other hand, there must be sufficient capacity to inject this energy through the smart converter. As the battery would also operate as part of self-consumption optimization or some energy price driven scheme, solely using the battery for frequency containment reserves seems unrealistic.

The targeted KPI is the self-sufficiency KPI, which requires total energy values for the energy consumed over the time interval, the excess energy provided locally, and the energy provided by the external source as well as energy losses. Due to our modelling assumptions, the energy losses are already part of the consumed energy. Therefore, this part of the summation is dropped. The energy consumed is comprised of the 1.5 MW base load and the 4% load peak. The self-sufficiency in providing the base load solely depends on the modelling assumptions. If it is assumed, that this energy is supplied from the outside grid, self-sufficiency is automatically always very low. If it is assumed that this energy is supplied from the side of the energy island, self-sufficiency is automatically higher than 96%. To avoid this direct dependency on the modelling assumptions rather than the behaviour of resources, this base load is excluded from the computation of self-sufficiency. Instead, only the power consumed by the additional load is considered as the consumed energy.

These modelling assumptions lead to 12 scenarios, which are reported in subsections VI.2.1.a. and VI.2.1.b. split according to the weak and strong scenario. Table 11 summarizes the momentary self-sufficiency in the different scenarios over a period of 30 seconds. Overall, the self-sufficiency is increasing with the increase in battery size. However, there is a significant difference in the importance of the battery comparing the strong to the weak scenario.

Table 11: Self-sufficiencies for Different Battery Sizes and Generator Ramping

Self-sufficiency	20%	10%	5%
Battery Size \ Generator Ramp			
0%	0.00%	0.00%	0.00%
10%	3.50%	6.47%	11.53%
20%	6.77%	12.02%	20.78%
30%	9.74%	16.78%	28.41%
40%	12.54%	21.06%	34.74%
50%	15.29%	25.02%	40.13%

VI.2. Expected Impact

The data of the simulation is recorded with a sampling frequency of 0.0001 seconds. The smart converters operation uses high frequency switching to perform phase wave modulation to generate an accurate power output. This switching is noticeable in the collected data as a noise, leading to an oscillation around the actual values. The overall conclusions drawn from the results are not affected by this as the energy remains the same even if such small oscillations are present, i.e., the peak above the average value fills the dip below the average value. Thus, the figures present in the following use 1 second averages of the power injection to present a clearer view on the data.

The self-sufficiency is computed based only on the additional energy. These energies are determined by considering the power measurements taken at each simulation step and multiplying them with the duration of said simulation step, i.e., the power is assumed to be constant during each simulation step and can therefore be integrated in this way to determine the energy.

VI.2.1.a. Strong Outside Grid

The results for the strong grid scenario are shown in Figure 59 and Figure 60. Due to the strong ramping of the synchronous generator the grid remains in a rather stable condition even if the disturbance occurs. The minimal frequency drop is 49.88 and the transient frequency is 49.95. These values are roughly the same for all sizes of the battery injection.

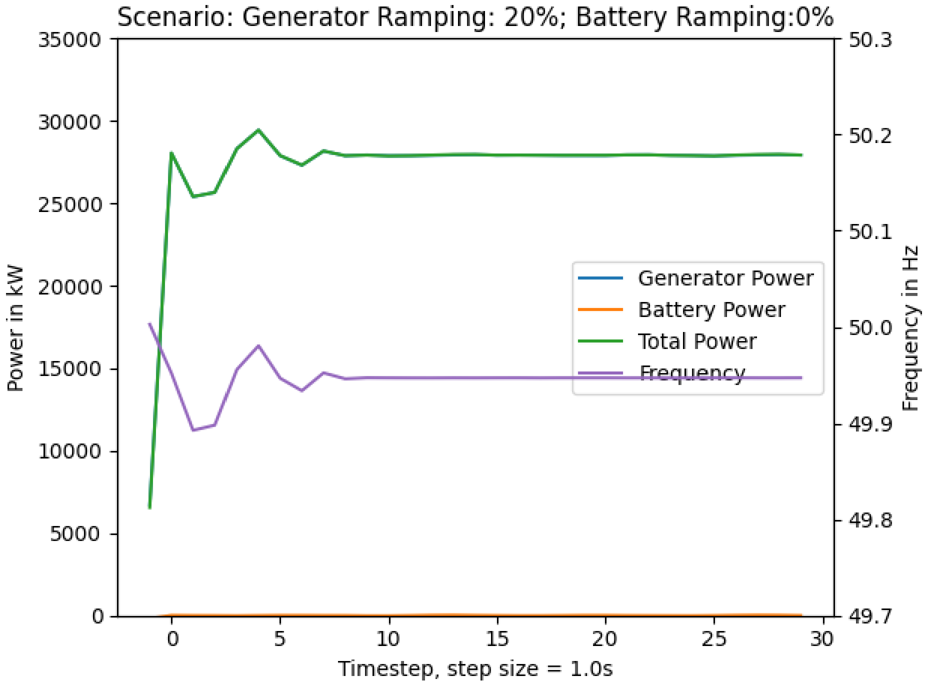

Figure 59: Generator Ramping Set to 20%, Battery Provides 0% of Peak

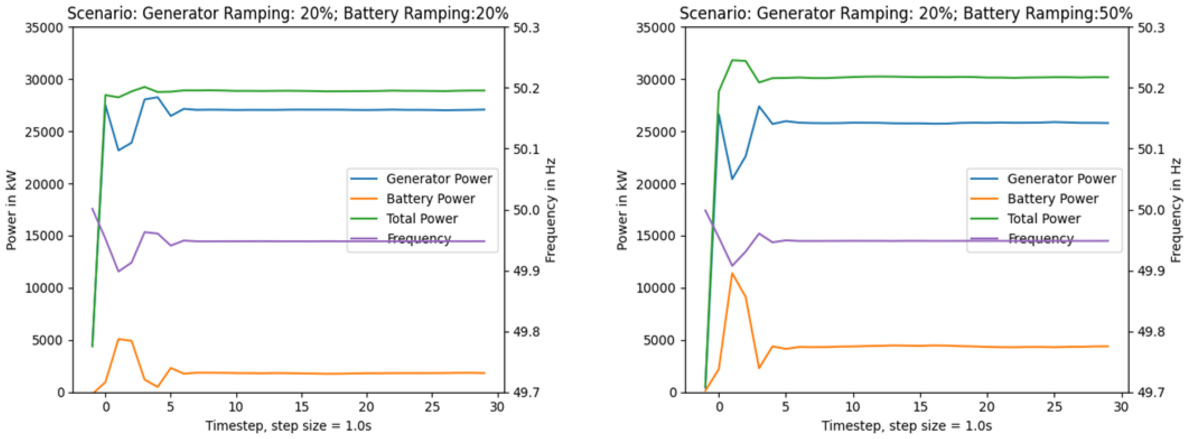

Figure 60: Generator Ramping set to 20%, Battery Provides 20% (left), 50% (right)of Peak

Thus, the impact of the battery injection on the frequency and therefore on the total power output by the synchronous generator is rather small due to these circumstances as well. The baseline for the self-sufficiency metric is given by the scenario in Figure 59with no battery injection. The power provided by the synchronous generator shows a typical pattern, whereas an immediate reaction to the frequency drop the inertial energy in the generator is discharged. This is the reason for the sharp peak at t=0 when the frequency disturbance occurs. At the same time the battery and the synchronous generator start ramping up their frequency containment reserves as a reaction to the frequency drop. The generator is then speeding up again which explains the short overshoot before the transient frequency is reached.

VI.2.1.b. Weak Outside Grid

In the weak grid scenario, the maximum ramping of the synchronous generator was halved. The results for the different battery sizes are shown in Figure 61 and Figure 62, respectively. The reduced ramping of the generator leads to a larger frequency drop with a frequency nadir between 49.81 - 49.86 Hz.

The larger frequency nadirs are observed for a larger available injection of the battery. Further, the batteries power injection is able to shorten the period until the transient frequency is reached significantly from about 12 seconds in the no battery scenario to only slightly more than 5 seconds with the 50% battery scenario. Yet, the transient frequency remains roughly the same at 49.93 Hz. Again, leading to an overall increase in the energy injected in the system while the battery is unable to reduce the synchronous generators power injection in this scenario. This effect of increasing the duration of the transient period is also the reason why the self-sufficiency is not growing linear with the size increase of the battery.

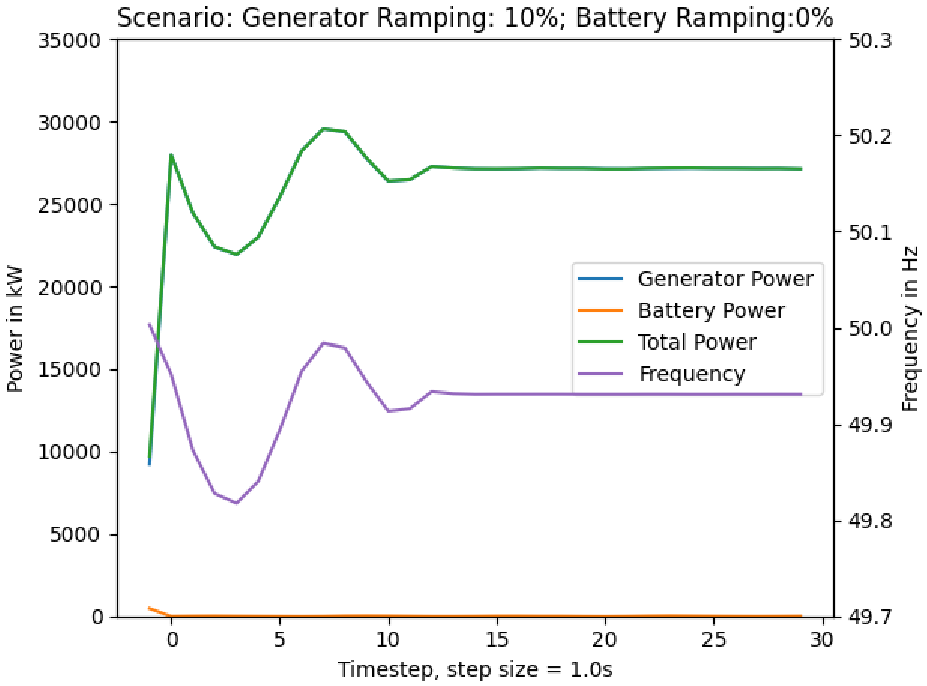

Figure 61: Generator Ramping set to 10%, Battery Provides no Power

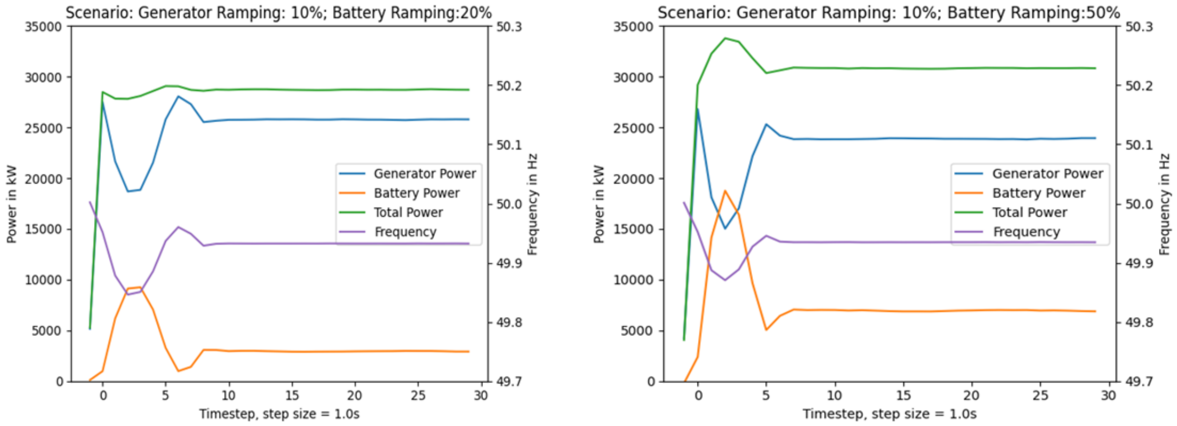

Figure 62: Generator Ramping set to 10%, Battery Provides 50% of Peak

VI.2.1.c. Insufficient Outside Grid

The results for the insufficient grid scenario are shown in Figure 63 and Figure 64 . Figure 63 again shows the baseline for the self-sufficiency metric with no battery injection. In this scenario, the frequency curve shows a stronger initial drop as the synchronous generator is not ramping up its power output fast enough. This leads to a stronger fluctuation of the frequency compared to the other scenarios.

A second effect which is most noticeable in this scenario is the impact of the battery. Due to its relative fast reaction, it is able to limit the frequency drop quicker than the synchronous generator. This leads to a higher frequency nadir, consequently less increase of the provided torque of the synchronous generator and a lower overshoot. Overall, the grid is more stable the larger the included battery is. This quick ramping with a high energy injection improves the self-sufficiency metric as a result.

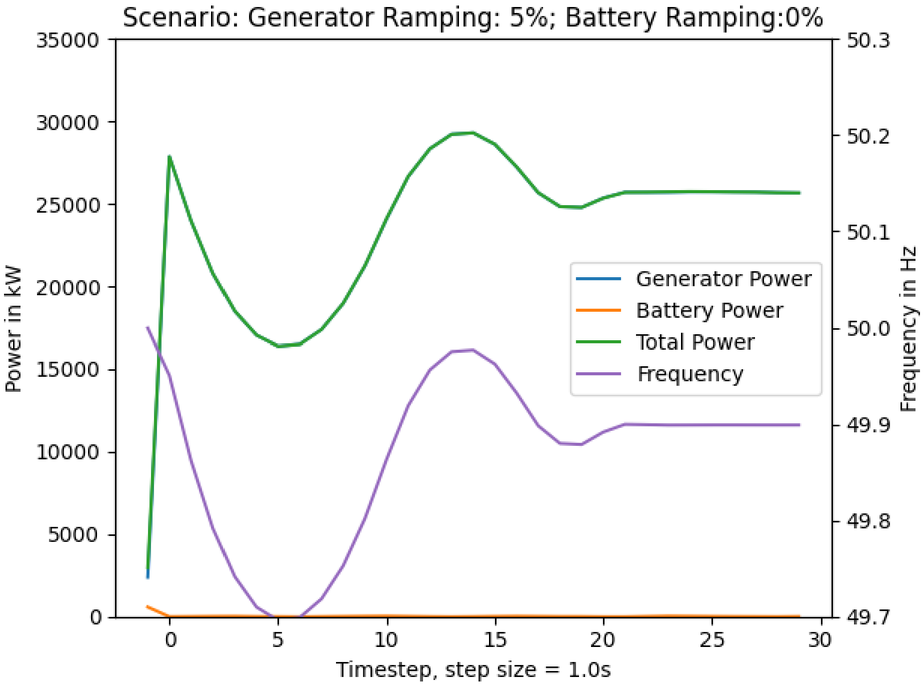

Figure 63: Generator Ramping set to 10%, Battery Provides 50% of Peak

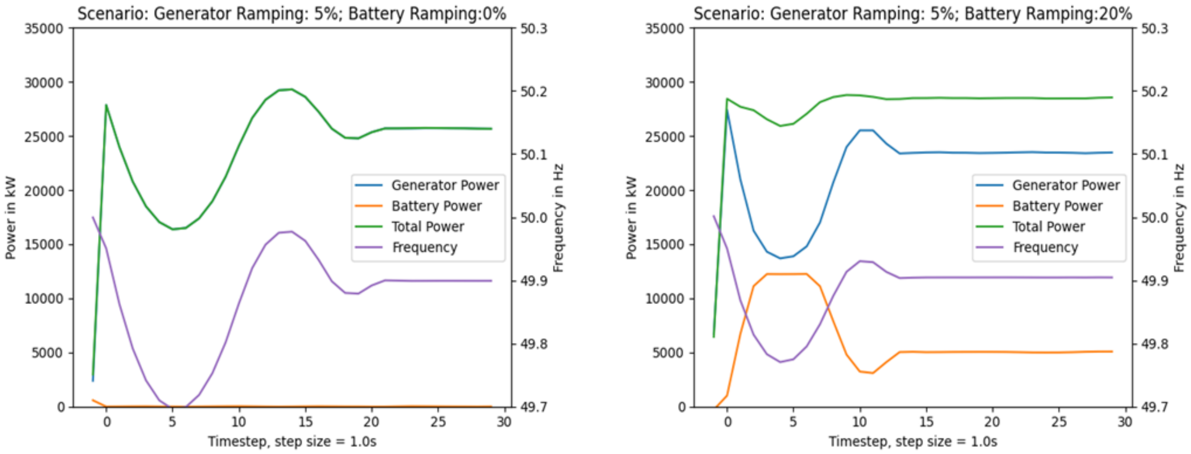

Figure 64: Generator Ramping set to 5%, Battery Provides 50% of Peak

VI.2.1.d. Interpretation of Results

Impact on self-sufficiency is weak if the outside grid is providing more than sufficient reserves. As synchronous generators are disconnected and the grid is integrating more renewables, the strength of the outside grid is expected to weaken. In this scenario batteries can provide a significant contribution to self-sufficiency depending on their sizing. This highlights the importance of considering use of distributed resources for grid stability services for the success of the energy transition.

These results show further that using the battery for the provision of frequency containment reserves can increase the momentary self-sufficiency of the energy island during a frequency disturbance. An important aspect to keep in mind is that the energy stored in the battery needed to be charged at some time before the disturbance and eventually should be recharged after the disturbance. Essentially, the operation of the battery is only capable of shifting the time of use of energy. Therefore, to realize these momentary gains in self-sufficiency into a real increase of self-sufficiency over a whole month/quarter/year, there need to be moments were recharging the battery can be done without impacting self-sufficiency, i.e., without decreasing the energy exported to the grid and without importing more energy from the grid. A straightforward example would be periods during which generation inside the energy island would have to be curtailed due to excess generation in the grid while demand inside the energy island and the grid is low. Thus, the next step is to evaluate the impact the short-term self-sufficiency improvement can have on other KPIs when combining the simulations with data collected over a longer timeframe.

From an economic point of view, there are two aspects not covered by this simulation. First, the batteries main task is to operate for self-consumption maximization or for revenue maximization by energy trading. Both functions are what provide the main revenue streams of the battery. Therefore, provision of frequency containment reserves should not have a negative impact on these functions. A possibility to benefit from these frequency containment reserves is to determine the optimal operation schedule in advance based on forecasts and then identify the moments in time where the batteries capacity could be used for frequency reserves without affecting the other functionalities. In this way, an additional revenue stream could be created by selling this service on the balancing markets. Thereby, decreasing the time until the breakeven point is reached and improving the rentability of the battery combined with a smart converter. This combination with long term scheduling can be investigated when joining this analysis with the multi-vector optimization realized by the global optimizer. Results from such analysis are set to be included in the final version of the impact report in deliverable D7.5.

VII. SUMMARY

This deliverable D7.3 is the first to attempt an impact analysis, after more than half of the project duration has passed. This is a point in time, where the project tasks have been concretized and poured into a set of epics describing the main components of the future RENergetic system. These main components include both the technical optimization and adaptation elements which for the cases where end-users, i.e., the EI inhabitants, are involved always integrate social-science measures supporting the application of any technical component.

For all epics “Energy Reduction Campaign/Social Campaigning”, “Heat Supply Optimization”, “Local Waste Heat Optimization”, “Heat DR”, “Electricity Supply Optimization”, “Electricity DR”, and “EV DR”, technical design and implementation tasks, e.g., creation of algorithms or data collection processes, have started and for most, first internal tests have been made. However, for some of them that has not been done on the level of epics as the basis for the main output of the project, but rather on an intermediate level, as e.g., creating the machine learning approaches for forecasting supply and demand volumes. This is why at this intermediate stage, most of the impact analyses are founded on the experience with these first two project years and present “expected” impact instead of the results from tests of the final components.

Exceptions are for the social impact of the HeatDR epic in Ghent, where user experiments have been completed, and for the technical impact of the application of the multi-vector analyser in Ghent as well as an economic analysis of the expansion of PV installations, also in Ghent. Ghent activities and real impact analysis could start early compared to the other pilots due to the comparably easy access to data of an already existing and harmonized monitoring system. In Poznan the same applies to the data centre heat data, which is why, also from an economic point of view the “Local waste heat optimization” epic could be explored in detail with a good data basis for a business impact analysis with Veolia. And finally, the virtual pilot in Passau was set up in time too also offer first results for the impact analysis of the epic “Electricity DR”.

The next and final version of the impact analyses in D7.5 will build on the processes and structures derived in the presented deliverable D7,3, to then offer a “final impact analysis” which will then show to which degree the expectations raised in D7.3 will be fulfilled by finalizing and testing the components of the RENergetic system.

VIII. APPENDIX

VIII.1. Ghent: Technical Baseline Assessment – Heat

The calculated figures are gauges enabling the tracking of some technical aspects of the energy island such as the greenness levels through the renewable based heat share in the overall heat provision, fossil fuel based heating, and CO2 intensity measures, heating security status at a certain moment in time based on the collected data through energy self-sufficiency KPI, and the energy capacity to achieve more steps towards its envisioned environmental and independency targets through energy potency. Besides, the levels of the infrastructure performance with regards to losses and monitored provision versus consumption through heating efficiency by measuring the levels of losses compared to what is actually being supplied by any heat sources.

In Table 12 the monthly values of each KPI are revealed for the study period spanning from January 2021 until January 2022. Based on the observations, there are several correlations between the technical KPIs since they determine, in some circumstances, each other based on the available data. For example, the RES Share and non-RES are two KPIs for the same concept and energy self-sufficiency is close to the KPI of RES share. Concerning the energy potency indicator, it is describing the ability to reach a certain level of achieving the stability and ultimate goal of being self-sufficient and neither overproducing nor underproducing any type of energy. The energy efficiency reveals the aptitude of the system to transport in a performant way the heat within the energy island. For the energy savings, it assesses the monthly pattern of consumption in Table 18. The trend shows a significant monthly fluctuation of all the KPIs which means that there is an interesting monthly impact and indirectly a quarterly effect (season wise). The values of the KPIs depend on several variables and most interestingly the levels of consumption, RES-sources provision, and also the management of the heating network.

Table 12: Monthly Values of the Defined KPIs (CO2 Intensity, RES Share, Fossil Fuel Share, Energy Potency, Energy Savings, and Energy Efficiency) (for Ghent-New Docks Energy Island)

	CO2 intensity (gCO2/kWh)	RES share (%)	Fossil fuel share (%)	Energy Self-sufficiency	Energy potency	Energy Savings (%)	Energy Efficiency (%)
January-21	157.2405	7.02%	92.98%	7.02%	0.952		93.38%
February-21	158.1299	9.90%	90.10%	9.90%	1.001	21.16%	88.23%
March-21	146.1464	17.96%	82.04%	17.96%	0.910	11.19%	85.27%
April-21	146.1658	19.49%	80.51%	19.49%	0.910	19.38%	83.42%
May-21	141.7216	24.75%	75.25%	24.75%	0.997	27.30%	70.44%
June-21	128.6354	39.95%	60.05%	39.95%	1.031	38.79%	52.73%
July-21	163.4725	23.39%	76.61%	23.39%	1.197	8.58%	50.67%
August-21	141.1403	33.84%	66.16%	33.84%	1.103	-0.85%	50.44%
September-21	154.0184	26.46%	73.54%	26.46%	1.137	-2.05%	53.29%
October-21	147.7762	19.15%	80.85%	19.15%	1.012	-70.70%	71.83%
November-21	157.3267	13.35%	86.65%	13.35%	0.957	-69.55%	86.88%

December-21	155.3573	10.57%	89.43%	10.57%	0.913	-67.65%	94.78%
January-22	153.9481	12.68%	87.32%	10.16%	0.892	13.26%	97.07%
Average (annual)	**150.08**	**19.88%**	**80.12%**	**19.69%**	**1.001**	**-5.93%**	**75.26%**

The calculation in Table 12 are based on the numbers shared by the energy managers for Ghent-New Docks Energy Island and are classified per KPI. In each of the following tables, the terms and calculated values per month for each KPI in the defined list are shown.

Table 13: Thermal Energy Self-Sufficiency KPI Calculation and its Terms (for Ghent-New Docks Energy Island)

Energy self-sufficiency	$E_{SS}^{T}(\text{heat}) = \frac{E_{Consumed}^{T} - E_{missing}^{T} + E_{excess}^{T} - E_{loss}^{T}}{E_{Consumed}^{T} + E_{loss}^{T}}$				
Terms	$E_{Consumed}^{T}(\text{kWh}_{th})$	$E_{missing}^{T}(\text{kWh}_{th})$	$E_{excess}^{T}(\text{kWh}_{th})$	$E_{loss}^{T}(\text{kWh}_{th})$	Values
Jan-21	151286.00	143533	0	10731.00	7.02%
Feb-21	112697.00	112778	0	15034.00	9.90%
Mar-21	96735.00	86471	0	16709.00	17.96%
Apr-21	76297.00	68097	0	15161.00	19.49%
May-21	46836.00	46612	0	19654.00	24.75%
Jun-21	21462.00	22721	0	19238.00	39.95%
Jul-21	18851.00	26173	0	18355.00	23.39%
Aug-21	18927.00	22804	0	18596.00	33.84%
Sep-21	20408.00	25645	0	17886.00	26.46%
Oct-21	46957.00	47739	0	18411.00	19.15%
Nov-21	96295.00	91491	0	14539.00	13.35%
Dec-21	176110.00	160015	0	9705.00	10.57%
Jan-22	156459.00	138983	0	4720.00	10.16%

Table 14: Thermal Energy Efficiency KPI Calculation and its Terms (for Ghent-New Docks Energy Island)

Energy Efficiency	$E_{eff}^{T} = 1 - \frac{E_{losses}^{T}}{E_{Consumed}^{T} + E_{losses}^{T}}$		
Terms	$E_{Consumed}^{T}(\text{kWh}_{th})$	$E_{loss}^{T}(\text{kWh}_{th})$	Values
Jan-21	151286.00	10731.00	93.38%
Feb-21	112697.00	15034.00	88.23%

Mar-21	96735.00	16709.00	85.27%
Apr-21	76297.00	15161.00	83.42%
May-21	46836.00	19654.00	70.44%
Jun-21	21462.00	19238.00	52.73%
Jul-21	18851.00	18355.00	50.67%
Aug-21	18927.00	18596.00	50.44%
Sep-21	20408.00	17886.00	53.29%
Oct-21	46957.00	18411.00	71.83%
Nov-21	96295.00	14539.00	86.88%
Dec-21	176110.00	9705.00	94.78%
Jan-22	156459.00	4720.00	97.07%

Table 15: Thermal Energy Potency KPI Calculation and its Terms (for Ghent-New Docks Energy Island)

Energy Potency	$\mathrm{E}^{\mathrm{T}}_{\mathrm{Pot}} = \frac{\mathrm{E}^{\mathrm{T}}_{\mathrm{missing}} + \mathrm{E}^{\mathrm{T}}_{\mathrm{excess}} + \mathrm{E}^{\mathrm{T}}_{\mathrm{losses}}}{\mathrm{E}^{\mathrm{T}}_{\mathrm{Consumed}} + \mathrm{E}^{\mathrm{T}}_{\mathrm{losses}}}$				
Terms	$\mathrm{E}^{\mathrm{T}}_{\mathrm{Consumed}}(\mathrm{kWh}_{\mathrm{th}})$	$\mathrm{E}^{\mathrm{T}}_{\mathrm{missing}}(\mathrm{kWh}_{\mathrm{th}})$	$\mathrm{E}^{\mathrm{T}}_{\mathrm{excess}}(\mathrm{kWh}_{\mathrm{th}})$	$\mathrm{E}^{\mathrm{T}}_{\mathrm{loss}}(\mathrm{kWh}_{\mathrm{th}})$	Values
Jan-21	151286.00	143533	0	10731.00	0.952
Feb-21	112697.00	112778	0	15034.00	1.001
Mar-21	96735.00	86471	0	16709.00	0.910
Apr-21	76297.00	68097	0	15161.00	0.910
May-21	46836.00	46612	0	19654.00	0.997
Jun-21	21462.00	22721	0	19238.00	1.031
Jul-21	18851.00	26173	0	18355.00	1.197
Aug-21	18927.00	22804	0	18596.00	1.103
Sep-21	20408.00	25645	0	17886.00	1.137
Oct-21	46957.00	47739	0	18411.00	1.012
Nov-21	96295.00	91491	0	14539.00	0.957
Dec-21	176110.00	160015	0	9705.00	0.913
Jan-22	156459.00	138983	0	4720.00	0.892

Table 16: Thermal Share of RES and Share of Fossil Fuel-based Heat KPI Calculation and its Terms (for Ghent-New Docks Energy Island)

Share of RES non-RES	$\text{Share}^{\text{T}}_{\text{RES}} = \frac{\text{E}^{\text{T}}_{\text{RES}}}{\text{E}^{\text{T}}_{\text{Consumed}} + \text{E}^{\text{T}}_{\text{losses}}} = \frac{\text{Heat}^{\text{T}}_{\text{recovery}} + \text{Heat}^{\text{T}}_{\text{HP RES-based}}}{\text{E}^{\text{T}}_{\text{Consumed}} + \text{E}^{\text{T}}_{\text{losses}}}$					$\text{Share}^{\text{T}}_{\text{fossil}} = 1 - \text{Share}^{\text{T}}_{\text{RES}}$
Terms	$\text{E}^{\text{T}}_{\text{Consumed}}(\text{kWh}_{\text{th}})$	$\text{E}^{\text{T}}_{\text{missing}}(\text{kWh}_{\text{th}})$	$\text{Heat}^{\text{T}}_{\text{recovery}}(\text{kWh}_{\text{th}})$	$\text{Heat}^{\text{T}}_{\text{HP RES-based}}(\text{kWh}_{\text{th}})$	Values	Values
Jan-21	151286.00	143533	11311.0	59.40	7.02%	92.98%
Feb-21	112697.00	112778	12550.0	93.34	9.90%	90.10%
Mar-21	96735.00	86471	20190.0	182.50	17.96%	82.04%
Apr-21	76297.00	68097	17482.0	339.61	19.49%	80.51%
May-21	46836.00	46612	16219.0	236.20	24.75%	75.25%
Jun-21	21462.00	22721	16144.0	117.32	39.95%	60.05%
Jul-21	18851.00	26173	8550.0	150.88	23.39%	76.61%
Aug-21	18927.00	22804	12581.0	116.31	33.84%	66.16%
Sep-21	20408.00	25645	10002.0	130.93	26.46%	73.54%
Oct-21	46957.00	47739	12412.0	106.92	19.15%	80.85%
Nov-21	96295.00	91491	14755.0	37.49	13.35%	86.65%
Dec-21	176110.00	160015	19606.0	31.35	10.57%	89.43%
Jan-22	156459.00	138983	20395.0	47.41	12.68%	87.32%

Table 17: CO2 Intensity KPI Calculation and its Terms for the Heat Energy Vector (for Ghent-New Docks Energy Island)

CO2 intensity KPI	${\text{CO}_2}^{\text{T}}_{\text{intensity}} = \frac{\text{Total CO2 Amount}}{\text{Total heat Load}} = \frac{{\text{CO}_2}^{\text{T}}_{\text{prod}} + {\text{CO}_2}^{\text{T}}_{\text{missing}}}{\text{E}^{\text{T}}_{\text{Consumed}} + \text{E}^{\text{T}}_{\text{Losses}}} = \frac{\text{CO2}^{\text{T}}_{\text{gas boilers}} + \text{CO2}^{\text{T}}_{\text{Grid-based heat HP}} + \text{CO2}^{\text{T}}_{\text{PV-based heat HP}}}{\text{E}^{\text{T}}_{\text{Consumed}} + \text{E}^{\text{T}}_{\text{Losses}}}$					
Terms	$\text{E}^{\text{T}}_{\text{Consumed}}(\text{kWh}_{\text{th}})$	$\text{E}^{\text{T}}_{\text{losses}}(\text{kWh}_{\text{th}})$	$\text{CO2}^{\text{T}}_{\text{gas boilers}}\ (\text{gCO}_2)$	$\text{CO2}^{\text{T}}_{\text{Grid-based heat HP}}\ (\text{gCO}_2)$	$\text{CO2}^{\text{T}}_{\text{PV-based heat HP}}\ (\text{gCO}_2)$	Values ($\text{gCO2 per kWh}_{\text{th}}$)
Jan-21	151286.00	10731.00	25059510.00	415015.06	1113.83	157.2405
Feb-21	112697.00	15034.00	20051010.00	145198.74	1886.20	158.1299
Mar-21	96735.00	16709.00	16240770.00	335678.92	2983.20	146.1464
Apr-21	76297.00	15161.00	13124160.00	239157.60	4712.91	146.1658
May-21	46836.00	19654.00	9175950.00	241757.03	5362.38	141.7216
Jun-21	21462.00	19238.00	5002830.00	227632.32	4997.47	128.6354
Jul-21	18851.00	18355.00	5824980.00	251940.60	5239.09	163.4725
Aug-21	18927.00	18596.00	5044410.00	247027.75	4568.22	141.1403
Sep-21	20408.00	17886.00	5670000.00	224231.33	3750.64	154.0184
Oct-21	46957.00	18411.00	9419760.00	238470.26	1603.84	147.7762

Nov-21	96295.00	14539.00	17200890.00	235638.48	624.06	157.3267
Dec-21	176110.00	9705.00	28622160.00	245152.82	400.88	155.3573
Jan-22	156459.00	4720.00	24562440.00	250100.33	655.61	153.9481

Table 18: Energy Saving KPI Calculation and its Terms for the Heat Energy Vector (for Ghent-New Docks Energy Island)

Energy Savings	$E^{T}_{Savings}(\%) = \frac{E^{T-1}_{consumed} + E^{T-1}_{loss} - (E^{T}_{consumed} + E^{T}_{loss})}{E^{T-1}_{consumed} + E^{T-1}_{loss}}$		
Terms	$E^{T}_{Consumed}(kWh_{th})$	$E^{T}_{losses}(kWh_{th})$	Values
Jan-21	151286.00	10731.00	
Feb-21	112697.00	15034.00	21.16%
Mar-21	96735.00	16709.00	11.19%
Apr-21	76297.00	15161.00	19.38%
May-21	46836.00	19654.00	27.30%
Jun-21	21462.00	19238.00	38.79%
Jul-21	18851.00	18355.00	8.58%
Aug-21	18927.00	18596.00	-0.85%
Sep-21	20408.00	17886.00	-2.05%
Oct-21	46957.00	18411.00	-70.70%
Nov-21	96295.00	14539.00	-69.55%
Dec-21	176110.00	9705.00	-67.65%
Jan-22	156459.00	4720.00	13.26%

VIII.2. Ghent: Technical Baseline Assessment – Electricity

Table 19: Electrical Energy Self-Sufficiency KPI Calculation and its Terms (for Ghent-New Docks Energy Island)

	Electricity Load	PV Electricity	Grid Electricity	Battery Electricity	Self Sufficiency
2021					
Mar	18583.6	3461.6	14345.4	**-766.7**	22.81%
Apr	28307.6	7331.4	20570.7	-405.5	27.33%
May	31668.4	7535.7	23444.4	-678.2	25.97%
Jun	**34627.1**	**7556.7**	27022.2	-48.2	21.96%
Jul	29949.7	7199.7	23019.6	269.6	23.14%

Aug	31398.6	6106.0	25572.9	280.3	18.55%
Sep	25138.5	5176.4	19905.2	-56.9	20.82%
Oct	29688.6	2666.6	27466.3	444.3	7.49%
Nov	33997.4	1161.6	33151.3	315.5	2.49%
Dec	31005.7	**632.0**	30747.1	373.3	0.83%
2022					
Jan	30780.0	1003.4	30102.2	325.6	2.20%
Feb	34354.3	2002.2	**32864.6**	**512.5**	4.34%
Mar	**15779.0**	2192.6	**13872.4**	285.9	12.08%
All Period	**375278.4**	**54025.9**	**322084.1**	**851.6**	14.17%

Table 20: Electrical Energy Self-Sufficiency KPI Calculation and its Terms (for Ghent-New Docks Energy Island)

	Electricity Load	PV Electricity	Grid Electricity	Battery Electricity	Self Sufficiency
2021					
Mar	18583.6	3461.6	14345.4	**-766.7**	22.81%
Apr	28307.6	7331.4	20570.7	-405.5	27.33%
May	31668.4	7535.7	23444.4	-678.2	25.97%
Jun	**34627.1**	**7556.7**	27022.2	-48.2	21.96%
Jul	29949.7	7199.7	23019.6	269.6	23.14%
Aug	31398.6	6106.0	25572.9	280.3	18.55%
Sep	25138.5	5176.4	19905.2	-56.9	20.82%
Oct	29688.6	2666.6	27466.3	444.3	7.49%
Nov	33997.4	1161.6	33151.3	315.5	2.49%
Dec	31005.7	**632.0**	30747.1	373.3	0.83%
2022					
Jan	30780.0	1003.4	30102.2	325.6	2.20%
Feb	34354.3	2002.2	**32864.6**	**512.5**	4.34%
Mar	**15779.0**	2192.6	**13872.4**	285.9	12.08%
All Period	**375278.4**	**54025.9**	**322084.1**	**851.6**	14.17%

Table 21: Electric Share of RES and Share of Fossil Fuel-based Electricity KPI Calculation and its Terms (for Ghent-New Docks Energy Island)

Share of RES non-RES	$\mathrm{Share}^{T}_{RES} = \frac{E^{T}_{RES}}{E^{T}_{Consumed} + E^{T}_{losses}} = \frac{E^{T}_{Photovoltaics}}{E^{T}_{Consumed} + E^{T}_{losses}}$					$\mathrm{Share}^{T}_{fossil} = 1 - \mathrm{Share}^{T}_{RES}$
Terms	$E^{T}_{Consumed}(kWh_{el})$	$E^{T}_{missing}(kWh_{el})$	$E^{T}_{Photovoltaics}(kWh_{el})$	$E^{T}_{loss}(kWh_{el})$	Values	Values
Mar-21	17806.98529	14345.375	3461.610289	0	20.57%	79.43%
Apr-21	27902.0883	20570.6875	7331.400799	0	20.02%	79.98%
May-21	30980.15895	23444.4375	7535.721452	0	19.92%	80.08%
Jun-21	34578.88456	27022.1875	7556.697059	0	18.56%	81.44%

Jul-21	30219.26124	23019.5625	7199.69874	0	19.99%	80.01%
Aug-21	31678.94323	25572.9375	6106.00573	0	17.33%	82.67%
Sep-21	25081.6197	19905.1875	5176.4322	0	18.83%	81.17%
Oct-21	30132.94577	27466.3125	2666.633273	0	13.97%	86.03%
Nov-21	34312.81528	33151.25007	1161.56521	0	4.10%	95.90%
Dec-21	31379.03662	30747.06271	631.9739085	0	4.09%	95.91%
Jan-22	31105.56978	30102.18771	1003.382068	0	3.65%	96.35%
Feb-22	34866.79112	32864.56273	2002.228396	0	5.25%	94.75%
Mar-22	16064.93497	13872.37516	2192.559811	0	11.90%	88.10%

In Table 21, the same remark mentioned for the other KPIs calculation also applies since the average values of the RES-share and non-RES are complementary and do not match the exact monthly KPI values owing to the granularity assessment impact. The current values are based on a quarterly value of RES-share and non-RES yielding other numbers when evaluating the energy island on a higher level of time resolution. This difference can be explained by the following simple example proving that the average of single KPIs per period t is not the same as the percentage for the whole amount.

Table 22: Monthly Electricity KPIs for Ghent-Now Docks Pilot (Period from 15/03/2021 until 15/03/2022)

CO2 intensity KPI	$\mathrm{CO_2}{}^{\mathrm{T}}_{\mathrm{intensity}}(\mathrm{elec}) = \frac{\text{Total CO2 Amount}}{\text{Total Electricity Load}} = \frac{\mathrm{CO_2}{}^{\mathrm{T}}_{\mathrm{prod}} + \mathrm{CO_2}{}^{\mathrm{T}}_{\mathrm{missing}}}{\mathrm{E}^{\mathrm{T}}_{\mathrm{Consumed}} + \mathrm{E}^{\mathrm{T}}_{\mathrm{excess}}} = \frac{\mathrm{CO2}^{\mathrm{T}}_{\mathrm{Grid}} + \mathrm{CO2}^{\mathrm{T}}_{\mathrm{PV}}}{\mathrm{E}^{\mathrm{T}}_{\mathrm{Consumed}} + \mathrm{E}^{\mathrm{T}}_{\mathrm{excess}}}$					
Terms	$\mathrm{E}^{\mathrm{T}}_{\mathrm{Consumed}}(\mathrm{kWh_{th}})$	$\mathrm{E}^{\mathrm{T}}_{\mathrm{missing}}(\mathrm{kWh_{th}})$	$\mathrm{E}^{\mathrm{T}}_{\mathrm{excess}}(\mathrm{kWh_{th}})$	$\mathrm{CO2}^{\mathrm{T}}_{\mathrm{Grid}}\ (\mathrm{gCO_2})$	$\mathrm{CO2}^{\mathrm{T}}_{\mathrm{PV}}\ (\mathrm{gCO_2})$	Values ($\mathrm{gCO2\ per\ kWh_{el}}$)
Mar-21	17806.98529	14345.375	20.625	2008352.5	155772.463	120.183
Apr-21	27902.0883	20570.6875	566.5	2879896.25	329913.0359	118.436
May-21	30980.15895	23444.4375	469.5625	3282221.25	339107.4653	118.910
Jun-21	34578.88456	27022.1875	179.4375	3783106.25	340051.3677	121.763
Jul-21	30219.26124	23019.5625	461.53	3222738.75	323986.4433	119.319
Aug-21	31678.94323	25572.9375	140.9375	3580211.25	274770.2579	122.758
Sep-21	25081.6197	19905.1875	167.45	2786726.25	232939.449	120.924
Oct-21	30132.94577	27466.3125	6.875	3845283.75	119998.4973	126.632
Nov-21	34312.81528	33151.25007	6.19	4641175.009	52270.43444	136.013
Dec-21	31379.03662	30747.06271	85	4304588.779	28438.82588	135.059
Jan-22	31105.56978	30102.18771	62.56250492	4214306.279	45152.19305	136.104
Feb-22	34866.79112	32864.56273	2.75000024	4601038.782	90100.27784	134.956
Mar-22	16064.93497	13872.37516	13.06250114	1942132.522	98665.19149	128.374

VIII.3. Ghent: Infrastructure Assessment – PV & Battery

ALIGNING LCOS WITH ELECTRICITY FROM THE GRID TARIFF

After calculating the LCOS based on the different features given in Table 4, the obtained value is 30.7 cents/KWh_el. This value can be compared to the average price of electricity in the same year of evaluation which is (15/03/2021-15/03/2022) which is 12.84 cents/KWh_el (no VAT and other costs included) and 17.74 cents/KWh_el (VAT and other costs included). As a consequence, while considering that the electricity prices are fluctuating and rising (the case of the two semesters of 2021), the operation of the battery and its optimal charging and discharging is of uttermost importance since the optimal technique of charging is dependent on the amount of solar energy available (which is only available during the day and more important during the summer months) as well as the intake prices of electricity when the battery is withdrawing from the electricity grid. In the studied year while based on real charging and discharging data of the battery as explained earlier in the LCOS calculation section, the algorithm is performing well to decide upon the best moments to charge and discharge.

In Figure 65, a more fine-grained (15-minute time resolution) price evolution for the studied use case of new Docks is shown. In this figure, the price fluctuation indicates that with the current configuration and smart charging algorithms, it is possible to achieve at certain periods a sort of peak shaving whereby observing the trend of the prices, it is better to prioritize the consumption from the BESS rather than consuming from the grid since the prices of electricity are higher than the calculated value of LCOS. Bearing in mind that the LCOS is also taking into account the charging cost, an optimal way of charging the BESS when the prices are low for a later consumption can be a good approach to lower the LCOS value on one hand and to favour the consumption from the grid if it is cheap enough on the other one.

In conclusion, in this instance, the LCOS serves as a measure to compare the electricity prices incurring on the grid if the consumption was entirely dependent on the external energy. This statement allows us to confirm that Lithium iron phosphate batteries offer a variety of advantages, including improved discharge and charging efficiency, longer life, and the ability to cycle deeply while maintaining performance. Although LiFePO4 batteries frequently carry a higher price tag, their superior cost over the course of the product’s life, need for little maintenance, and occasional replacement make them an excellent long-term investment (Maxworld, 2022)

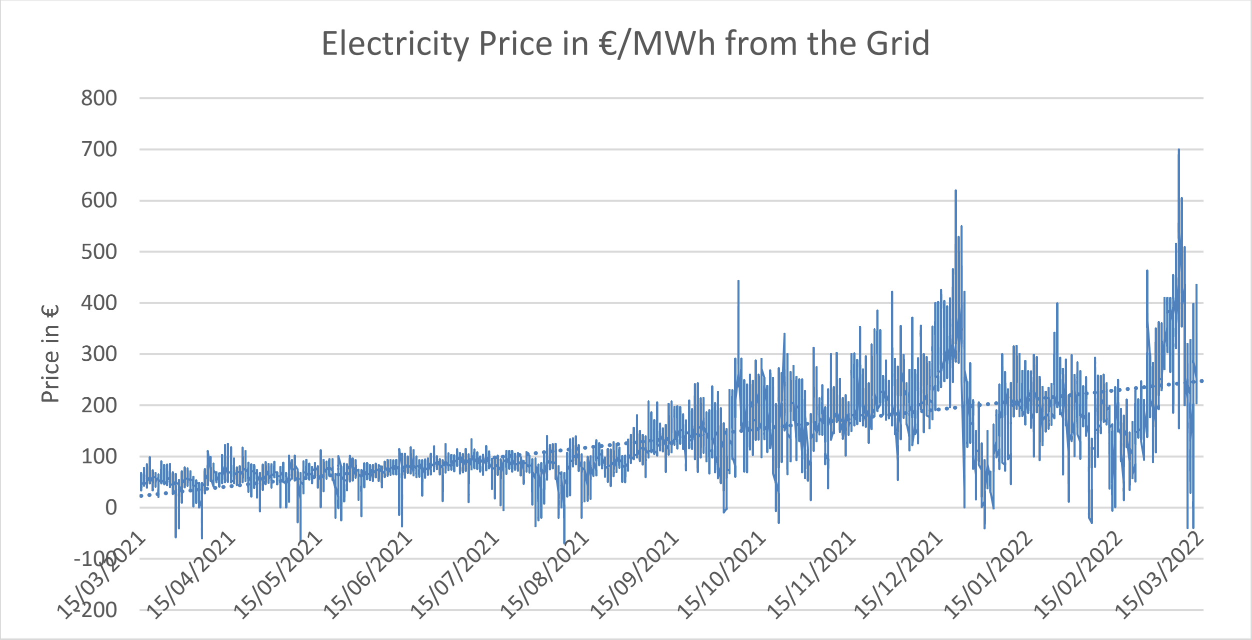

Figure 65: Electricity Price Fluctuation in the Period (15/03/2021 until 15/03/2022) for Ghent-New Docks Energy Island

VIII.4. Poznan: Technical Baseline Assessment – Heat

In Table 24, the monthly values of each KPI are revealed for the study period spanning from February 2021 until January 2022 (both starting month and end month included).

Table 23: Monthly Values of the Defined Heat KPIs (CO2 Intensity, RES Share, Fossil Fuel Share, Energy Potency, Energy Savings, and Energy Efficiency) (for Poznan-Warta Campus Energy Island)

	CO2 intensity (gCO2/kWh)	RES share (%)	Fossil fuel share (%)	Energy Self-sufficiency	Energy potency	Energy Savings (%)	Energy Efficiency (%)
1-Feb-2021	231.6649	43.97%	56.03%	0.4397	0.5802		100.00%
1-Mar-2021	218.3489	55.14%	44.86%	0.5514	0.4827	14.12%	100.00%
1-Apr-2021	188.7048	69.15%	30.85%	0.6915	0.3651	30.74%	100.00%
1-May-2021	181.0538	63.96%	36.04%	0.6396	0.4545	45.82%	100.00%
1-Jun-2021	165.1246	54.76%	45.24%	0.5476	0.9374	57.71%	100.00%
1-Jul-2021	283.5733	1.60%	98.40%	0.0160	1.2684	-197.34%	100.00%
1-Aug-2021	249.0187	18.57%	81.43%	0.1857	0.9787	21.46%	100.00%
1-Sep-2021	272.5394	7.12%	92.88%	0.0712	1.0442	-19.40%	100.00%
1-Oct-2021	190.4191	58.85%	41.15%	0.5885	0.4776	-54.83%	100.00%
1-Nov-2021	194.6542	66.75%	33.25%	0.6675	0.3650	-43.70%	100.00%
1-Dec-2021	203.5947	66.80%	33.20%	0.6680	0.3624	-40.54%	100.00%
1-Jan-2022	229.1230	40.67%	59.33%	0.4067	0.6125	-4.75%	100.00%

Average	217.3182	45.61%	54.39%	0.4561	0.6607	-17.335%	100%

As mentioned earlier, it should be noted that the calculation is based on the numbers entered by the energy managers for the Poznan-Warta campus energy island in the Excel spreadsheet and is categorized by KPI. In each of the following sections, the terms, and calculated values per month for each KPI in the defined list are described and listed. It is worth mentioning that the input data for the Poznan-Warta campus energy heat island figures are received as monthly data by the energy managers. This monthly granularity made it possible to measure every month the evolution of the values of the different KPIs. In sections 0, 0, 0, 0, and, further explanations are provided with regards to each of the defined KPIs and the data required for measuring it correctly.

Table 24: Thermal Energy Self-Sufficiency KPI Calculation and its Terms (for Poznan-Warta Campus Energy Island)

Energy self-sufficiency	$E_{SS}^{T}(\text{heat}) = \frac{E_{\text{Consumed}}^{T} - E_{\text{missing}}^{T} + E_{\text{excess}}^{T} + E_{\text{loss}}^{T}}{E_{\text{Consumed}}^{T} + E_{\text{loss}}^{T}} = \frac{E_{\text{Consumed}}^{T} - E_{\text{imported}}^{T} - E_{\text{HP NonRES}}^{T} + E_{\text{excess}}^{T} + E_{\text{loss}}^{T}}{E_{\text{Consumed}}^{T} + E_{\text{loss}}^{T}}$					
Terms	$E_{\text{Consumed}}^{T}(\text{GJ})$	$E_{\text{imported}}^{T}(\text{GJ})$	$E_{\text{HP NonRES}}^{T}(\text{GJ})$	$E_{\text{excess}}^{T}(\text{GJ})$	$E_{\text{loss}}^{T}(\text{GJ})$	Values
Feb-21	523.2	203.2	89.93	0	0	0.4397
Mar-21	449.3	104.3	97.25	0	0	0.5514
Apr-21	311.2	21.2	74.79	0	0	0.6915
May-21	168.6	29.6	31.16	0	0	0.6396
Jun-21	71.3	26.3	5.95	0	0	0.5476
Jul-21	212.0	208	0.60	0	0	0.0160
Aug-21	166.5	129.5	6.08	0	0	0.1857
Sep-21	198.8	181.8	2.85	0	0	0.0712
Oct-21	307.8	72.8	53.87	0	0	0.5885
Nov-21	442.3	40.3	106.74	0	0	0.6675
Dec-21	621.6	42.6	163.79	0	0	0.6680
Jan-22	651.1	293.1	93.21	0	0	0.4067

Table 25: Thermal Energy Self-Sufficiency KPI Calculation and its Terms (for Poznan-Warta Campus Energy Island)

Energy Potency	$E_{\text{Pot}}^{T} = \frac{E_{\text{missing}}^{T} + E_{\text{excess}}^{T} + E_{\text{losses}}^{T}}{E_{\text{Consumed}}^{T} + E_{\text{losses}}^{T}} = \frac{E_{\text{imported}}^{T} + E_{\text{HP NonRES}}^{T} + E_{\text{excess}}^{T} + E_{\text{loss}}^{T}}{E_{\text{Consumed}}^{T} + E_{\text{loss}}^{T}} = 1 - E_{SS}^{T}\ (E_{\text{excess}}^{T} + E_{\text{loss}}^{T} = 0)$					
Terms	$E_{\text{Consumed}}^{T}(\text{GJ})$	$E_{\text{imported}}^{T}(\text{GJ})$	$E_{\text{HP NonRES}}^{T}(\text{GJ})$	$E_{\text{excess}}^{T}(\text{GJ})$	$E_{\text{loss}}^{T}(\text{GJ})$	Values
Feb-21	523.2	203.2	89.93	0	0	0.5802
Mar-21	449.3	104.3	97.25	0	0	0.4827
Apr-21	311.2	21.2	74.79	0	0	0.3651

May-21	168.6	29.6	31.16	0	0	0.4545
Jun-21	71.3	26.3	5.95	0	0	0.9374
Jul-21	212.0	208	0.60	0	0	1.2684
Aug-21	166.5	129.5	6.08	0	0	0.9787
Sep-21	198.8	181.8	2.85	0	0	1.0442
Oct-21	307.8	72.8	53.87	0	0	0.4776
Nov-21	442.3	40.3	106.74	0	0	0.3650
Dec-21	621.6	42.6	163.79	0	0	0.3624
Jan-22	651.1	293.1	93.21	0	0	0.6125

Table 26: Thermal Share of RES and Share of Fossil Fuel-based Heat KPI Calculation and its Terms (for Poznan-Warta Campus Energy Island)

Share of RES non-RES	$\mathrm{Share}^{T}_{\mathrm{RES}} = \frac{E^{T}_{\mathrm{RES}}}{E^{T}_{\mathrm{Consumed}} + E^{T}_{\mathrm{losses}}}$			$\mathrm{Share}^{T}_{\mathrm{fossil}} = 1 - \mathrm{Share}^{T}_{\mathrm{RES}}$
Terms	$E^{T}_{\mathrm{Consumed}}(\mathrm{GJ})$	$E^{T}_{\mathrm{RES}}(\mathrm{GJ})$	Values	Values
Feb-21	523.2	230.07	43.97%	56.03%
Mar-21	449.3	247.75	55.14%	44.86%
Apr-21	311.2	215.21	69.15%	30.85%
May-21	168.6	107.84	63.96%	36.04%
Jun-21	71.3	39.05	54.76%	45.24%
Jul-21	212.0	3.40	1.60%	98.40%
Aug-21	166.5	30.92	18.57%	81.43%
Sep-21	198.8	14.15	7.12%	92.88%
Oct-21	307.8	181.13	58.85%	41.15%
Nov-21	442.3	295.26	66.75%	33.25%
Dec-21	621.6	415.21	66.80%	33.20%
Jan-22	651.1	264.79	40.67%	59.33%

Table 27: CO2 Intensity KPI Calculation and its Terms for the Heat Energy Vector (for Poznan-Warta Campus Energy Island)

CO2 intensity KPI	$\mathrm{CO_2}^{T}_{\mathrm{intensity}} = \frac{\text{Total CO2 Amount}}{\text{Total heat Load}} = \frac{\mathrm{CO_2}^{T}_{\mathrm{prod}} + \mathrm{CO_2}^{T}_{\mathrm{missing}}}{E^{T}_{\mathrm{Consumed}} + E^{T}_{\mathrm{Losses}}} = \frac{\mathrm{CO2}^{T}_{\mathrm{Imported}} + \mathrm{CO2}^{T}_{\mathrm{Grid-based\ heat\ HP}} + \mathrm{CO2}^{T}_{\mathrm{RES-based\ heat\ HP}}}{E^{T}_{\mathrm{Consumed}} + E^{T}_{\mathrm{Losses}}}$				
Terms	$E^{T}_{\mathrm{Consumed}}(\mathrm{kWh_{th}})$	$\mathrm{CO2}^{T}_{\mathrm{Imported}}(\mathrm{KgCO_2})$	$\mathrm{CO2}^{T}_{\mathrm{Grid-based\ heat\ HP}}$ $(\mathrm{KgCO_2})$	$\mathrm{CO2}^{T}_{\mathrm{Res-based\ heat\ HP}}$ $(\mathrm{KgCO_2})$	Values $(\mathrm{gCO2\ per\ kWh_{th}})$
Feb-21	145345.0	16200.9	17438.76	31.72	231.6649
Mar-21	124815.5	8315.7	18857.12	80.53	218.3489
Apr-21	86451.4	1690.2	14502.99	120.55	188.7048
May-21	46837.1	2360.0	6042.69	77.37	181.0538
Jun-21	19807.1	2096.9	1154.56	19.22	165.1246
Jul-21	58893.6	16583.5	115.84	1.26	283.5733
Aug-21	46253.7	10324.9	1178.95	14.24	249.0187
Sep-21	55226.6	14494.7	552.31	4.46	272.5394

Oct-21	85506.8	5804.2	10446.20	31.69	190.4191
Nov-21	122870.9	3213.1	20698.32	5.96	194.6542
Dec-21	172680.5	3396.4	31760.29	0.11	203.5947
Jan-22	180875.6	23368.5	18073.27	1.03	229.1230

Table 28: CO2 Intensity KPI Calculation and its Terms for the Heat Energy Vector (for Poznan-Warta Campus Energy Island)

Energy Savings	$\mathrm{E}^{\mathrm{T}}_{\mathrm{Savings}}(\%) = \frac{\mathrm{E}^{\mathrm{T-1}}_{\mathrm{consumed}} + \mathrm{E}^{\mathrm{T-1}}_{\mathrm{loss}} - (\mathrm{E}^{\mathrm{T}}_{\mathrm{consumed}} + \mathrm{E}^{\mathrm{T}}_{\mathrm{loss}})}{\mathrm{E}^{\mathrm{T-1}}_{\mathrm{consumed}} + \mathrm{E}^{\mathrm{T-1}}_{\mathrm{loss}}}$		
Terms	$\mathrm{E}^{\mathrm{T}}_{\mathrm{Consumed}}(\mathrm{kWh_{th}})$	$\mathrm{E}^{\mathrm{T}}_{\mathrm{losses}}(\mathrm{kWh_{th}})$	Values
Feb-21	523.2	0	
Mar-21	449.3	0	14.12%
Apr-21	311.2	0	30.74%
May-21	168.6	0	45.82%
Jun-21	71.3	0	57.71%
Jul-21	212.0	0	-197.34%
Aug-21	166.5	0	21.46%
Sep-21	198.8	0	-19.40%
Oct-21	307.8	0	-54.83%
Nov-21	442.3	0	-43.70%
Dec-21	621.6	0	-40.54%
Jan-22	651.1	0	-4.75%

The following images show the impact of heat, especially seasonal impact, on the COPs of the heat pumps.

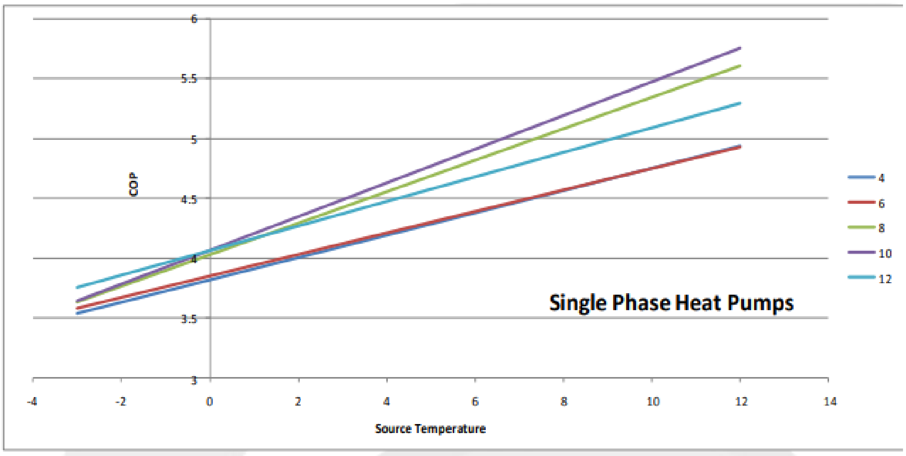

Figure 66: COP Values by Heat Power Levels and Impact of Inlet Temperature (Kensa Group Company, 2023)

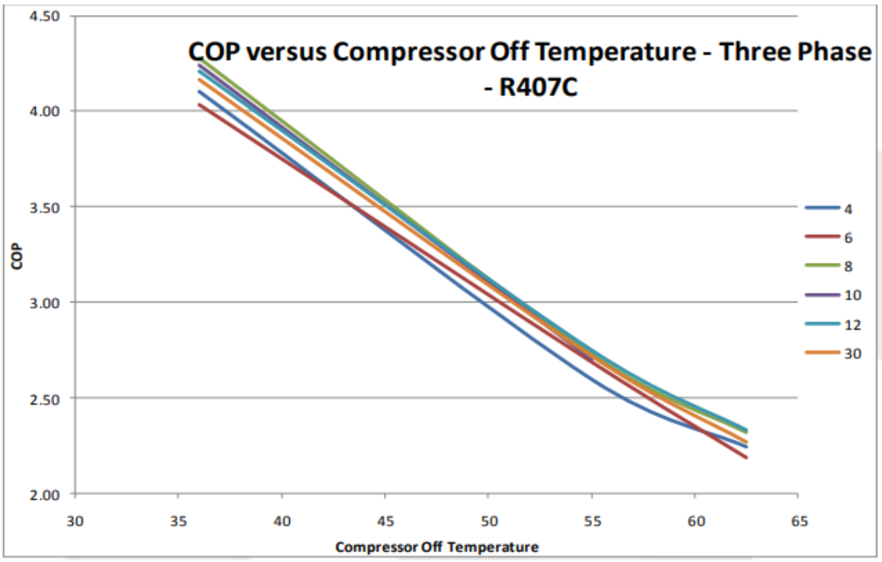

Figure 67: COP Values by Heat Power Levels and Impact of Outlet Temperature (Kensa Group Company, 2023)

VIII.5. Poznan: Technical Baseline Assessment – Electricity

Table 29: Monthly Values of the Electricity KPIs for Poznan-Warta Campus Energy Island

KPIs	Self-Sufficiency	CO2 Intensity	RES Share	Non-RES Share	Energy Potency
2020					
Jan	0.00%	698.0	0.00%	100.00%	100.00%
Feb	0.00%	698.0	0.00%	100.00%	100.00%
Mar	8.24%	644.2	8.24%	91.76%	91.76%
Apr	24.49%	538.1	24.49%	75.51%	75.51%
May	23.08%	547.3	23.08%	76.92%	76.92%
Jun	15.18%	598.9	15.18%	84.82%	84.82%
Jul	17.32%	584.9	17.32%	82.68%	82.68%
Aug	21.13%	560.0	21.13%	78.87%	78.87%
Sep	11.72%	621.4	11.72%	88.28%	88.28%
Oct	3.64%	674.3	3.64%	96.36%	96.36%
Nov	0.78%	692.9	0.78%	99.22%	99.22%
Dec	0.24%	696.4	0.24%	99.76%	99.76%
2021					
Jan	0.11%	697.3	0.11%	99.89%	99.89%
Feb	2.74%	680.1	2.74%	97.26%	97.26%
Mar	6.21%	657.5	6.21%	93.79%	93.79%
Apr	11.41%	623.5	11.41%	88.59%	88.59%
May	16.56%	589.9	16.56%	83.44%	83.44%
Jun	20.51%	564.1	20.51%	79.49%	79.49%
Jul	14.45%	603.7	14.45%	85.55%	85.55%

Aug	15.77%	595.0	15.77%	84.23%	84.23%
Sep	11.13%	625.3	11.13%	88.87%	88.87%
Oct	4.49%	668.7	4.49%	95.51%	95.51%
Nov	0.44%	695.1	0.44%	99.56%	99.56%
Dec	0.01%	698.0	0.01%	99.99%	99.99%
2022					
Jan	0.09%	697.4	0.09%	99.91%	99.91%
Feb	2.49%	681.7	2.49%	97.51%	97.51%
	7.62%	**648.2**	**7.62%**	**92.38%**	**92.38%**

Table 30: Aggregated Table of technical Electricity KPIs Calculated for Poznan-Warta Campus (CDWTch Building)

Item/KPI	Electricity consumption (kWh)	Electricity Imported (kWh)	RES-based Electricity	Electricity Stored	Electricity Excess	Electricity Losses	KPI1	KPI2	KPI3	KPI4	KPI5
Jan-20	148534.51	148534.51	0	0	0	0	698.000	0.00%	100.00%	0.000	1.000
Feb-20	139070.40	139070.40	0	0	0	0	698.000	0.00%	100.00%	0.000	1.000
Mar-20	101417.56	93065.56	8352	0	0	0	644.224	8.24%	91.76%	0.082	0.918
Apr-20	63477.21	47933.21	15544	0	0	0	538.096	24.49%	75.51%	0.245	0.755
May-20	77055.75	59273.75	17782	0	0	0	547.309	23.08%	76.92%	0.231	0.769
Jun-20	99555.59	84445.59	15110	0	0	0	598.891	15.18%	84.82%	0.152	0.848
Jul-20	104232.22	86177.22	18055	0	0	0	584.888	17.32%	82.68%	0.173	0.827
Aug-20	83419.10	65796.10	17623	0	0	0	560.048	21.13%	78.87%	0.211	0.789
Sep-20	85632.87	75593.87	10039	0	0	0	621.447	11.72%	88.28%	0.117	0.883
Oct-20	107917.18	103994.18	3923	0	0	0	674.262	3.64%	96.36%	0.036	0.964
Nov-20	110140.28	109284.28	856	0	0	0	692.925	0.78%	99.22%	0.008	0.992
Dec-20	114243.77	113967.77	276	0	0	0	696.422	0.24%	99.76%	0.002	0.998
Jan-21	122925.34	122790.34	135	0	0	0	697.283	0.11%	99.89%	0.001	0.999
Feb-21	102123.34	99323.34	2800	0	0	0	680.096	2.74%	97.26%	0.027	0.973
Mar-21	115089.51	107944.51	7145	0	0	0	657.460	6.21%	93.79%	0.062	0.938
Apr-21	98411.74	87179.74	11232	0	0	0	623.471	11.41%	88.59%	0.114	0.886
May-21	95796.48	79932.48	15864	0	0	0	589.862	16.56%	83.44%	0.166	0.834
Jun-21	95191.70	75667.70	19524	0	0	0	564.068	20.51%	79.49%	0.205	0.795
Jul-21	106850.61	91415.61	15435	0	0	0	603.672	14.45%	85.55%	0.144	0.856
Aug-21	86477.87	72841.87	13636	0	0	0	595.034	15.77%	84.23%	0.158	0.842
Sep-21	88277.76	78449.76	9828	0	0	0	625.301	11.13%	88.87%	0.111	0.889
Oct-21	123282.90	117746.90	5536	0	0	0	668.677	4.49%	95.51%	0.045	0.955
Nov-21	132108.64	131521.64	587	0	0	0	695.099	0.44%	99.56%	0.004	0.996
Dec-21	136509.43	136502.43	7	0	0	0	697.967	0.01%	99.99%	0.000	1.000
Jan-22	136509.43	136388.43	121	0	0	0	697.421	0.09%	99.91%	0.001	0.999
Feb-22	107981.24	105288.24	2693	0	0	0	681.714	2.49%	97.51%	0.025	0.975

VIII.6. Segrate: Technical Baseline Assessment – Electricity

Table 31: Aggregated Table of technical Electricity KPIs Calculated for Poznan-Warta Campus (CDWTch Building)

	Peak Values (KW)
2021	**51.5**
Qtr3	**51.5**
Sep	51.5
Qtr4	**48.786**
Oct	48.786
Nov	38.894
Dec	44.518
2022	**56.185**
Qtr1	**56.185**
Jan	49.729
Feb	56.185
Mar	49.15
Qtr2	**46.563**
Apr	35.982
May	46.563
Jun	31.888
Qtr3	**46.478**
Jul	43.073
Aug	31.193
Sep	46.478
Qtr4	**46.223**
Oct	46.223
All Period	**56.185**

Please note that the values above were calculated as realized peak values, not averaging them over time.

VIII.7. KPIs Modified or Adapted

REDEFINITION OF THE TERM "SELF-SUFFICIENCY" TO REFLECT THE OVERALL OBJECTIVES OF THE PROJECT

The self-sufficiency indicator as defined in D7.2 does not fully reflect the real impact of certain load shifting and DR events either on the electricity or on the heating domains. The modification with the new version of self-sufficiency serves to fairly reflect the effects of those events and load shifting actions.

Thus, the new self-sufficiency version can be written as follows while eliminating the value of the energy excess where the exported electricity/heat is not figuring in the numerator which levels out the impact by also favouring the excess of energy at certain moments. This is given by the following formula:

$$E_{SS}^{T} = \frac{E_{Consumed}^{T} + E_{losses}^{T} - E_{missing}^{T}}{E_{Consumed}^{T} + E_{losses}^{T}}$$

- E_{SS}^{T} represents the self-sufficiency KPI values over an observed period T. The formulation is generally applied to an annual calculation based on the predefined period of interest T to be considered, although it can be adapted to other time horizons as well (a month, a day, an hour, etc.).
- $E_{Consumed}^{T} = \sum_{t=1}^{t=T} E_{consum}^{t}$ represents the total heat/electricity energy consumed by the energy island and more specifically by the end-users over an observed period T.
- The parameter t represents the temporal granularity within the observed period T. Concretely, it means the equal portions of time (time intervals) in T, which can be typically hourly depending on the available datasets. It can also vary depending on the assessment purpose, whether we want to unveil a seasonal trend, a weekly behavior, a more fine-grained action impact, etc.
- $E_{missing}^{T} = \sum_{t=1}^{t=T} E_{missing}^{t}$ represents the amount of energy imported and/or generated locally directly or indirectly exclusively by fossil fuel resources and/or imported from the public heat/electricity network depending on the use case over an observed period T.
- In the same logic, the $E_{losses}^{T} = \sum_{t=1}^{t=T} E_{losses}^{t}$ reflects the heat/electricity amount that is lost or wasted during the energy transformations stages to be able to change the energy type from any type to thermal or electric form in the system aiming to fulfill the end-consumers thermal /electrical requirements over the observed time horizon T.

The losses in terms of thermal/electricity energy are classified as energy consumed though separated in another term to be able to differentiate between the actual heat/electric consumption and the one that is lost because of any technical or environmental barriers.

CALCULATION OF RES FOR POZNAN HEAT DOMAIN

The general formula of the KPI as described in D7.2 is applied with a certain modification. This change concerns the way of measuring heat from renewable energy sources. In the case of Poznan Warta Campus, the value of heat supplied by RES-based heat pumps is important since the heat is taken from the ground that was stored during the warm season to be reused by the energy island in winter. This source is called a low heat source (LHS). In detail, the evaporator of the heat pumps is placed in the ground where the temperature is more favourable in winter (higher than the ambient temperature outside). Then, the heat is extracted by the action of the heat pump which reverses the thermodynamic flow of heat (from the warm to the colder media to maintain the heat balance). Based on the mechanical action of the pumps inside the heat pumps and the availability of a warmer heat source, due to electricity usage, the heat is concentrated delivered to the heating system. This contributes to higher values of COP and more electricity savings required to meet the output temperature of compressor. Hence, the value of the term $\mathrm{E}_{\mathrm{RES}}^{\mathrm{T}}$ can be written as follows:

$$\mathrm{E}_{\mathrm{RES}}^{\mathrm{T}} = (\mathrm{E}_{\text{Heat from LHS}}^{\mathrm{T}} + \mathrm{E}_{\text{Electricity missing HP}}^{\mathrm{T}}) * \theta_{\text{Heat}-\text{Waste}} - \mathrm{E}_{\text{Heat HP Non RES}}^{\mathrm{T}}$$

Such that:

- $\mathrm{E}_{\text{Heat from LHS}}^{\mathrm{T}}$ is the amount of heat measured within the ground available for being extracted and is called the heat from a low heat source (LHS)
- $\mathrm{E}_{\text{Electricity missing HP}}^{\mathrm{T}}$ is the amount of electricity consumed by the heat pumps from the grid
- $\theta_{\text{Heat}-\text{Waste}}$ represents a waste of heat factor for the heat pumps and is calculated as follows:

$$\theta_{\text{Heat-Waste}} = \frac{E^{T}_{\text{Heat to heating system by HP}}}{E^{T}_{\text{Heat from LHS}} + E^{T}_{\text{Electricity missing HP}}}$$

- $E^{T}_{\text{Heat HP Non RES}}$ represents the heat provided from the heat pumps based on non-RES. This value is given by the following formula:

$$E^{T}_{\text{Heat HP Non RES}} = E^{T}_{\text{Electricity missing HP}} * (1 - \text{RES Share Electricity}) * \theta_{\text{Heat-Waste}}$$

These steps allowed to accurately calculate the amount of the actual renewable amount of heat based on the multiple sources of generation and thereafter to compare it to the amount of total consumed heat of the energy island.

VIII.8. Additional KPIs, not Introduced in D7.2

Some KPIs mentioned in this deliverable are intermediary KPIs; therefore, they were not mentioned in D7.2, which was dedicated to the results on energy island level. However, some of the epics individually impact not KPIs on energy island levels but intermediate KPIs. These are presented in this section.

ENERGY SAVINGS

The formula for the energy saving KPI is given in what follows:

$$E^{T}_{\text{Savings}}(\%) = \frac{\text{Energy previous period} - \text{Energy current period}}{\text{Energy previous period}}$$

$$E^{T}_{\text{Savings}}(\%) = \frac{E^{T-1}_{\text{consumed}} + E^{T-1}_{\text{loss}} - (E^{T}_{\text{consumed}} + E^{T}_{\text{loss}})}{E^{T-1}_{\text{consumed}} + E^{T-1}_{\text{loss}}} = 1 - \frac{E^{T}_{\text{consumed}} + E^{T}_{\text{loss}}}{E^{T-1}_{\text{consumed}} + E^{T-1}_{\text{loss}}}$$

Such that:

- $E^{T}_{\text{Savings}}(\%)$ is the KPI for thermal energy saved from period T-1 to T (reduced energy) and is preferred to be positive meaning that the thermal energy is being saved.
- $E^{T-1}_{\text{consumed}}$ represents the value of the thermal consumed energy by the end-users (energy sinks) for the previous period (T-1) in comparison with the current one T.
- E^{T-1}_{loss} represents the value of the thermal energy lost due to some insulation/distance conditions for the previous period (T-1) in comparison with the current one T.
- E^{T}_{consumed} represents the value of the thermal consumed energy by the end-users (energy sinks) for the current period T.
- E^{T}_{loss} represents the value of the thermal energy lost due to some insulation/distance conditions for the current period T.

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