This project has received funding from
the European Union's Horizon 2020
research and innovation programme
under grant agreement No 957845

LC-SC3-ES-3-2018-2020

Integrated local energy systems (Energy islands)

RENergetic

Community-empowered Sustainable Multi-Vector Energy Islands

Project Nº 957845

D7.2 – Description of evaluation metrics & KPIs used for common demonstration results & impact

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Document Reference :	D7.2
Dissemination Level:	Public
Version:	2.0
Date:	27 March 2023

Executive Summary

This deliverable describes the RENergetic approach towards a common evaluation of actions developed within energy island. The approach contains the evaluation of KPIs (based on metrics) in 3 different domains: technical, economic, social. It allows to measure the impact of the envisioned action in a standardized way.

First, the importance of common evaluation of actions and the need to develop a multidisciplinary approach is sketched. Then, the selected KPIs in the different domains are introduced. For each domain, relevant literature references are given and a generic procedure as well as some potential pitfalls are described, explaining how to actually evaluate those KPIs (how to get to numbers). A detailed overview of all KPIs is included, using formulae where appropriate and given attention to the listing of required input data (metrics).

In the technical domain the selected KPIs are the self-sufficiency indicator (the degree at which the system can sustain itself without external support), the energy efficiency indicator (the ability of consuming efficiently the energy produced without losses), the energy potency indicator (how efficiently the energy island can integrate renewable energy sources), the share of RES (share of renewable energy sources in the energy provision portfolio), the share of fossil fuel (amount of fossil-fuel based energy provided in the energy island) and the CO2 intensity (amount of CO2 released by the energy island per kWh.

In the economic domain, the selected KPIs are the levelized cost of energy (LCOE), the net present value (NPV, sum of discounted cash flows), the internal rate of return (IRR), the (undiscounted as well as discounted) payback period (PP), the load purchasing from the grid and the energy sold to the grid.

In the social domain, more KPIs are selected in order to adequately grasp all relevant concepts. The selected social KPIs are the share of local ownership in energy infrastructure equipment, the share of local participation in energy system related orders, high acceptance of the community hubs reflected in increasingly positive attitudes, self-identification with community, self-identification with local energy production and usage, social Inclusion, energy behaviour intentions, individual sustainable energy behaviour, communal sustainable energy intentions, social cohesion, job creation through EI, thermal comfort, evaluation of the performance of the solutions proposed, democratic participation, behavioural intention to become active, preference of participation and collective efficacy beliefs.

After defining all selected KPIs, some first evaluation results are included. They consider the evaluation of technical KPIs for the heat network in New Docks (Ghent) as well as the evaluation of the social KPIs for the New Docks energy community with respect to demand response. Note that these results are included here for illustrative purposes on how to use and interpret the metrics KPIs. The actual common evaluation of demonstration results follows in a later project stage and in Deliverables D7.3 and D7.5.

Finally, the relevance of the KPIs for the replication package is described.

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 will be carried out over the stretch of 42 months involving 12 European partners: Inetum (Spain, France, and Belgium), 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), Energy Kompass GMBH (Austria) and the University of Mannheim and the University of Passau (Germany).

Disclaimer:

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Table of Acronyms and Definitions

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
TSO	Transmission System Operator

I. INTRODUCTION

I.1. Purpose and organization of the document

The goal of this deliverable is to describe the approach we developed concerning a common evaluation of the impact reached by the three pilot sites. On one hand, we introduce technical, economic, and social KPIs that can be used for common evaluation of the pilot actions. On the other hand, we describe initial evaluation results based on the current status of implementation of the different action at the Ghent pilot site. In this way, this deliverable contains intermediate results related to the Tasks 7.1 and 7.2.

In section II, we describe the background and the importance of KPIs as a measure for benchmarking different actions developed within energy islands. Section III, IV and V contain the selected KPIs in the technical, social and economic domains respectively. First evaluation for specific pilot implementation and communities are described in section VII. The KPIs will be a key element in the remainder of the RENergetic project. Their application with respect to replication is described in VII. The deliverable is summarized in the final section VIII, whereas references are given in section IX.

I.2. Scope and audience

The deliverable focuses on the definition of the evaluation metrics and KPIs that will be used for evaluating common demonstration results and impact. These will be applied later on in Deliverable D7.3 “Initial evaluation of common demonstration results and impact” and also in the Deliverable D7.5 “Final evaluation of common demonstration results and impact”. It will also be applied in WP8 on replication.

The first evaluation results included in the current deliverable are there for illustrative purposes on how to use and interpret the metrics KPIs. The actual common evaluation of pilot action results follows in a later project stage.

As this is a public deliverable, it will be available to all interested readers. These include, first, the RENergetic partners that will be able to use the described KPIs for actual evaluation of their pilot demonstrations. Next, stakeholders in other energy islands can be interested in applying the same metrics. Finally, researchers in the broader domain as well as policy makers on different levels can learn from this suggested multidisciplinary evaluation approach.

II. KPIS AS A MEANS FOR BENCHMARKING

II.1. Evaluation Model for the Success of Energy Islands and the need for KPIs

In order to check to what extent, the concept of energy islands contributes to the achievement of climate neutral goals through the use of renewable energy sources, it makes sense to measure the success of an energy island.

First of all, the question of what success means in this context is relevant. In the context of this research, success is defined as the achievement of the objectives of an energy island. The greater the degree of objective fulfilment, the greater the success of the corresponding energy island. It is important to first define the goals of energy islands in order to then consider how the achievement of those goals can be measured. For this purpose, a general model of an energy island was created based on so-called key performance indicators (KPIs), which has been defined to measure the various objectives. Lastly, a success evaluation must be carried out to compare the success of (specific scenarios within) energy islands with each other or over different time periods.

The modelling of the success of an energy island is carried out within three dimensions (technical, economic and social), which relate to the different perspectives towards energy islands already indicated in the RENergetic DoA (**Figure II-1**) First, the technical dimension represents the energy island with all its possible energy sources and electricity/heat consumption elements, together with the external grid and the environment. It includes the technical and environmental KPIs. Second, in the economic dimension KPIs aiming at finding average cost for a certain element in the local energy system or evaluation a potential investment from the perspective of one of the involved stakeholders. Finally, the social dimension represents the energy island with all the people and organizations that are influenced by it to measure the social success with focus on the consumers of energy islands.

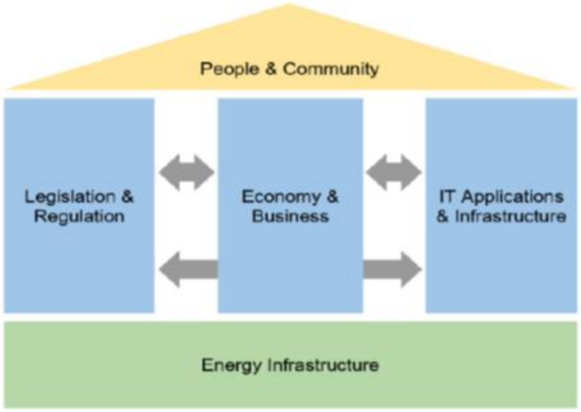


Figure II-1: Different perspectives on energy islands. *Source: RENergetic DoA*

In order to measure in an objective way the degree of fulfilment of the corresponding goals of these dimensions, KPIs must be defined. KPIs are indexes that measure the effectiveness of a project or a venture and/or its proposed solutions towards the achievement of the pre-defined specific key objectives. The process of selecting KPIs also assists the “clarification of project objective’s degree of success” (Pramangioulis et al, 2019).

KPIs should be meaningful, understandable, and quantifiable. They can assess technical, environmental, economic, social, and legal areas (Pramangioulis et al, 2019) and are often created using the SMART method. SMART stands for Specific, Measurable, Attainable, Realistic, and Timely and describes how a KPI should best be defined. Specific in this context means that the KPI should be clear so that no misunderstandings arise, while Measurable checks whether the indicator can be quantified and making it comparable with other data. Attainable asks whether the KPI is achievable, reasonable and credible. It can also stand for Assignable, in which case it should be clear who will be responsible for it. Realistic looks at whether the indicator can be evaluated/measured given available resources. Timely ensures that the KPI can be evaluated in the given time frame (Franceschini et al, 2019).

The calculation of KPIs requires so-called metrics. First of all, a metric is a pure key figure that is obtained from raw data. It presents the data without any context, a KPI, on the other hand, has a concrete question as orientation (Hutter, 2020) (Breeder, 2021). An example of a KPI would be the Net Present Value (NPV) which is calculated by a formula to evaluate the profitability of a project. This requires the initial investment and the cash flow per period, which are metrics.

After the KPIs have been defined according to the main question and measured with the help of metrics, certain methods must be used to be able to carry out a success evaluation of energy islands that goes beyond the mere observation and comparison of KPIs. For this purpose, so-called multi-criteria decision making (MCDM) methods can be used. They will be explained as well in later deliverables where actual evaluations are performed.

Figure II-2 brings together the different dimensions in the developed evaluation model for the success of energy islands. Further details concerning the different subparts are given in the following chapters.

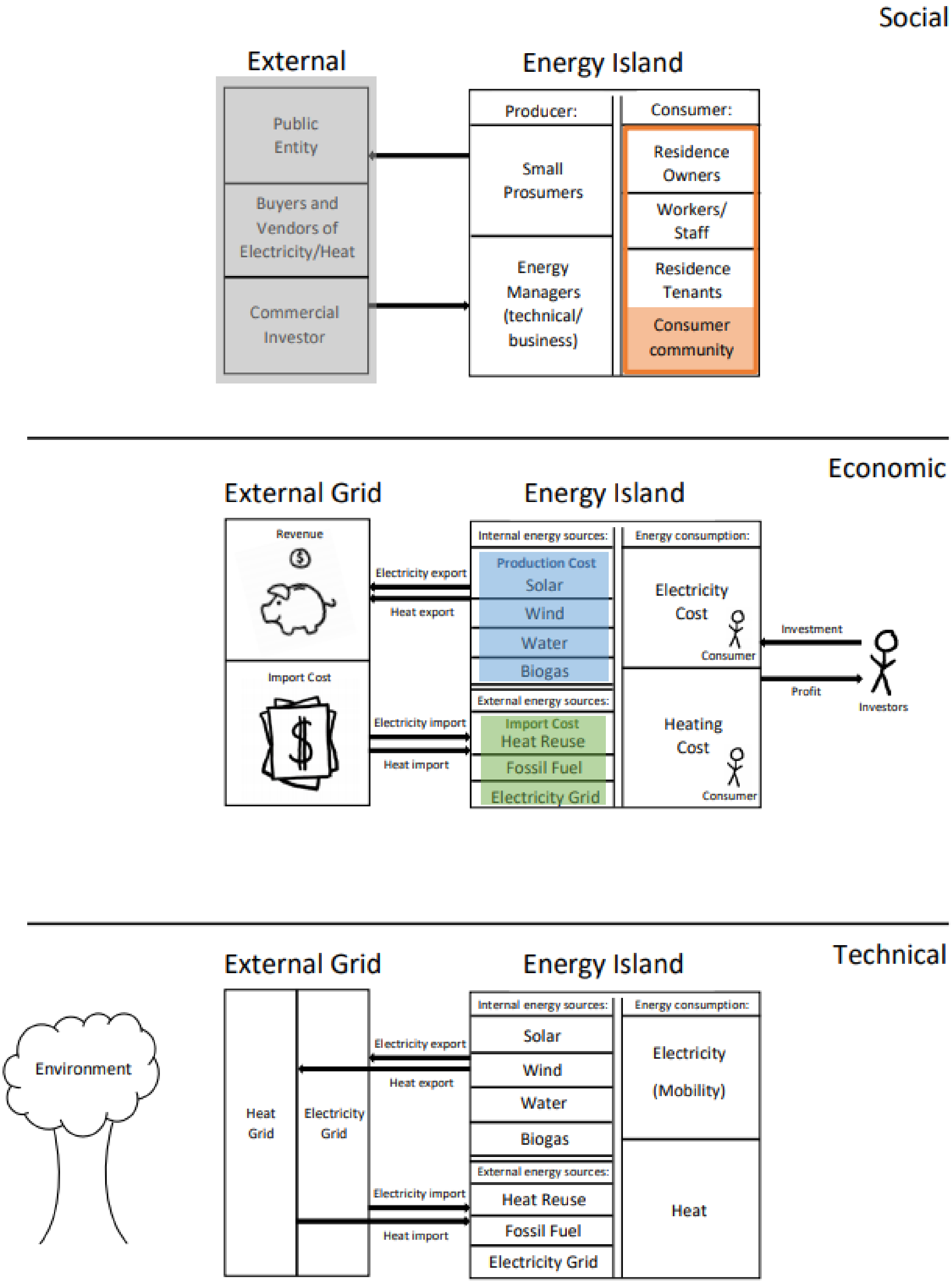


Figure II-2: Model of an Energy Island with all dimensions. *Source: Own creation*

II.2. Practical perspective towards the KPIs

II.2.1. RENergetic process towards the selection of KPIs

One of the main objectives (#4) of RENergetic project is to ensure a high replication potential across Europe. The identification of common KPIs and metrics for the evaluation of the pilot actions plays a crucial role in this regard. As shown on **Figure II-3** the overview of all relevant KPIs has been updated from several sources, including an extensive literature review on energy island/energy community performance, investment analysis guidebooks and constructs related to social impact. Also, a detailed interaction has been performed with the different pilots sites (in WP4, WP5 and WP6 resp.) in order to ensure that the KPIs are indeed relevant for measuring the success of the pilot actions at hand.

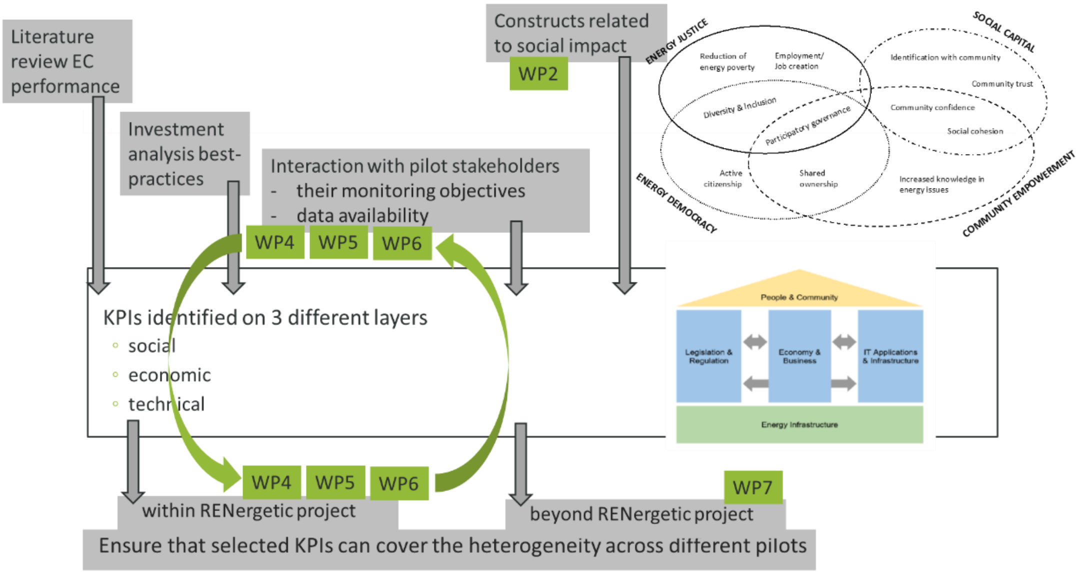


Figure II-3: RENergetic process towards selection of the KPIs. *Source: Own creation*

II.2.2. Where do the KPIs come from?

The KPIs listed in the remainder of this deliverable are defined starting from a literature analysis. Literature review first led to a longlist of potential KPIs. Then, KPIs were selected for a shortlist as far as they fit the concept of energy islands and are important for measuring the degree of fulfilment of a certain pilot objective. If KPIs did not fulfil one of these requirements, they were not included in the shortlist and therefore not mentioned explicitly in this deliverable. The set of the proposed KPIs has partly been supplemented by self-defined KPIs (KPIs that have not been substantiated by a source, mainly in the social dimension), where gaps were identified.

This decision depends on each individual energy island and the related objectives. This subset can be considered an appropriate standard set for energy island actions and a good impact for replication activities (as argued in different literature resources, see literatures specific sections later below). Note that the applicability of a certain KPI, finally, also depends on the availability of the needed input data for the scenario/ energy island under consideration.

II.2.3. More insights in the different dimensions

In order to measure the degree of success of an energy island through the fulfilment of its goals, a model of an energy island is designed with all its possible components, as already introduced in section II.1. On the one hand, this should show which KPIs are required in order to cover all facets of an energy island. On the other hand, it can be used to show how a particular energy island is equipped.

The success evaluation model of an energy island is based on three dimensions, as explained in the previous section. Those dimensions can be seen as three superimposed levels. The lowest level is the technical dimension, which includes the environment in addition to the technical data of the energy island as well as the external grid. On top of the technical level is the economic dimension, which primarily deals with the financial data. The financial data is largely based on the technical values. At the top level is the social dimension, which deals with the composition and well-being of the various members of the energy island.

II.2.3.a. Technical dimension

The technical level consists of the component’s environment, external grid and the actual energy island. The external grid can be divided into the heat grid and the electricity grid, which are connected to the energy island via heat as well as electricity imports and exports. Within the energy island, the energy sources, i.e. the energy production and the energy consumption, face each other. The sources can be differentiated between internal and external energy sources, depending on whether the respective resources are located within the energy island (solar, wind, water, biogas) or need to get imported from outside (heat reuse, e.g. waste heat, fossil fuel, external electricity grid). The energy is consumed in the form of electricity and e-mobility (e.g. electric cars) as well as heat.

II.2.3.b. Economic dimension

The economic level is structured in a similar way as the technical level. However, the environment is disregarded in this dimension, investors have been added, and the technical components are now considered from a financial point of view. For consumers and investors, the economic KPIs are of particular interest. Consumers have costs for electricity and heating according to their consumption. Investors invest money in energy islands to make a profit. The external grid is now the source of costs and revenues through imports and exports of an energy island while energy sources are considered in the context of their production or import costs. The economic perspective on an energy island depends on its observer. Thus, the interests and priorities regarding the economic KPIs differ depending on whether the energy island is viewed as a whole or by individual consumers and producers.

II.2.3.c. Social Dimension

In the social dimension, the KPIs focus particularly on the members, residents or somehow involved stakeholders within the energy Island, including management and operation. Participation, and being part of the Energy island is expected to have a positive social impact on these internal stakeholders.

II.2.4. KPIs as a means for comparison?

The overall goal of selecting KPIs for energy island and energy communities (on different layers, as explained above) is to have a means for monitoring the evolution within a certain pilot. KPIs allow to measure the impact of certain initiatives (related to epics). For that purpose, the same KPIs in a certain pilot are evaluated at several points in time. This can help to answer questions like the following. Does demand response really impact level of autarky of the LEC? Do community measures really have an impact on the social cohesion with the community? These questions and answers can be relevant for different stakeholders. E.g. for an energy island project developer it is interesting to have a means to answer the question “Is the investment worthwhile?”, for a energy community member (inhabitant) it can be relevant to understand “Do my actions really have impact?”

Note that the intention is not to compare pilot sites as such. As the pilots are very different in nature (stakeholders, energy vectors, state of deployment, greenfield vs retrofit), they should not be rank ordered. Individual initiatives can be compared across pilots, though, if their context is comparable.

III. TECHNICAL KPIS RELATED TO ENERGY ISLANDS

III.1. Literature background on evaluation of energy islands based on technical KPIs

Several papers in the field of energy systems point to KPIs in the technical dimension that can also be relevant for the technical assessment of energy island or scenarios therein. As stated in (Pramangioulis et al., 2019), technical KPIs take into account the operational settings and the defined constraints of a particular use case. This consideration seeks to reflect those completely technical numbers (metrics) into congregate and insightful measurements able to monitor the efficiency of an energy system on the various evaluated energy vectors (thermal and electrical energy).

Technical KPIs play a fundamental role in valorising the impact of certain solution-driven approaches or an innovative technology by spotting and quantifying the benefit guaranteed by the latter's introduction. In this context, (Baneshi and Hadianfard, 2016) studied the southern Iranian use case of the hybrid generation (diesel/PV/wind/battery) for a non-residential large electricity consumer by comparing the grid-integrated and grid-independent alternatives from a techno-economic perspective. For that purpose, HOMER Pro Software is used in order to model the use case fed with the different technical, economic, and environmental parameters. The impact of the battery size along with the introduction of PV panels and wind turbines in a grid-connected or an off-grid fashion is assessed by calculating the influence on the cost of electricity range and the RES share. It should be mentioned that the battery rises the cost of electricity but ensures a higher resilience.

Another study dedicated to self-sustaining domestic water heating, electrical-based heating, and a cooling system addressed the option of meeting heat and cooling demands in a completely electric fashion on the local community level in north California (Brum et al., 2015). More technically, the technologies used to reach this two-fold autarky are a heat pump based on a central ground source as well as a heat boiler functioning on electricity.

In another field of application, (Padrón et al., 2019) investigated the potential of combining multiple RES (wind and solar) to ensure an autonomous system for seawater desalination on two specific islands of the Canary Islands.

More towards the energy island framework, (Herenčić et al., 2021) addressed the multi-vector energy communities (MECs) and assessed the usefulness of electrifying a part of the energy vectors alongside combining it with the conventional energy supply from the grid. In this study, numerous technical indices are proposed to gauge techno-economically the multiple configurations of energy supply resources and to compare their performances. Among the findings, the battery energy systems (BESSs) are capable of improving the energy potency and self-sufficiency only with limited RES supply volumes, as well as they can decrease the carbon intensity, although the increase of BESS size comes at its cost.

The energy management process spans from the production phase by the energy suppliers or other techniques when the energy provision is also local or occurring within the energy island borders (existence of prosumers) until the consumption phase. In several scenarios, the technical KPIs can be dedicated to assessing some technology to demarcate more visibly the benefit, the worthless, or the loss of that endeavour.

Technical KPIs could be focussed on at least two different perspectives, on one hand focussing on resilience and on the other hand focussing on ‘greenness’ (renewables).

When considering technical KPIs from a resilience perspective, the viewpoint of several internal and external stakeholders involved in the energy island becomes relevant. As an example, the TSO and the DSO are striving continuously to guarantee a satisfactory quality of electricity and heating service to meet the requirements of the on-grid customers. From a load-consumption point of view, the demand peaks that can create a blackout situation for instance are monitored carefully, especially in some critical settings where the end energy consumers are healthcare facilities. In this context, the consumption patterns are direct indicators of how these operators should cope with some scenarios if they occur. Furthermore, the energy suppliers on the market can benefit from closely observing the impact of certain technologies capable of generating more balanced trends or better energy resilience and thus more investable ventures for them.

Along the same lines, aside from the external actors, within the energy island, the technical KPIs are of paramount importance to the energy managers that keep an eye on the different variables related to the technical performance of the technologies implemented as well as the status of effectiveness in terms of the different determined operational KPIs. Using real-time monitoring of those several indicators, the energy managers could be more knowledgeable about the actual situation of the energy island in general. Additionally, if a simplistic picture of the energy technical indicators is displayed to the public, the actual performance of the energy island could be more impactful by granting access to end-consumers to be more informed and engaged regarding technicalities. This would anchor the grounding of mutual energy transparency intending to stimulate end-users to act accordingly to rationalize and even save in some circumstances to align with the multi-objective ambitions of the energy island (eco-friendly, economically, technically, etc.).

When considering technical KPIs from a greenness perspective, relevant KPIs include energy self-sufficiency, carbon intensity, and energy potency. Resulting assessment focus on the amounts of renewables, amounts of loss, etc. By reviewing the different technologies of electrifying the energy systems and hybridizing numerous electricity resources along with the grid, we can also include specific settings such as e.g. the weather particularities of certain regions reflected in the RES generation capabilities. Indeed, the core motivation behind the determination and then the calculation of the technical KPIs is the data gathering stream from various data sites according to the type of energy being assessed. Practically, the metrics collected from either the heating or electricity network provided by electrical meters that can be smart in some cases and from the calorimeters (also known as heat meters) when it is concerning the thermal load are the main drivers for the evaluation process along the energy management process.

Different literature sources mentioned above lead to a longlist of potentially relevant technical KPIs. Pramangioulis et al. (2019) proposed a methodology intending to identify and define the KPIs for smart grid development in the island energy systems. These authors identified 45 KPIs for the assessment process, dispatched into 18 technical KPIs, 5 environmental KPIs, 7 economic KPIs, 7 social KPIs, and 4 legal KPIs. Next, a reduction of the number of KPIs was performed, based on the convenience and the suitability of their application concerning the goals of a particular energy-related project, inspired by (Herenčić et al., 2021).

On the technical side, this led to a shortlist of the following key indicators: energy self-sufficiency, carbon intensity, and energy potency. This shortlist is believed (Herenčić et al. 2021) to reflect the essential and most insightful indicators to ensure a realistic picture of the different energy island use cases and attempt to standardize the significance of those numbers. Certainly, the purpose is to deliver fewer indicators but ensure vivid insight and demonstrate the results on real-world datasets of actual case studies.

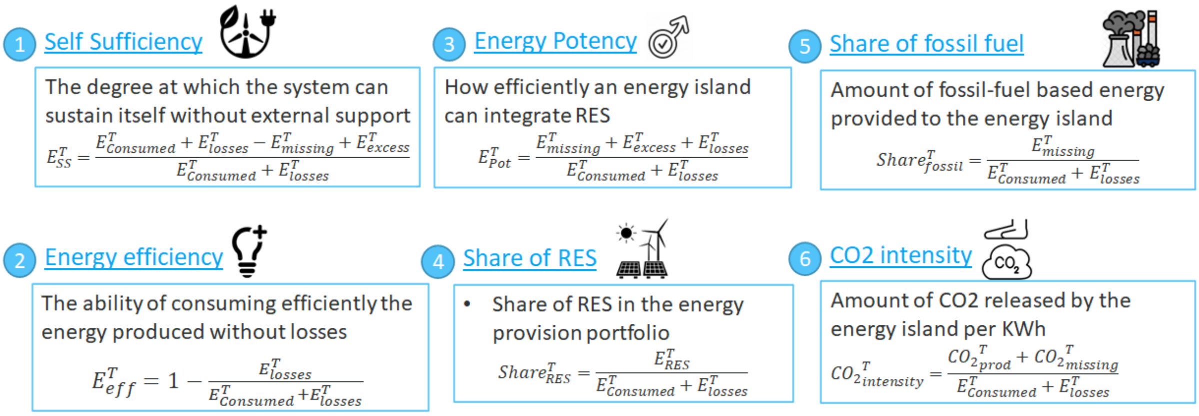
Hence, in the next subsections, a classification of the technical KPIs based on the type of so-called energy vectors (heat and electricity) is indicated to correctly categorize the different types of energy being consumed and/or provided. This categorization is stemming from the actual requirements of the different pilot sites to reflect separately the performance of each of the energy types or vectors and assist in tracking them independently.

III.2. Selected technical heat/electricity KPIs

In this subsection, the heat/electrical KPIs measurements, definition, and mathematical formulas are discussed. The shortlisting process yielded six different KPIs that could be monitored and tracked. Those technical heat/electrical KPIs are dedicated exclusively to assessing the heat/electrical sector within a district, an energy island, or a local energy community. These KPIs are namely:

1- Self-sufficiency or autarky indicator
2- Enegy efficiency indicator
3- Energy potency indicator
4- Share of fossil fuel
5- Share of Renewable Energy Sources (RES)
6- CO2 intensity

An overview of the different selected technical KPIs is given in



① Self Sufficiency

The degree at which the system can sustain itself without external support

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

② Energy efficiency

The ability of consuming efficiently the energy produced without losses

$$E_{eff}^{T} = 1 - \frac{E_{losses}^{T}}{E_{Consumed}^{T} + E_{losses}^{T}}$$

③ Energy Potency

How efficiently an energy island can integrate RES

$$E_{Pot}^{T} = \frac{E_{missing}^{T} + E_{excess}^{T} + E_{losses}^{T}}{E_{Consumed}^{T} + E_{losses}^{T}}$$

④ Share of RES

- Share of RES in the energy provision portfolio

$$Share_{RES}^{T} = \frac{E_{RES}^{T}}{E_{Consumed}^{T} + E_{losses}^{T}}$$

⑤ Share of fossil fuel

Amount of fossil-fuel based energy provided to the energy island

$$Share_{fossil}^{T} = \frac{E_{missing}^{T}}{E_{Consumed}^{T} + E_{losses}^{T}}$$

⑥ CO2 intensity

Amount of CO2 released by the energy island per KWh

$$CO_{2}{}_{intensity}^{T} = \frac{CO_{2}{}_{prod}^{T} + CO_{2}{}_{missing}^{T}}{E_{Consumed}^{T} + E_{losses}^{T}}$$

Figure III-1: Summary of selected technical KPIs

In the following sections, the different indicators are explained one by one.

III.2.1. Self-sufficiency or autarky indicator

In simple terms, the self-sufficiency indicator reflects the degree to which a certain district, an energy island, or a local energy community is independent from the public heating/electricity grid system or network and/or from the unrenewable energy heat/electrical sources. It represents the extent of autarky at a certain moment or time interval T to meet the requirements in terms of heat/electricity. Similarly, it embodies the percentage of energy being consumed from non-sustainable resources also dubbed as energy missing (imported energy from the grid) compared to the one consumed locally by the end-users in addition to the central consumption within the buildings as well as the heat/electricity losses volumes occuring after the energy provision (Herenčić et al., 2021).

The formula to calculate this KPI is given in the following for the heat/electricity energy vector and is adapted from the one proposed by (Herenčić et al., 2021).

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

E_{SS}^{T} represents the self-sufficiency KPI values over an observed period T. The formulation is generally applied to an annual calculations 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. Concretly, 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 assessement 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. Indeed, the actual heat or electricity amount was not fully transported to the consumption sinks but instead it undergoes several decreases all over the transport network (district heating or electric grid). This type of energy is lost in the conversion operations or along the heat pipes, or in the wiring system in the electricity distribution network.

On other hand, the $E_{excess}^{T} = \sum_{t=1}^{t=T} E_{excess}^{t}$ reflects the amount of heat/electricity that is available at some time interval T but cannot be nor consumed neither stored for some technical impediments or behavioral restrictions during some period of time T and thus injected to the public heating network/electricity grid.

The suitability of this indicator lies in that it assesses the actual performance status in terms of thermal/electrical energy independency of the energy island and to what extent it is achieving its autarky goal in percentage.

In this context, it is notable that the metric $E_{excess}^{T} - E_{missing}^{T}$ is an algebraic value. Its value is positive when there is an exportation of thermal/electric energy to the grid, otherwise its value is negative when the energy island is importing energy from the grid. Certainly, the value of this KPI is positive and usually lies in the interval [0%-100%]; however, in the case of exporting the excess heat/electricity compared to the actual consumption and losses, its value exceeds 100% expressing that the energy island is self-sufficient and is a net exporter of thermal/electrical energy at a certain period T.

According to (Hauck et al., 2021), a more electricity focused conclusion is drawn regarding the effect of finer granularities or time resolutions on the overall picture of energy systems cumulative flows. The impact of reducing this value is investigated through the introduction of three different time resolution models (1-second, 1-minute, and 1-hour resolution). It is underlined that finer-grained temporal resolutions had non-significant influence on the self-consumption and self-sufficiency indicators.

Furthermore, this KPI can inform the decision makers about the independency situation for the selected time horizon T and somehow incentivize people to act to enhance it by saving energy and reducing wasted heat/electricity or some other behavioral practices such as not using the energy-intensive consuming devices in certain time intervals. It should be highlighted that the selection of the evaluation time period T strongly affects the values of the self-sufficiency KPI. Similarly, it emphasizes the importance of being capable of retaining the energy excess by consuming it at the right moment of overproduction or storing it effectively or exporting it to the grid. Finally, the optimization of energy missing which is imported can be performed through the introduction of variable thermal/ electric energy supply sources that are local and sustainable in terms of being eco-friendly and green-driven resources (RES integration). Therefore, this indicator could be crucial for both the energy managers and the citizens as important stakeholders in the energy island.

III.2.2. Energy efficiency indicator

Briefly, the energy efficiency indicator designates the potential of having zero energy losses of energy in addition to quantifying the distance to attain that goal.

In formal words, the key indicator for the assessment of energy efficiency of the modeled energy island E_{eff}^{T} evaluates how efficiently an energy island can resolve the problem of having energy losses all over the network with its borders. An energy island that is perfectly efficient in terms of no losses would have an E_{eff}^{T} value of 100%.

In order to calculate this indicator, we rely on the formula below.

$$E_{eff}^{T} = 1 - \frac{E_{losses}^{T}}{E_{Consumed}^{T} + E_{losses}^{T}}$$

Where the terms of the formula were introduced earlier.

In this regard, the $E_{losses}^{T}$are assumed to be negligible for the electricity network evaluation within an energy island based on (Kenneth Van den Bergh et al., 2014). In detail, the resistive loss values for AC current is around 3.34% per 1000Km line of electric power loss (Curt Harting, 2010). However, in the heating domain they are significant (‘heat losses’, 2022). In this regard, this indicator is more destinated to appraise the performance of the heat energy rather than the electricity since its value will be always 100% for the electricity energy-vector.

The utility of this indicator is the assessment of the potential of the energy island to reach the ideal state by reducing each kind of losses during the various transformation processes and the energy transit infrastructure.

III.2.3. Energy potency

Briefly, the energy potency indicator designates the potential of having zero energy losses, zero energy excess, and zero import of energy from the grid in addition to quantifying the closeness to attain it in that regard. Moreover, this KPI reflects the aptitude for improvement to reach the optimal energy island status which is being energetically self-sufficient. One could also say that this KPI represents the ”Energy Island Balance Ideal”.

In formal words, the key indicator for the assessment of potency of the modeled energy island is E_{Pot}^{T} and it evaluates how efficiently an energy island can integrate variable RES. In this sense, the energy potency KPI tends to assess the capability of an energy island to match the provision and load profiles without any excess of energy whilst being supplied exclusively by RES in the most optimal scenario. As such, the excess of energy that could not be neither consumed nor stored at a some time t will add up to penalize this KPI. Also, when the energy losses incur either imported or locally provided by RES are better stored or directly consumed. Indeed, an energy island that is perfectly efficient in terms of no losses, excess, or missing energy would have an E_{Pot}^{T} value of 0 (Herenčić et al., 2021).

In order to calculate this indicator, a formula is proposed by (Herenčić et al., 2021) and includes different terms that can be challenging to measure in some circumstances. The following formula enables us to do the calculation of this KPI.

$$E_{Pot}^{T} = \frac{E_{missing}^{T} + E_{excess}^{T} + E_{losses}^{T}}{E_{Consumed}^{T} + E_{losses}^{T}}$$

Where $E_{Consumed}^{T} = \sum_{t=1}^{t=T} E_{consum}^{t}$ as explained earlier is the amount of heat/electricity energy spent during some period of time T.

Likewise, the $E_{missing}^{T} = \sum_{t=1}^{t=T} E_{missing}^{t}$ is representing the imported amount of heat/electricity energy during some period of time T.

$E_{excess}^{T} = \sum_{t=1}^{t=T} E_{excess}^{t}$ reflects the amount of heat/electricity that is available at some time interval T but cannot be nor consumed neither stored for some technical impediments or behavioral restrictions during some period of time T and thus injected to the public heating network/electricity grid.

Similarly, $E_{losses}^{T} = \sum_{t=1}^{t=T} E_{losses}^{t}$ are the sum of amounts of energy losses during an observed period of time T.

The utility of this indicator is the assessment of the potential of the energy island to reach the ideal state by minimizing each of the terms of that formula first by reducing each kind of loss during the various transformation processes, the energy transit infrastructure, and applying the best practices. Similarly, it emphasizes the importance of being capable of retaining the energy excess by consuming it at the right moment of overproduction or storing it effectively. Finally, the optimization of energy missing which is imported can be performed through the introduction of variable thermal/ electric energy supply sources that are local and sustainable in terms of being eco-friendly and green-driven resources (RES integration). In a nutshell, the energy potency KPI is substantial to quantify the extent to which the energy island is distant or close to reaching its optimal balance state in terms of energy management.

III.2.4. Share of fossil fuel

Another KPI of significant interest is the share of fossil fuels in the thermal/electric energy consumption overall array. This percentage expresses the real amount of thermal/electric energy being taken from either the grid deemed as a fossil fuel-driven source or locally generated with gas boilers or any other engines for heat/electricty generation functioning on natural gas. Therefore, this value represents the proportion of energy stemming from non-renewable energy concerning the entire heat/electricity energy consumed by the end-users which can be households, industries, or machines plus the energy losses in the system.

Formally, this measure is calculated through the ratio of the sum of each heat/electricity energy supplying the energy island relatable to fossil-fuel generation (non-RES resources) divided by the final thermal/electric energy reaching the end-users (thermal/electric energy sinks) as well as the energy losses occurred within the energy island. The following formula expresses mathematically the computation of this value.

$$Share_{fossil}^{T} = \frac{E_{missing}^{T}}{E_{Consumed}^{T} + E_{losses}^{T}}$$

The different terms figuring in the $Share_{fossil}^{T}$ KPI were explained earlier and are similar in values for this KPI.

III.2.5. Share of Renewable Energy Sources (RES)

Following the same logic and based on (Pramangioulis et al., 2019), an additional KPI considerably noteworthy is the share of Renewable Energy Sources (RES) in the thermal/electrical energy consumption evaluation process. This percentage expresses the real amount of thermal/electrical energy being withdrawn from either sustainable and eco-friendly heat/electricity resources in any generation fashion (energy transformation from a renewable source to thermal/electrical, direct/indirect production of heat/electricity out of renewables, etc), or imported thermal/electrical energy wasted from other external sources outside the energy island borders or reused heat/electricity energy. Therefore, this value represents the proportion of energy stemming from renewable energy with respect to the entire heat/electricity energy consumed by the end-users.

Formally, this measure is calculated through the ratio of the sum of each heat/electricity energy supplying the energy island relatable to non-fossil-fuel generation (RES resources) divided by the final thermal/electrical energy reaching the end-users as well as the energy losses occurred within the energy island. The following formula expresses mathematically the computation of this value.

$$Share_{RES}^{T} = \frac{E_{RES}^{T}}{E_{Consumed}^{T} + E_{losses}^{T}}$$

In this equation, $Share_{RES}^{T} = \sum_{t=1}^{t=T} Share_{RES}^{t}$ represents the overall amount of thermal/electrical energy sourcing from RES or re-used heat/electricity from external sources. In this regard, the reusability potential of the heat/electricity is valorized and thus the amount that is loaded to the energy island stemming from fossil-based resources but destined for a second-time use (heat excess by-product from a factory) is classified as a renewable energy. For instance, the dissipating heat energy is rather used for other useful purposes such as injection to the district heating sytem than wasted and unexploited.

III.2.6. CO2 Intensity

$CO_2\, intensity$ is a KPI used for the environmental assessment of the energy island’s performance. Referring to (Herenčić et al., 2021), this indicator can also be considered under the technical environmental dimension since its calculation is heavily dependent on the technical values of thermal and electrical energy generation. Bearing in mind that the objective of integrating various innovative energy-related technologies in the energy islands, essentially by increasing the variable RES and encouraging low carbon technologies, quantifying the effect of those endeavors on the GHG emissions is of primary concern knowing that the EU countries are implementing the energy transition targetting the zero-emission goal.

This measure reveals the temporal evolution of the CO2 emissions intensity within the energy island unlocking the driveway to monitor the CO2 footprint of the heat/electrical energy consumed. In mathematical terms, the formula for calculating the average CO2 intensity for a certain energy island is given in what follows and inspired by (Herenčić et al., 2021).

$$CO_{2\,intensity}^{\;T} = \frac{CO_{2\,prod}^{\;T} + CO_{2\,missing}^{\;T}}{E_{Consumed}^{T} + E_{losses}^{T}}$$

Where $CO_{2\,prod}^{\;T} = \sum_{t=1}^{t=T} CO_{2\,prod}^{\;t}$ represents the amount of CO_2 emissions generated while locally producing heat/electricity by any technology through RES or non-RES over an observed time horizon T. This metric can include the gas imports that are destined for natural gas-fired boilers to generate heat, the CO2 emissions incurred by consuming the electricity required by the heat pumps to generate heat, and any other operation designed to produce energy within the energy island to meet the end-users' requirements.

The second term concerns the ${CO_2}_{missing}^{T} = \sum_{t=1}^{t=T} {CO_2}_{missing}^{t}$ which represents the amount of CO_2 emissions caused by the 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.

Following the same logic in (Herenčić et al., 2021), the emissions occured during the lifecycle of the different equipement (manufactoring, recycling and disposal processes) are discarded. Concerning the CO_2 intensity values, the average of emissions' intensity when withdrawing the power from the grid is calculated based on an average yearly factor for the electricity for the specific use case since there is a lack of data on the general grid emission factor.

III.3. Identified process for technical KPI evaluation

In order to allow for reliable and replicable assessment of KPIs, a standardized process is needed. The suggested approach for dealing with the data to acquire the different equation terms (metrics) needed to proceed with the different calculations of the selected technical KPIs for both energy vectors heat and electricity is given in **Figure II-2**.

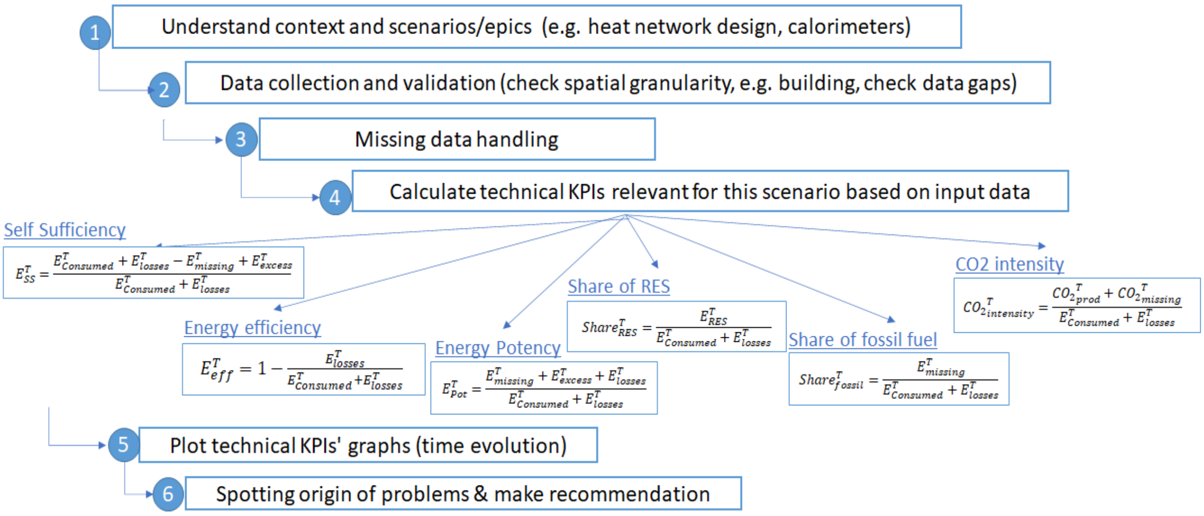


Figure III-2: Technical KPIs assessement process. *Source: Own creation*

The first phase in the assessment process concerns grasping the environment of interest and distinguishing between both energy vectors since their evaluation is separate. At this stage, simplified versions of the heat network as well as the electricity structure existing within the energy island need to be designed aiming to shed light on the different techno-economic features and more concretely on the various determined technical KPIs involvement. Similarly, in this step, pinpointing the scenarios of concern for the heat and electricity energy vectors for pilots pursuing the defined epics is addressed. At this level, a tight connection with the pilot sites is required intending to compile the infrastructure characteristics and comprehend the nature of the challenges faced within each of the energy vectors.

The second phase concerns the data gathering operation where the availability of the required figures is checked and confirmed. Besides, the meaning and labelling of the data are discussed to properly reflect the correct measures and convey the right numbers to the KPIs' formulas. Here, the definition of the Spatio-temporal granularity is addressed to standardize the calculations. This means that the locations of the various physical components (electrical meters, calorimeters, sensors, pipes, wiring, intermediate energy conversion appliances, and so forth) in addition to the areas of the energy consumption units (the buildings and others) are specified concerning the spatial dimension on the one hand. On the other hand, regarding the time resolution aspect, a common agreement on the temporal granularity (yearly, monthly, hourly, etc.) needs to be explicitly defined as well at that stage. The final sub-step in this phase is to validate the data collected and its correctness.

In the third phase, regarding particularly the fine-grained data streams, some bottlenecks can show up concerning the smooth flow of the data capturing process where several reasons can cause the interruption of getting data for some time interval. This disruption can be problematic if we are aiming at measuring the technical KPIs. Therefore, in this respect, the lacking data is managed according to its type and logic following certain approaches. More specifically, certain patterns can be fed to the models, and thereafter an inference technique is applied.

In the fourth phase, the different technical KPIs are assessed with the input data models that have been collected and treated. Each of the technical KPIs for both energy vectors heat and electricity are fed to the constituent equation terms.

The next phase deals with the graphical representation of the technical KPIs. Indeed, the graphs are provided in a time evolution trend to reflect the temporal progress of those with the envisioned energy island objectives defined locally, at several other layers (regional, national, European, and international).

In the final phase, the emphasis is shed on pinpointing the influential terms or sub-terms to act accordingly to optimize the value of certain technical thermal or electrical KPIs. Undoubtedly, several points cannot be changed due to the impossibility of acting on those. There are a few characteristics that can be changed either by energy managers or by the community itself by behaving in a certain way. After the identification of the problematic origins, a recommendation making can be performed aiming to optimize and rationalize the behaviour in terms of energy management.

III.4. Encountered Challenges and Solutions

Throughout the process of technical KPIs assessment, several challenges can be encountered that interrupt the regular and smooth flow of the evaluation procedure. In the following sections, we are going to enumerate the different pitfalls faced in this process together with the solutions proposed to tackle those issues.

In the first subsection, the complexity of the energy island energy systems involved, and the entanglement of energy-vectors is discussed. Across the second section, the gap between the data labelling and actual physical components is reported, the data accessibility constraints and dependence on energy managers for data gathering is discussed, the data anomaly or inconsistency in some circumstances is addressed, and the energy excess calculations intricacies are presented. In the last subsection, the uncertainty regarding the decision of classifying certain energy streams is addressed.

III.4.1. Energy islands systems complexity and energy-vectors entanglement

Diving into the technical aspects of the energy island can be time-consuming, especially when comprehensively involving the different components of the infrastructure. In fact, the differentiation between both energy vectors studied for the energy islands is not always evident since there are several interactions between both areas of energy. Both network designs of heat and electricity are mandatory to drive the calculation towards a sound direction of KPIs computation. For that reason, the different elements providing and consuming the specific type of energy were represented in an attempt to model as realistic as possible the infrastructural specificities for each of the energy islands taking into consideration the thermal/electric perspective.

To overcome this issue, we devised an abstract representation twin comprising just the principal elements (the consuming and producing units) with a zoom on the most impacting ones for each of the networks.

III.4.2. Data issues

In a data-related context, grasping the meaning of the different metrics coming from each of the items existing in the network, and linking them to a meaningful term in the technical KPIs can be a challenging task. Here, we can give the example of binding the available data on the IT tool (Grafana platform) to the infrastructure for the Ghent case. More in detail, the mapping of certain parameters such as the photovoltaics designation’s convention are not easily straightforward. The calorimeters’ labelling is knowledge-dependent meaning that it requires a profound understanding of the infrastructural components as well as their locations. Some meetings with the energy manager(s) and data responsible (s) took place to clarify the meaning of the labels and what do they represent, aiming to solve this problem.

Under the same scope, the historical data collection depends sometimes on the energy managers of the energy island themselves, especially when aggregated over some specific time interval. As a matter of fact, providing these data requires effort and time by the energy managers and is a whole process for them particularly when the gathering is not fully automated. For instance, in Poznan pilot site, the thermal data must be collected by the energy manager(s) in a manual fashion from all the buildings under scope in the energy island.

Additionally, the accessibility to some specific data streams impacts the evaluation process of technical KPIs, notably when the numbers are figuring in the technical KPIs formulas. In that regard, we can mention the example of the Ghent case concerning the residential heat consumption data that was not accessible for each apartment involved in the energy island/ energy community. In this scenario, the problem is the data availability, that needs to be granted by the end-users to be able to use it.

Another encountered barrier is the inconsistency or anomaly in data numbers even after investigating their origins. As a matter of fact, the flow of certain numbers, particularly of the consumption and losses across the heating network can be illogical which can have various reasons either merely related to the data quality and its accuracy or to the real situation of the energy island under the scope. In that respect, the Ghent case for detecting substantial losses on the heating network in the heat transportation from one location to another depicts an obvious example of the illogicality when comparing it to the energy being provided from fossil-fuel resources in certain cases. Aiming to overcome certain real-world restrictions, certain assumptions were adopted in accordance with the energy managers to proceed with the calculation, such as the approximation of the heat consumed per square meter while considering the insulation performance of the apartments and generalizing to the whole inhabited area.

In the same vein, a similar constraint came across the way concerning the energy excess measures that can be tricky to obtain since it is not straightforward to know precisely how much energy was available and cannot be consumed at a certain time. In fact, the different measures regarding the formulas’ terms are heavily dependent on the existence of physical installations metering the loads inflowing and outflowing such as the calorimeters and the electrical meters in addition to where they are placed which defines especially for the heat quantification the current load to be able to draw conclusions of the energy that is really consumed or lost in the system. Thus, the number and the performance of those devices strongly influence the quality of the obtained results in terms of technical KPIs assessment.

III.4.3. Decision uncertainty about RES or non-RES categorization

The last roadblock encountered was the uncertain decision about classifying the recovery of heat energy as renewable or non-renewable since recuperation is a reusing behaviour and is appreciated. However, its categorization as eco-friendly or not was problematic. In this regard, the classification of the heat recuperated from a neighbouring factor (Christyens) in Ghent is most relevant example about uncertainty in deciding about including it as RES or non-RES for thermal energy provision. This uncertainty is caused by the reusability principle since this heat is destined for a second lifetime instead of wasting it in the atmosphere even though that the original source is non-RES. For that reason, several assumptions were adopted to proceed with the assessment. Those assumptions are pilot-site specific and need to be described on a per scenario basis.

Likewise, it was a challenge to decide upon the energy transformation process where certain appliances are at the borders between both energy types. For instance, the heat pumps (HPs) are considered as devices that heat the households by using an electric motor. In this case, its evaluation can be included in the heating energy vector as well as in the electricity energy vector. Following the logic of only focusing on the generated type of energy (whether it is heat or electricity), the classification of the trans-border devices is decided.

IV. ECONOMIC KPIS RELATED TO ENERGY ISLAND

IV.1. Literature background on evaluation of energy islands based on economic measures

In the economic dimension, the focal point is the cost-benefit analysis while taking into account the different stakeholders' viewpoints. In this regard, several business goals are sought. Among those objectives, striving to implement technological solutions for energy management that are deemed viable and worthwhile investments. For that reason, determining and defining business driven KPIs is of the uttermost priority. Those indicators are useful to point to the performance of the different technological implementations and the physical installations being evaluated.

For example, the energy managers would like to be informed about the costs of production and consumption of the different types of energy, and residents of apartments would like to have a view of the economic benefit of their flexible consumption behaviour.

Certainly, the economic scope is of interest to all the stakeholders like mentioned in (Pramangioulis et al., 2019). Concerning the market operators' perspective (energy providers, energy suppliers, energy aggregators where a cluster of companies form partnership for large-scale energy pricing advantages benefitting from the so-called economy of scale, energy service companies providing an array of energy services such as infrastructure outsourcing, retrofitting and upgrading certain non-friendly energy aspects, and so forth), their principal goal is profit maximization from their investment. Thus, the technology or the set of actions and implemented smart methods that are investable and profitable from the economic aspects are of major interest to those actors. Monitoring the economic KPIs for energy islands can be a direct index for the market operators to take share in certain endeavours by investing in a viable technology or DR services project.

Referring to the literature, several economic KPIs are used to assess the energy-related scenarios. The economic evaluation in (Brum et al., 2015) lies in this context where a standalone electricity-based system is proposed against the business as usual (BAU scenario) in order to ensure the heating, domestic hot water, and air-conditioning requirements of three dwellings. The defined two scenarios are the proposed improvement scenario consisting of centralizing the system to provide the space conditioning as well as the domestic hot water supply by introducing a central ground-sourced heat pump together with a central electric boiler. The baseline scenario is the regular business consisting of a decentralized system where there is individual heaters and storage-type water heaters based on electricity, and air conditioning units. Based on the levelized cost financial values, a conclusion is drawn concerning the prohibitive cost of entirely electrifying the system since substantial capital expenditures for installing certain appliances are unavoidable. Thus, the business as usual had a less levelized cost in contrast to the proposed scenario with centralization fashion. It has been shown that even though the consumption of electricity is less important with the introduction of the ground-source heat pump, the capital cost to purchase the proposed appliances are high.

In a related context, (Baneshi and Hadianfard, 2016) investigates the potential of transforming the electric generation fashion of large non-residential electricity consumers into a hybrid fossil, RES-based, and Battery system based. The impact assessment is addressed through a techno economic KPIs comparison of the BAU and the envisioned hybrid scenario regarding the settings in the specific area of southern Iran. The success indicators to quantify that effect are the cost of electricity (COE), the fraction of RES (Share of RES), the Net Present Value (NPV), and the Internal rate of return (IRR). Results showed that with the same sizes of RES-based generation units (PVs and wind turbines), the standalone off-grid energy system along with the battery system induced higher cost of electricity. On the other hand, for the grid-tied system configuration without including the battery storage, the costs of electricity are less. It is also worth mentioning that there is no direct correlation between the battery system introduction and the RES share for that studied instance.

In an electricity generation context, based on the assessment of both economic variables, (Abdelhady, 2021) addressed the profitability of the solar dish (SD) technology based power plant in the Egyptian desert relying on the NPV and LCOE values. The results showed that the LCOE is computed to be 13.38 ¢/KWh and the LCOE and the NPV measures are susceptible to the collector cost.

Other several use cases assessment studies are investigated in (Ma et al., 2018). In this paper, a hybrid distributed energy resources (DER) system comprising a combined heat and power (CHP), Photovoltaics (PVs), and a wind power (WP) is proposed. The scenarios to be evaluated are defined for seven different Chinese cities while considering a baseline scenario consisting of grid-tied and a non-RES fashion energy generation. The assessment is conducted relying on several technical, economic, and environmental variables. The economic ones are the cost of energy (COE), total net present cost (NPC), return on investment (ROI), and payback period (PBP). The results obtained on the different scenarios concluded that the optimized DER system contributed to meet the requirement loads (electrical and thermal) in addition to the achievement of an environmental decarbonization and a decrease of the lifetime costs for the majority of the scenarios against the reference scenario.

From a community-oriented perspective, in (Viti et al., 2020), we find an investigation of the feasibility of the energy community framework and an assessment of its role to propel the energy transition as well as an economic benefits quantification of acting as a cluster of prosumers instead of self-consumption units. It has been found out that the energy communities (ECs) constitute a favourable framework that catalyses the integration of RES within the community buildings by increasing the self-consumption technical indicator against the self-consumption environment. In this study, numerous economic KPIs are used to financially appraise the performance of the new proposed setup of EC. In this regard, the measures of NPV and IRR were positive for the different economic scenarios consisting of the comparison between the business-as-usual environment and the different EC’s settings.

In richer settings and by including the hydrogen energy-vector, (Herenčić et al., 2021) studied two different environment-related energy Multi-vector energy communities (MECs) in island Ærø in Denmark and the island Vis in Croatia from a techno-economic perspective. In this regard, they concluded, based on the levelized cost of energy (LCOE) consumed obtained values, that the Hydrogen-based solutions implemented to meet the heat and electricity requirements of the energy islands are still premature solutions and show prohibitive costs. In the case of the hybridization of RES-based technologies along with the battery system and the gas imports, the solutions are more cost-effective, but they do not fulfil the decarbonization goal as envisioned.

In the reviewed literature, numerous approaches are proposed and evaluated with respect to baseline scenarios that urge the envisioned energetic transition. These models are able to quantify in certain cases the extent of the simulated configurations proposed of energy systems. In other circumstances, the involvement of those energy systems within a broader framework called energy islands or energy communities is investigated.

Hence, from an economic perspective, the application of carefully selected and then assessed financial KPIs is a key driver to gauge the multiple scenarios in each of the energy islands’ settings.

IV.2. Selected economic KPIs

Across this section a more detailed description of the different economic KPIs investigated is addressed. In the literature, several KPIs are proposed and assessed. The selection process implies the incorporation of the ones prevailing and commonly used in evaluating the energy systems in majority based on the idea that energy islands are constructs involving multi-energy projects operating synergistically towards the achievement of the manifold goals of greenness, sustainability, financial viability, and social success.

Similar to the technical KPIs that were reduced to a shortlist, the economic KPIs as well are shortlisted to fewer ones to reflect different level of insights and to be concise in conveying the essential information judged relevant by the different stakeholders.

The economic KPIs are namely:

1- Levelized cost of energy (LCOE)
2- Net present value (NPV)
3- Internal rate of return (IRR)
4- Payback period (PP)
5- Discounted payback period (DPP)
6- Load purchasing from the grid
7- Energy sold to the grid

For instance, the LCOE is defined clearly in (Ferrari, 2021), and it is used widely in the literature. In (Cusano et al., 2019), it was usual to make a comparison between several ocean related renewable energy producing technologies. Following the same track, in (Herenčić et al., 2021) employed the LCOE consumed in order to assess the different energy producing alternatives and pick the profitable option among them. In (Sang et al., 2018), the different options of ocean-based power plants and drawing comparison between on-shore and off-shore wave power plants based on the LCOE measures is performed. It should be highlighted that the LCOE and NPV are closely related economic KPIs and therefore in (Abdelhady, 2021), the focus is on the sensitivity analysis of the LCOE and NPV for a specific use case in the south of Egypt. As a matter of fact, the NPV as well is a broadly used economic metric to assess the profitability of various sorts of projects in all fields. For instance, the NPV as a mean of economic viability indicator was utilized in (Bravo-Fritz et al., 2016) to appraise the numerous scenarios defined in relation to the microalgae-based biorefinery. Additionally, the NPV is used in (McInerney and Bunn, 2017) to measure the added value of wind turbine over-installation.

In the next subsections, a one-by-one description of the selected economic KPIs is given, while respecting the energy vector being assessed either it is thermal energy type or electrical one.

IV.2.1. Levelized cost of energy (LCOE)

According to the Energy Information Administration in the US (‘EIA’, 2022) Levelized Cost of Energy (LCOE) is often cited as a convenient summary measure of the overall competitiveness of different technologies.

LCOE can also be called Levelized Energy Cost (LEC) and is a KPI employed to examine and compare various energy systems. There are two different usages identified in the literature for the utility of this indicator. It represents either the per-kWh cost of building and operating a generating plant over an assumed financial life and duty cycle (LCOE generated), or the per-KWh cost of consuming energy (LCOE consumed).

Essential to the LCOE is that it does not capture the cost of energy at a specific moment rather levelized (averaged) over the overall lifetime of the project. It takes into account the time-value of money to discount the costs of the project’s lifetime.

IV.2.1.a. LCOE consumed assessment

The KPI LCOE_consumed represents the overall energy consumed on all different energy vectors (heat, electricity) and the whole set of technologies implemented or expected to be implemented.

According to (Herenčić et al., 2021), the LCOE analysis includes capital costs, fuel costs, and operation and maintenance costs, as well as costs of missing energy (imported energy). That way the energy community can assess the costs for the used energy and compare different multi-energy vector options available for the energy island. The LCOE formula is as follows, based on (Herenčić et al., 2021)

$$LCOE^{T}_{consumed} = \frac{CRF_{Il} * \frac{T}{T_y} * (\sum_{l=1}^{L}(C_{Il} + C^{T}_{Fl} + C^{T}_{OM\,l}) \ + C^{T}_{missing})}{E^{T}_{consumed} + \ E^{T}_{losses}}$$

Where:

The energy island in this case is viewed as a whole and all the technologies are assessed in a comprehensive way. More technically, the different terms existing in the numerator are representing all the possible costs that a technology (gas-driven, RES-driven, Hydrogen-driven) can incur throughout its assumed lifetime.

- C_{Il} are investment costs in each technology l, l ∈ {1,2, ⋯, L}. Those costs are known as well capital expenditures (Capex). Those represent the property, plant and equipment and intangible assets related to technology implemented.
- C^{T}_{Fl}:fuel cost over the observed time horizon T (When inflation plays, we can apply LEF)
- $C^{T}_{OM\,l}$: $operation\ \&\ maintenance\ costs$ over the observed time horizon T
- CRF_{Il} (Capital recovery factor) = $\frac{\mathrm{i}(1+i)^{T_{Il}}}{(1+i)^{T_{Il}}-1}$. This value serves to annualize the investment costs by using the investment lifetime T_{Il}. (Meaning: it is expressing the upfront investment cost by an equivalent series of recurring annual investments). See appendix for more info on this factor.
- T_{Il} : $lifetime\ of\ the\ investment\ in\ technology\ \boldsymbol{l}$
- i: $the\ weighted\ average\ cost\ of\ capital$ (WACC)
- $\frac{T}{T_y}$: $the\ ratio\ of\ the\ observed\ time\ horizon\ T\ and\ horizon\ of\ one\ year$

IV.2.1.b. LCOE generated assessment

LCOE_generated regards the assessment of the investment worth in terms of generation capacity of energy. Based on the UK government definition (UK government, 2020) LCOE (generated) is "defined as the ratio of the net present value of total capital and operating costs of a generic plant to the net present value of the net electricity generated by that plant over its operating life."

Note that, opposite to the case for the LCOE_consumed, there is no consideration of the fuel or gas costs in the LCOE_generated as we consider the levelized cost of the power plant (energy generating energy island).

In (Cusano et al., 2019), the LCOE generated is computed for certain RES-based simulated power plants. The LCOE generated serves to compare the different promising technologies for energy production and to decide according to the current $LCOE_{generated}$ in San Andres (Colombia). Let's follow the approach given there for the calculation of the $LCOE_{generated}$ for RES-based power plant.

First factor in the equation, similar to what we had for the LCOE_consumed is the investment cost for each technology.

$$\begin{aligned}&\text{Total installed cost}\\ &\qquad = \text{Power Plant output rating} * \text{system availability} * \text{average capacity factor}\\ &\qquad * \text{Capital Cost/KW}\end{aligned}$$

Where:

- Power Plant output rating is the nameplate capacity or rated output which is the amount of power that a power-generation plant can output while it is running, in specific ideal conditions ('Energymag', 2013).
- System availability is the percentage of the power plant availability during a year to generate the power. It is calculated based on the downtime of the power-generating plant.
- Average capacity factor reflects the intermittency of the power plant. Referring to (Neill and Hashemi, 2018), it is defined as "the actual electricity production divided by the maximum possible electricity output of a power plant, over a period of time". It is noteworthy to mention that the intermittency is a challenge for RES-based power plants. On the contrary, for the non-RES power plants, this value is higher reflecting less intermittency issues.

Next, also similar to what we did in LCOE_consumed, we introduce the CRF (see appendix) in order to get to the Levelized Cost of Investment (LCI):

$$\text{Levelized Cost of Investment } (LCI) = CRF_{i,n} * Total\ installed\ cost$$

Accordingly, when considering the annual energy production (AEP), we can also calculate the cost of energy for a unit of KWh produced as follows:

$$\text{Annual energy production (AEP)} = \text{Power Plant output rating} * \text{system availability} * \text{average capacity factor} * 365 * 24 \text{ (KWh)}$$

$$Unit\ Cost_{invest} = \frac{LCI}{AEP}$$

Now that we know the unit cost for the investment, we can focus on the calculation of the unit cost for operation, maintenance, repair, and replacement (OMR&R) across the lifetime of the power plant. Also, this is similar to the operational cost part in the LCOE_consumed, with the difference that we focus on generation here and therefore gas and fuel costs are not considered.

In the absence of inflation, Levelized Expenses Cost (LEC) would simply equal OMR&R costs.

Under the presence of inflation, the Levelized Expenses Cost (LEC) can be calculated by applying the ELF (see appendix), resulting in this equation

$$LEC = OMR\&R * ELF$$

In a next step, the cost of energy as a result of the OMR&R cost would be obtained by dividing the LEC by the AEP:

$$Unit\ Cost_{OMR\&R} = \frac{LEC}{AEP}$$

Finally, the sum of the cost of electricity from the capital cost and that from the OMR&R cost would generate the total levelized cost of energy (LCOE):

$$LCOE_{generated} = Unit\ Cost_{invest} + Unit\ Cost_{OMR\&R}$$

Equivalently to the LCOE, another metric following the same logic is called the levelized cost of heat (LCOH) which is more steered towards the thermal energy (Yang et al., 2021). Briefly, these values give us an idea about the overall cost per unit of production and enables us to compare the technologies of energy generation.

IV.2.1.c. LCOE consumed versus LCOE produced

It is worth noting that both calculation methods in sections IV.2.1.b. and IV.2.1.a. are almost equivalent, however there are some noticeable differences.

Where the LCOE_generated focusses on the case of a standalone RES power plant (no consideration of the fuel or gas costs), the LCOE_consumed tends to lump all the possible parameters for the selected technologies to be evaluated in an energy island. In this calculation technique, the energy island is seen as a unit consisting of diverse technologies (RES- and fossil fuel-based).

Another difference resides in the denominator of both calculations where the focus in the first method is on the energy produced by a certain power plant. However, the second method considers the overall energy that is consumed by the energy island as well as energy imported.

IV.2.2. Net present value (NPV)

Based on (JASON FERNANDO, JULIUS MANSA, et al., 2022), the net present value (NPV) reflects the profitability and viability of a certain entrepreuneurial venture. More concretely and as described in investopedia, it represents the algebraic difference between the present value of cash inflows of the specific project and the present value of its cash outflows, spanning over a studied period of time that can be its lifetime.

The usefulness of using NPV as an economic KPI for energy island evaluation is that is the Island has to assess its opportunities to invest in energy generation, savings or reuse, and these investments have to be profitable for someone, so that we need to put some euros on it and see whether the investment is worthwhile.

Indeed, the NPV assists the investors essentially to engage in a certain project that is deemed investable and profitable according to this financial index. Referring to (JASON FERNANDO, JULIUS MANSA, et al., 2022) and (A. Monti et al., 2016), the NPV is of-interest to be positive thereby the project would be worthwhile the investment thus attractive to the investors.

Concretely speaking, the project's outlay is required to be able to calculate this NPV value. This calculation is normalized to a specific time point at which the holistic image of numbers can be fairly converted based on the discount rate. This metric is employed in the discounted cashflow analysis to render the future cashflows to their today-values. This technique is called the timevalue of money. In what follows the general formula of NPV is provided and explained.

$$NPV = \sum_{t=0}^{n} \frac{CF_t}{(1+r)^t}$$

Where:

CF_t: representing the actual net cash value invested (outflow) or earned (inflow) during a specific time period. It is the subtraction of the inflow value minus the outflow.

t: represents the number of time periods investigated in a specific project (years or another granularity).

r: indicates the discount rate or the percentage of return that can be acquired when investing in other projects.

IV.2.3. Internal rate of return (IRR)

Similarily to the NPV calculations, the IRR is considered also as a financial index that reflects the profitability of an investment and to what extent can the venture be investable. The input data required to proceed with its calculation is the cash flow table of a certain project.

According to investopedia (JASON FERNANDO, KHADIJA KHARTIT, et al., 2022), the IRR is a financial estimator of the viability of investments. Technically, it is a discount rate that renders the NPV of the whole project zero while taking into account the time-value of money of the different cashflows.

The IRR value is provided in what follows.

$$NPV(irr) = \sum_{t=0}^{n} \frac{CF_t}{(1+irr)^t} = 0$$

In this case, CF_t is the cashflow at a generic year t.

As mentioned earlier, both the NPV and IRR rely on an identical formula. They also give similar information but the interpretation of one or the other concept might be easier depending on the situation. When comparing several projects (with known MARR), comparing them based on NPV and selecting the one with the highest NPV is the natural approach. On the other hand side, when evaluating a single project, it is probably more insightful to compare the calcualted IRR to the know MARR.

IV.2.4. Payback period (PP)

In the same logic of the two previous economic KPIs and based on (JULIA KAGAN et al., 2022), the payback period is a financial metric that represents from a temporal perspective the amount of time required a project or an investment to reach its breakeven point. Indeed, investors either corporation or people are expecting from a project to return their capital expenditure money back in the shortest possible timespan to be sure of the profitability and to prevent the exposure to risk.

Actually, the higher the value of the payback period (PP), the riskier the exposure to the market uncertainties are. Hence, the determination of this economic KPI is of interest for multiple stakeholders and especially the investors to overview the temporal viability of such endeavor.

In the concept of the evaluation of an energy island, we want to assess the time needed to pay back the investment in a certain element in the energy island, like PV panels or a community battery.

In formal terms, the payback period value is simply obtained by dividing the initial investment costs by the average cash flows (inflows - outflows) expected in the future. Indeed, the average cashflows comprehend the money value throughout the project lifetime considering the inflows such as earnings and actual returns of the project and the outflows including any type of charges or fees incurred under the scope of the project.

The formula to calculate the payback period value is provided in what follows.

$$Payback\ Period = \frac{CF_0}{Average\ annual\ revenue} = \frac{CF_0}{\frac{\sum_{t=1}^{n} R_t}{n}}$$

Where:

- CF_0 represents the cost value of the initial investment at t=0 (before the project's start)
- $Average\ annual\ revenue = \frac{\sum_{t=1}^{n} R_t}{n}$ is representing the sum of the anticipated cashflows for each time period t divided by the number of the considered number of periods in the project's lifetime.

IV.2.5. Discounted payback period (DPP)

The discounted payback period is covered the same idea as the payback period, but it is taking into account the time value of money. It is therefore a more correct metric, this is on the other hand side a little less straightforward to interprete.

The discounted payback period does not take into account the cash flows at the specific time period but rather the present value of each of the cashflows at that specific time point.

The formula to compute this economic KPI value is given as follows and is quite similar to the previous KPI.

$$Discounted\ Payback\ Period = \frac{CF_0}{Average\ annual\ discounted\ revenue} = \frac{CF_0}{\frac{\sum_{t=1}^{n} \frac{R_t}{(1+r)^t}}{n}}$$

Where

- $Average\ annual\ discounted\ revenue$ is representing the sum of the foreseen cashflows for each time period t discounted by the discount rate value and divided by the considered number of periods in the project's lifetime.

IV.2.6. Load purchasing from the grid

This economic KPI (self-explanatory) is strongly related to the technical dimension since it requires the amount of energy that is withdrawn from the external grid. The type of energy involved can be heat as well as electricity.

The load purchasing from the external grid KPI is defined in (Pramangioulis et al., 2019) as the overall expenses paid (the bill for the whole energy island). It includes the costs of energy that are invoiced for loads of the various activities provided by the seller to supply energy to the end-users, the transport charges related to the activities for the delivery and metering of the power supplied (transmission infrastructure, distribution services,etc.). Also the system charges covering the costs related to the general national gas/electricity network/grid (maintenance operations, RES subsidies,etc.). In this category, the taxation on thermal/electric energy is taken into account as well (VAT and others) (Viti et al., 2020).

The formula to compute the load purchasing from the grid economic KPI is given in what follows.

$$Load\ purchasing\ from\ the\ grid = \sum_{t=1}^{n} E_{Consumed}^{t} * Pr_{paid}^{t}$$

Where:

- $E_{Consumed}^{t}$ represents the value of the actual thermal/electricity load that is consumed (defined earlier in the technical KPIs section)
- Pr_{paid}^{t} represents the cost per unit consumed of heat/electricity in €.

It should be noted that the formula is generic and can be applied to several contract payment modalities, depending on the evaluated use case or the scenarios being assessed. Numerous arrangements based on the type of contract could be considered. Indeed, it can include, based on the different circumstances and contract terms, other fees to be paid to the energy provider such as network costs namely distribution costs and transport costs, and taxes and surcharges. The additional fees can be added as a fixed percentage or fixed costs to be paid on top of the actual energy that was withdrawn and figuring therefore in the bill.

This economic KPI is relevant for all the stakeholders that pay electricity/heating bills within the energy island. In this regard a lower value for this KPI represents the potential savings we make increasing the level of autarky in the island.

IV.2.7. Energy sold to the grid

Referring to (A. Monti et al., 2016), the energy sold to the grid is an economic KPI that represents the income structure of the energy island as a whole. Depending on the energy policy defining the feed-in tariff levels and the modalities of energy trading, the cash inflows are incorporated as the power load that is injected to the external grid which can be seen in some settings as a direct cash inflow or in other cases a saving structure by subtracting the amount that is delivered from the one that is withdrawn from the external grid which can be more profitable depending on the use case.

Similar to the load purchasing from the external grid KPI, the energy sold to the grid follows the same logic but considering the injection of energy instead of the consumption load.

$$Energy\ sold\ to\ the\ grid = \sum_{t=1}^{n} E_{excess}^{t} * Pr_{sold}^{t}$$

Where:

- E_{excess}^{t} represents the value of the actual thermal/electricity load that is injected to the grid
- Pr_{sold}^{t} represents the revenue per unit sold of heat/electricity in €

IV.2.8. Overview of selected economic KPIs

In summary, the seven economic KPIs are compactly presented in the following figure.

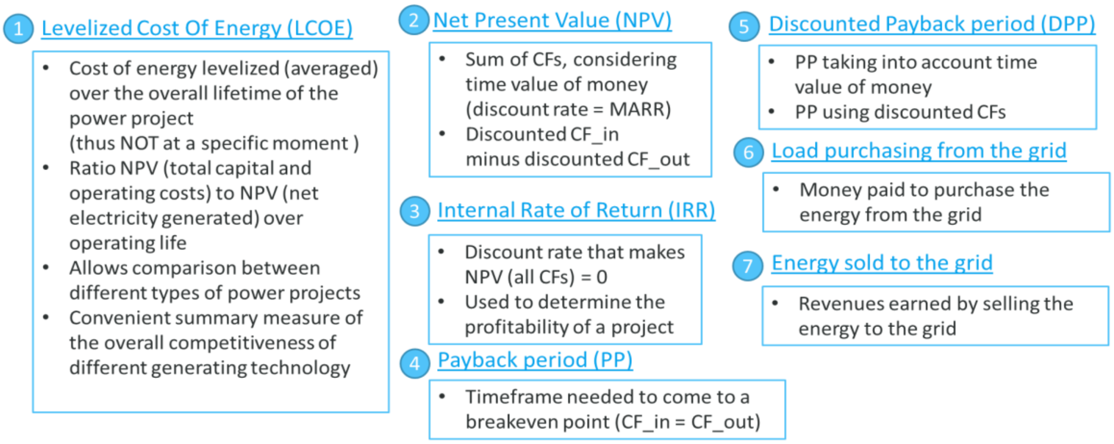


Figure IV-1: Summary of selected technical KPIs

IV.3. Identified process for economic KPI evaluation

Figure IV-2 below summarizes the different steps in the identified economic KPIs assessment process.

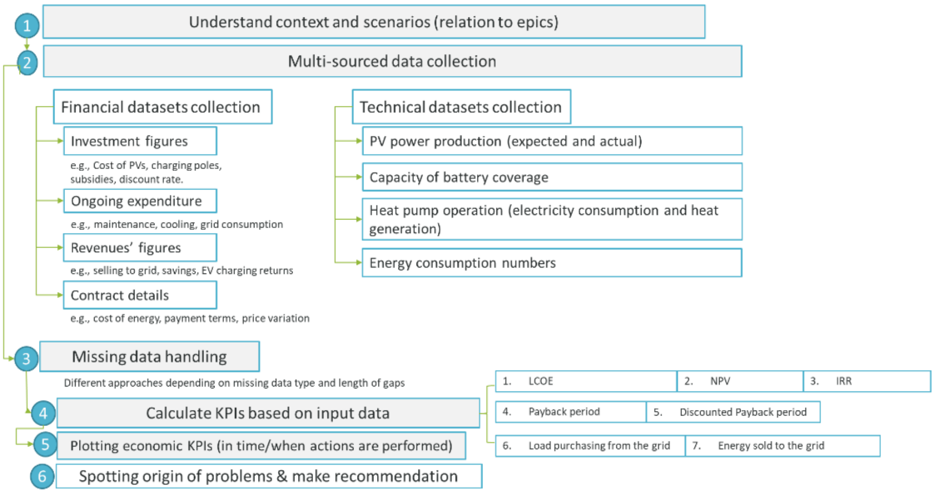


Figure IV-2: Process of economic KPI calculation.

The identified process for the economic assessment of energy islands is built on the generalization from the starting point of Ghent use case, since it is source where there is most data available. The first stage consists of understanding the economic context and the financial challenges that concern the different stakeholders. Thereafter, a definition of the principal scenarios that require to be assessed. Those scenarios can be related to the various epics determined beforehand by each of pilot sites to be implemented. In these settings, the database being constructed intending to quantify the economic KPIs requires more than the purely technical data. In fact, the other type of data concerns the financial numbers. In detail, a financial data collection step was carried out.

This financial data includes the investment figures related to the capital expenditure (Capex) and operational expenditure (Opex) figures such as the costs of Photovoltaics acquisition and installation, the costs of the charging poles implementation and installation, the different subsidies' structure, the battery energy storage system acquisition, etc. Another value of an uttermost importance is the discount rate that is used in different energy projects co-existing within the energy island.

Regarding the ongoing costs, several numbers can be classified under this category. For instance, the maintenance, cooling, and grid consumption expenses exist within this category. Moreover, the energy cost is affected by operation, maintenance, repair, and replacement (OMR&R) across the lifetime of the different energy projects and this needs to be accounted.

Concerning the revenues figures, they represent the cash inflows intended by the implementation of a certain energy investment. Under this category, there are several useful numbers that are required to proceed with the different economic KPIs calculation. For instance, the feed-in tariff, the savings accumulated as a result of the technologies implemented, and the returns from the electric vehicles charging poles are examples of the income.

Finally, another element should be mentioned concerning the modalities of energy consumption and the defined nature of costs. Here, the contract specifying the payment terms and the price variations is an essential financial aspect to be able to quantify the overall incurred energy consumption costs over time.

On the other side, in addition to the financial details, the technical datasets are the second pillar enabling the overall economic analysis. Indeed, the different numbers of RES and non-RES systems operating within the energy island must be captured in a comprehensive manner. Additionally, the characteristics and factors influencing the regular functioning of certain RES appliances such as the BESS (e.g., capacity of battery coverage, number of cycles) and the PVs (are investigated to define the extent of impact of the different parameters on the economic dimension. Indeed, another concept can be introduced to assess the cost for storing the energy which is the Levelized Cost of Storage (LCOS). In this context, it is obvious that the overall thermal and electrical energy consumed by the energy island is an indispensable value that needs to be collected individually.

The following step is comparable to the technical KPIs calculation process. As a consequence of the data missing for several reasons (as explained earlier in the section III.3.) the handling of data seems a necessary step. In detail, the data missing encountered during the multi-sourced data collection process concerns essentially the electricity data that is recorded on the PVs electrical meters and collected online (for instance with IT tools like the Ghent's Grafana Dashboard) as well as the electricity consumed by the energy island. For that purpose, two different approaches are devised to tackle the data holes after a metadata analysis step concerning the percentage of data lacking, the temporal granularity, and the longest data gap. First, for coping with the PV data issues, a parallel day-night pattern is fed to the data to spot the real lacking data points. Thereafter, a daily approximative inference is applied to fill the lacking data. In the same line with the previous data filling method, the second one deals with the electricity consumption that lacks in some periods. To address that issue, the idea is to assume a weekly consumption pattern for the people to fill out the lacking data points.

The next step consists in the economic KPIs measurement depending on the input data from the constructed dataset. Technically, they are specific to each project within the energy island apart. For instance, the LCOE value is specific to the PV project in the studied use case of Ghent. Also, a similar value for the battery investment is defined and called Levelized Cost of Energy Stored (LCOS) and specific to that BESS initiative.

In that respect, it is wiser that the impact of a set of investments such as the introduction of the PVs and the battery along with the standard grid electricity consumption is assessed intending to compare both scenarios from an economic perspective. Therefore, on top of the individual economic KPIs appraisal for each project, the combined effect of several investments is investigated.

In the following step, the graphical representation is provided for the different economic KPIs. This representation can be a temporal evolution in historical fashion or an action-driven one meaning it reflects the economic effect of certain actions such as saving energy or heat demand response actions after being performed.

The final step regards the solution proposition level in which we aim at spotting the origins of the problem and provide recommendations. At this level, we can indicate how to lower costs of how to prioritize certain energy sources over the others.

IV.4. Encountered Challenges and Solutions in economic KPIs evaluation

Similarly, throughout the process of economic KPIs assessment, numerous pitfalls are encountered. The major barrier is the access to the datasets required and the data availability to proceed with the economic calculations. Also, the data lacking can be also problematic in the output’s accuracy and the results’ reliability if there is a considerable amount of data needed that is missing. Indeed, to tackle this problem, the methods discussed in the section IV.3. are developed.

In this context, referring to (Drummond and Sculpher, 2005), even though the conclusions are based on the health deployed technologies economic appraisal, comparable flaws are faced in the economic evaluation process of energy-related sector. For example, overlooking certain prominent financial numbers (costs and benefits) can degrade the quality of the output. In that regard, the scarcity of financial data for certain scenarios leads to mediocre results. Here also, the consistency of the data sources is at the core of the future economic measurements.

In order to resolve this problem, several assumptions are adopted which is a mechanism to drive the results forward. For instance, some assumptions are made in the economic process regarding the feed-in tariff stipulating that the selling price is the same as in the electricity contract. Those numbers are an input from the spot market as used in the corresponding Ghent energy dashboard Grafana (BelPex prices: (Elexys, 2022)).

In line with the pitfalls identified in (Klemenjak et al., 2019), there are several issues regarding the heterogeneity of datasets concerning the electricity consumption. These constitute an impediment when exploiting the data for finding useful results technically and economically. For example, the sampling rate, the physical installations of the smart electrical meters and sensors, the resolution, as well as the storage methods and formats are factors that directly influence the data sets’ quality, readability, and exploitability. To solve this problem, the idea is to gather in a centralized dataset the required technical and economic data by means of data transformation, data resampling, extrapolation in certain cases, and adaptation.

Lastly, in the process of economic KPIs assessment, another question surfaced concerning narrowing the scope of interest that should be evaluated to be able to quantify the added-value or cost-saving by certain technology or certain set of actions. In short, the assessment’s uncertainty corresponds to the consideration of the energy island as a whole consisting of all the technologies already existing plus the envisioned ones as well as the actions to be performed or focused on certain scenarios in particular. Aiming to drive the evaluation in a sound and quantifiable way, the remedy was to define several scenarios to appraise in comparison to baseline ones.

V. SOCIAL KPIS FOR ENERGY ISLAND COMMUNITIES

V.1. Literature background on evaluation of energy communities based on social measures

Literature offers many insights of local impacts and potentially positive impacts of energy communities, including those that go beyond just renewable energy penetration. Outcomes are often categorized in economic benefits, environmental benefits, technical benefits, and social benefits (Gjorgievski et al., 2021; Koirala et al., 2018), as also indicated in previous sections.

In the process of evaluation for Energy Islands, the role of social impact on the community and the individual well-being should therefore also be considered. Social impact is conceptualized as a change to one or more of the following: "people's way of life, their culture, their community, their political systems, their environment, their well-being, their personal and property rights as well as their fears and aspirations" (Vanclay, 2003, p. 8). Social impact may but does not necessarily have to relate to economic benefits for communities (Berka & Creamer, 2018). It rather refers to the broader social consequences of an energy community beyond the immediate instantiation (Creamer et al., 2019). Social impact of Energy Island communities is therefore concerning the direct or indirect affective change in individuals or a community on a perceptual or physical perspective (Berka & Creamer, 2018; Heiskanen et al., 2010), associated to social value creation (Karytsas et al., 2020).

To make social impact measurable, social indicators are used: These should operationalize and measure effects of actions, fulfilling the demanding task of quantifying social impact. Developing proper indicators and metrics is crucial for social impact assessment (Maas & Liket, 2011): In this context, KPIs require both definition and resulting quantitative assessment of social impact, allowing to measure the effectiveness (and therefore the impact) of certain actions targeted towards the community (Pramangioulis et al., 2019). Social KPIs therefore relate to concrete, understandable and quantifiable values and metrics reflecting social impact (Pramangioulis et al., 2019).

Social impacts of energy communities often play an essential role when describing the positive impact that collectively organized energy initiatives, such as Energy Islands, can and should have: These are expected not only to strengthen citizens' participation in energy matters and raise acceptance for renewable energy transition, but are meant to have wide social benefits on community and individual level (Bilek, 2012; Brummer, 2018; Huybrechts & Mertens, 2014; Soeiro & Ferreira Dias, 2020). The community approach of Energy Island communities should strengthen broad social consensus (Yildiz et al., 2015) as well as energy justice and energy democracy (Camarizu, 2020; van Bommel & Höffken, 2021; van Veelen & van der Horst, 2018). This should lead to a greater expansion of renewable energies and to a higher acceptance of these within the community (Brummer, 2018). In addition, such communities are often associated with a change in social norms and contribution to social cohesion, social capital and community empowerment (Caramizaru et al., 2020; Coy et al., 2021).

The described social benefits are considered inherent to the implementation of a project as a 'community'. This intuitive assumption is increasingly criticized as a 'romanticized narrative'. Creamer at al (2019) conclude that "there has been a broad tendency – in academia as well as policy and practice – towards an uncritical assumption that such collective energy projects will inevitably lead to positive outcomes for the communities in which they are located (in addition to a material contribution to renewable energy generation capacity)." (p. 10).

To measure and reflect social impact in KPIs, therefore, first an overview is needed on what exactly is considered as social impact in our Energy Island communities. Community empowerment, social capital, energy justice and energy democracy are central concepts of social impact expected and implied in the context of community driven energy actions (Campos & Marín-González, 2020; Caramizaru et al., 2020). To enable measurement of social impact, we need indicators which reflect these concepts of impact.

We examined their definitions and operationalization, to disentangle their underlying components. This analysis is building on various scientific sources (Becker & Naumann, 2017; Berka & Creamer, 2018; Coy et al., 2021; Hanke et al., 2021; Hanke & Lowitzsch, 2020; Szulecki & Overland, 2020; van Veelen & van der Horst, 2018). A large overlap in the operationalization of the different constructs can be noted. In order to clarify the underlying similarities, but also delimitations in the definition of the constructs, these are visualized in **Figure V-1**, based on a literature review.

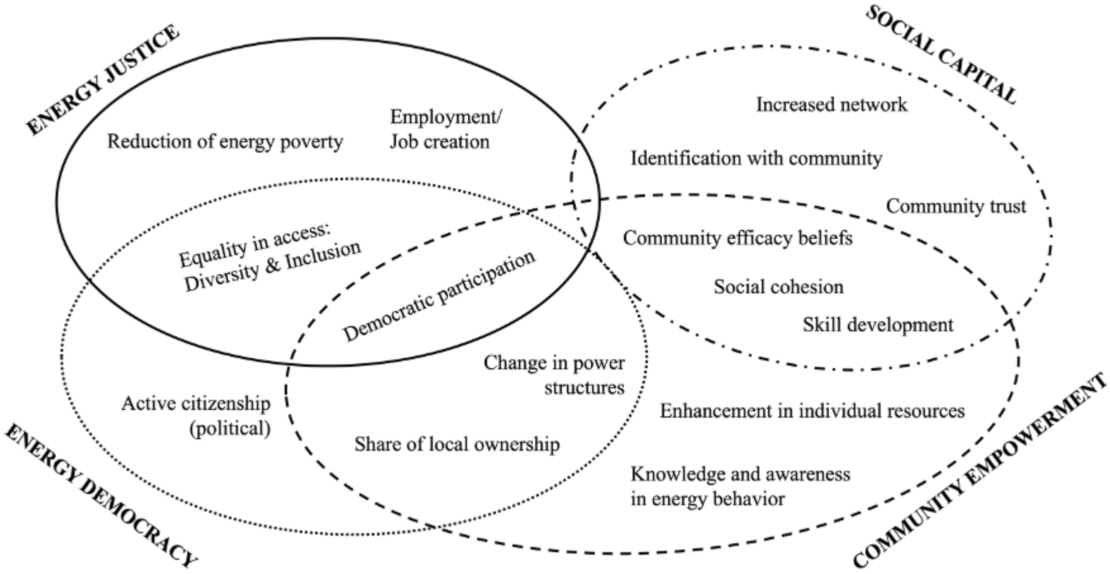


Figure V-1: Constructs relevant for social KPI definition.

Energy justice includes procedural justice, distributive justice and recognitional justice (van Bommel & Höffgen, 2021; Jenkins et al., 2016). Procedural justice refers to transparency and fairness in decision-making processes, while distributive justice reflects the fairness of distribution of e.g., benefits and burdens. Recognitional justice particularly focusses on the inclusion and recognition of more vulnerable households, e.g., through reduction of energy poverty.

Energy democracy is often seen as part of energy justice, reflecting procedural justice: Energy democracy comprises all democratic principles and processes associated with participation in decision-making, active political citizenship and greater control over energy-related resources (Becker & Naumann, 2017; Szulecki & Overland, 2020). A bigger access to resources also is part of the definition of community empowerment, together with community resilience and confidence: “the process of an individual, group or community increasing their capacity and contextual power to meet their own goals, leading to their transformative action.” (Coy et al., 2021, p. 6). Closely related and somehow considered as a precondition for community empowerment (Berka & Creamer, 2018; Coy et al., 2021) is the concept of social capital, which refers to the creation of shared identities, stronger interpersonal networks and community trust (Berka & Creamer, 2018).

These definitions lay the groundwork for our definition and assessment of social impact. The components, which reflect social impact as defined in literature, were therefore partly translated into our list of KPIs. Additionally, we considered it relevant to understand whether being part of an energy island community and the related involvement positively influences people’s perception of the proposed solutions for renewable energies. Review of the literature showed some positive evidence for participation in community energy leading to a more positive attitude towards renewable energy technologies as such (Bauwens & Devine-Wright, 2018).

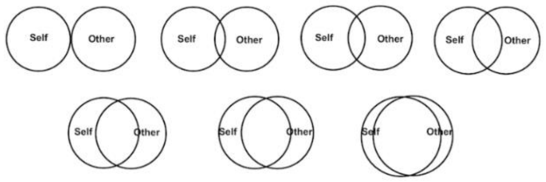
To be able to assess social impact, it is recommended to have not only a one-point measurement, but rather longer-term measurement designs with measurement at several points in time: “evidence would be strongest if longitudinal impact monitoring (…) could be done to see if changes happen over time, taking stock of trends in impacts.” (van der Waal, 2020, p.138). We therefore aim to have at least two timepoints of measurement in each Pilot to detect change and to be able to make actual statements about the impact over time.

V.2. Selected social KPIs

By concretizing the expected social impacts, scales and metrics can be derived to measure them. These can then serve as inputs towards the KPIs used to capture the social impacts on the energy island communities.

Considering that social impact is not a fixed state, but rather both an outcome and process of social change based on planned interventions (Vanclay, 2003), the social consequences of ECs and interventions related to them must be considered holistically. From the broader list of all identified social KPI components, we structured and extracted the most relevant ones from Energy Island perspective through collaborative discussion and an internal project workshop. This resulted in the following list of social KPIs, which will then serve for both the Pilots and replication as basis for further selection criteria. This list is primarily intended to serve as a basis for selection: It should be checked in the respective context of the Energy Island which of the social KPIs are suitable and which should therefore be measured. For this reason, the list of social KPIs is longer than the others, as in most cases it is not assumed that all KPIs are applicable to the respective context.

Name	Description (what is measured?)
Share of local ownership in energy infrastructure equipment	Shared ownership can refer to energy generation, distribution, supply, consumption, aggregation, energy storage and/or energy efficiency services -> i.e. the financial participation of residents as 'shareholders’ —> possibility of financial participation and thus 'co-ownership'; should be measured by investments and ownership shares from community members, which should further lead to a participation in decision making (reflected also in: democratic participation)
Share of local participation in energy system related orders	This refers particularly for cases, where behaviour change or compliance with system related orders is required from community members, as e.g.. in the case for some demand response systems $Share\ of\ ES\ related\ orders = \frac{\#BehaviourChange}{\#BehaviourChangeRequests}$
High acceptance of the community hubs	High acceptance and intention to become a part of the community hubs reflected in increasingly positive attitudes towards the hubs and the energy island community as such; assessed through the agreements to statements, e.g. ‘In my opinion, being part of an energy community hub is desirable.’ -> Likerst Scale
Self-identification with community	Self-identification with local energy production and usage assessed through the agreements to statements, e.g. ‚I feel a sense of belonging to my Energy community. ‘->Likert Scale

Social Inclusion (participants profiles e.g. social demographics)	This is particularly referring to the diversity of community members, making sure to reflect also marginalized and vulnerable groups; assessed through sociodemographic variables, such as gender, age and/or level of education within community members and participants in surveys/trials
Energy Behaviour Intentions	This reflects both the individual and collective intentions to save energy, act more conscious in consumption patterns and accept renewable energies, assessed through the agreements to statements. Individual sustainable energy behaviour, e.g. ‚I find it important to be conscious about my energy behaviour ‘ Community sustainable energy intentions, e.g. ‚I want to save energy together with other people in my community. ‘ -> Likert Scale
Social cohesion	Closeness to community: Sense of community or belonging to the Energy Island community, bonds and cohesion between the people involved. Picture based scale, building on Aron, Tudor & Nelson (1991) to examine visually the relationships between community members 
Job creation through EI	Creation of jobs locally associated with the development, maintenance, and operation of the energy infrastructure. Sub-criteria of employment, based on Sheikh et al. (2016): - Job creation - Addition to employment diversity - Availability of workforce - Poverty alleviation - Increase in production employment - Increase in total employment
Thermal comfort	This was added due to the high relevance of heat related actions within the project and should reflect the potential impact of actions (as e.g., demand response in heating) on community members’ comfort. Evaluation of the performance of the heating solutions proposed, assessed through the agreements to statements, e.g. ‘Last week, I was satisfied with the thermal comfort in my household‘-> Likert Scale
Attitude towards solutions	Participation in and being part of the island community is expected to strengthen positive attitudes towards renewable energies, or rather, to the new solutions proposed and developed within the energy island. This can be adapted to the

	specific context, depending on which solutions or new technologies related to renewable energies are introduced. Assessment through agreement to statements, e.g. ‘More solar power should be established in our districts’ or ‘I think, the community heat innovation is a good solution’ -> Likert Scale Note: One can also assess perceptions about the attitudes of the other community members, in order to compare individual attitudes vs. Assumed attitudes of community.
Democratic Participation	Democratic Participation in decisions related to the energy island and energy transition in general; assessed through the agreements to statements, e.g. ‘Most members in this community get a chance to participate in local decision making‘->Likert Scale
Behavioural intention to become active	This was added as a pre-condition for democratic participation. Since the degree of participation can also depend on the level of development of the energy community, this construct reflects the general intention to participate more actively when established. Preference of participation assessed through the agreements to statements, e.g. ‚I'm interested in contributing actively to the energy transition in my local community. ‘ -> Likert Scale
Collective efficacy beliefs	Reflecting the efficacy-beliefs on community level; how much capacity to act and efficacy is assumed for the energy island on a collective level to reach shared goals and actually make a positive change, assessed through the agreements to statements, e.g. ‘I am certain that together, we will find ways to heat more sustainably’ -> Likert Scale

Table V-1: overview of social KPIs

While we do not claim our list of social impacts to be exhaustive, the concrete level indicators identified are based on the conceptual discussion of higher-level impacts often associated with positive social benefits of ECs. Both behavioural (e.g. democratic participation, behaviour intention to become active) and affective (e.g. social cohesion, efficacy beliefs) social impacts are to be made tangible and, above all, measurable. Understanding them as KPIs, we assume that the Energy Island communities can have a positive influence, i.e. bring about a positive change in the impacts mentioned. To capture this quantitatively, concrete scales are needed. For each impact, we therefore propose a form of measurement in the form of a scale or metric. It is recommended to assess each scale with multiple items, in order to draw conclusions about reliability and validity of scales. Nevertheless, the recording of social KPIs might in some places be less quantitatively ascertainable than the other KPIs. It is therefore conceivable to pursue a mixed-method design, i.e. to collect the scales proposed here and to supplement them after some time with qualitative methods such as interviews or focus groups.

V.3. Identified process for social KPI evaluation

The proposed indicators can only be understood as KPIs if either certain values are expected on the respective scales (thus as target achievement) or by measuring changes on the indicator values. Building on recommendations in literature, longitudinal studies are necessary to capture the actual impacts of Energy Communities (Berka & Creamer, 2018; Creamer et al., 2019). Therefore, when aiming for a quantitative assessment of the social impact of ECs, we plan to have least have one pre-post measurements as longitudinal impact monitoring within each Pilot. Additionally, it should be considered relevant to take into account the impacts on the community beyond people being highly involved within the project board and management to add actual value (Creamer, 2019), but also stakeholders of the energy island beyond these, e.g. via monitoring the creation of employment in the area. And finally, the selected KPIs must fit to the scope and goals of the specific pilot. It could therefore be necessary to adapt and differentiate between relevance of different social KPIs for different social groups addressed.

The social impact literature review described earlier was the basis for the process of developing and evaluating the social impact through Energy Island on the community. To clearly define how social impact is operationalized in the RENergetic project for both the Pilots and for Replication, we used the following questions as a guide:

- What kind of impact can, or would we expect?
- What social concepts play an important role in motivating people, especially motivation for sustained engagement, in community energy projects?
- What processes and outcomes should be considered?
- What are the scales, what are possible reliability analyses, and how can we adapt these scales to our needs?

Then, for replicability reasons, we developed an overarching list that also goes beyond concepts that are applicable only in our specific demo sites. This is intended to serve as a foundation and outline of potentially suitable social KPIs, from which those relevant to the specific pilots can then be selected, as described above. Working closely with the pilots, we discussed both the fit of the KPIs and decided which social KPIs should be included, and which might be particularly relevant for their context. This has led to the addition of some constructs alongside the literature review, such as the addition of thermal comfort, as this is of key importance in the Ghent and Poznan settings.

The measurement of the KPIs presented here was then implemented using an online questionnaire. For this purpose, a selection of KPIs that fit the context was made for each pilot and the scales of the constructs were translated into the respective language. For data collection, it was particularly important to define stakeholder groups. Here, we encountered a challenge of finding and contacting the right stakeholder groups for social KPIs. To address this challenge, especially also with regard to the different maturity levels of the pilots, we made the decision to combine the collection of social KPIs (1st round) with concrete actions at demo sites. A further follow-up survey will then be conducted at a later stage in the project.

Through the online survey and linked data analysis, we can already present first descriptive results. At a later stage, a second survey will make it possible to identify differences on the respective scales and thus to quantitatively map social impact.

V.4. Some pitfalls when evaluating social KPIs

One challenge identified both in the definition of social impacts as well as within the definition of energy communities and their goals per se is the differentiation between process and outcome: Vanclay (2002) states that social changes is not equivalent to social impacts, but rather that “social impacts result from social change processes that result from a planned intervention.” (p. 192). This goes hand in hand with the perspective between the two dimensions of process and outcome taken up by Walker & Devine-Wright (2008): "First, a process dimension, concerned with who a project is developed and run by, who is involved and has influence. Second, an outcome dimension concerned with how the outcomes of a project are spatially and socially distributed—in other words, who the project is for, who it is that benefits particularly (…)” (p. 498). In some cases, the process and outcome of social impact might not be clearly distinguishable: Some of the identified process factors within energy communities may reflect the positive social impacts targeted in the final outcome (Creamer et al., 2019; Walker & Devine-Wright, 2008). Often, there is also a strong overlap between identified drivers and outcomes of energy communities, e.g., when talking about energy democracy (van Bommel & Höffken, 2021) or community empowerment (Coy et al., 2021). Therefore, we will take into account both a process and an outcome dimension when assessing social KPIs, in order to reflect social impact in a broader scope. This refers e.g., to more democratic governance – which can be both conceptualized from a process perspective as ways of participation and an outcome perspective as perception of democratic principles.

The collection of social KPIs through scales, and also the potential addition of interviews, has an inherent pitfall: because the methods are based on self-report, they can be biased, for example by social desirability. Therefore, as described above, we aim to rely only on reliable and validated scales to assess the proposed KPIs and aim for representative sample sizes. Another difficulty when we look at evaluating social impact by comparing values between two points in time is the non-replicability of the sample. To conduct a scientifically clean pre-post measurement, it would require the exact same group of participants at both measurement time points in a research setting. While this is feasible in some contexts (for example, it is possible in Ghent through apartment code and personalized link), it is not feasible in all pilot sites. If this is not possible, as for example in Segrate / Poznan, the alternative solution is therefore to work with mean values and at least keep the sample as comparable as possible. In addition, at this point it would be a good idea to enrich the quantitative assessment of social impact with qualitative methods and field reports.

VI. PRELIMINARY PILOT SCENARIO ASSESSMENTS BASED ON KPI EVALUATIONS

VI.1. Status of preliminary assessments

Although the different RENergetic pilot sites have significant similarities, as stated in the RENergetic DoA, they were mainly selected for their heterogeneity in terms of local stakeholders involved, focus on energy vectors and state of deployment (greenfield versus retrofit). Because of this heterogeneity, also there are major differences in the data availability needed for pilot scenario assessment.

Data gathering related to technical KPIs in most cases involves talking to system engineers or questions 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. For Ghent we can largely rely on the IT tool that lets a user query the data (the Grafana Dashboard).

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

Concerning the social KPIs, the major challenge is the identification of and contact to the correct stakeholder groups. Therefore, we decided to connect the collection of the first round of social KPIs to concrete actions within the demo sites. Therefore, in Ghent the collection of data was aligned with a trial in Heat demand response, where participants were asked to participate in the survey both via mail and a flyer. In Poznan, the data collection took part within an engagement event of local students. For Segrate, a community event in September 2022 was identified as a good opportunity for assessing social KPIs, which is why no social KPIs have been collected at this timepoint.

Table VI-1 **current status of KPI assessment in relation to RENergetic pilots**

indicates the status of the assessment at the time of writing (August 2022),

	Ghent	Poznan	OSR/Milano2
Technical KPIs	Calculations done for heat networks, see section VI.2. Data processing ongoing for electricity	Calculations done for heat for one building. Data gathering in progress for electricity	Data gathering ongoing
Economic KPIs	Definition of scenarios ongoing Data gathering ongoing	Checking data availability	Checking data availability
Social KPIs	1st assessment together with “Heat DR Trial” done	1st assessment together with “Engagement Event” done	1st assessment planned in September 22 together with Segrate

			public community Event

Table VI-1 current status of KPI assessment in relation to RENergetic pilots

The results of the preliminary assessment of some selected scenarios are described in the section below. Follow-up assessment based on KPI evaluation will follow in later Deliverables D7.3 and D7.5. Exemplary results included in the current Deliverable relate to the following scenarios:

- Technical assessment heat network New Docks
- Social assessment New Docks energy community

VI.2. Technical assessment heat network New Docks (Ghent)

For the Ghent-New Docks pilot site, a technical thermal KPI-driven evaluation was conducted, aiming to assess the performance of the energy island based on analysis over time. This energy island can be considered as an energy community since there is a shared environment in which people are acting accordingly to optimize their energy consumption behaviour on the two energy vectors being assessed (the heating and electricity sector).

The current assessment will focus on the heat network only, and it is indicated in the information card in Table VI-2: information card for the technical assessment performed for New Docks pilot.

General question(s) to be answered	To what extent does the system act as a genuine energy island (without the need for external energy sources) and to what extent does it rely on renewable sources?	
KPIs	Domain	Technical
	Individual KPIs of interest	Self-sufficiency, energy potency, share of fossil fuel, share of RES, CO2 intensity
Scope of the assessment	Pilot	New Docks (Ghent pilot)
	Considered subpart	Heat network = the buildings (school, residential area, kindergarten, sport center, offices) + the HP+ water treatment unit+ office ventilation+ the gas boilers + the connection with the factory
Data source	Grafana Dashboard	

Table VI-2: information card for the technical assessment performed for New Docks pilot.

In what follows, we rely in the different steps in the identified process for technical KPI calculation as described in section III.3. The first step consisted in a bilateral communication with Ghent energy manager(s) to grasp the specificities of the heat network and eventually obtaining its simplified design. In that context, the different elements of the heating network were designed, annotated, and communicated.

In Figure VI-1, the heat network, also known as DuCoop district heating, is depicted.

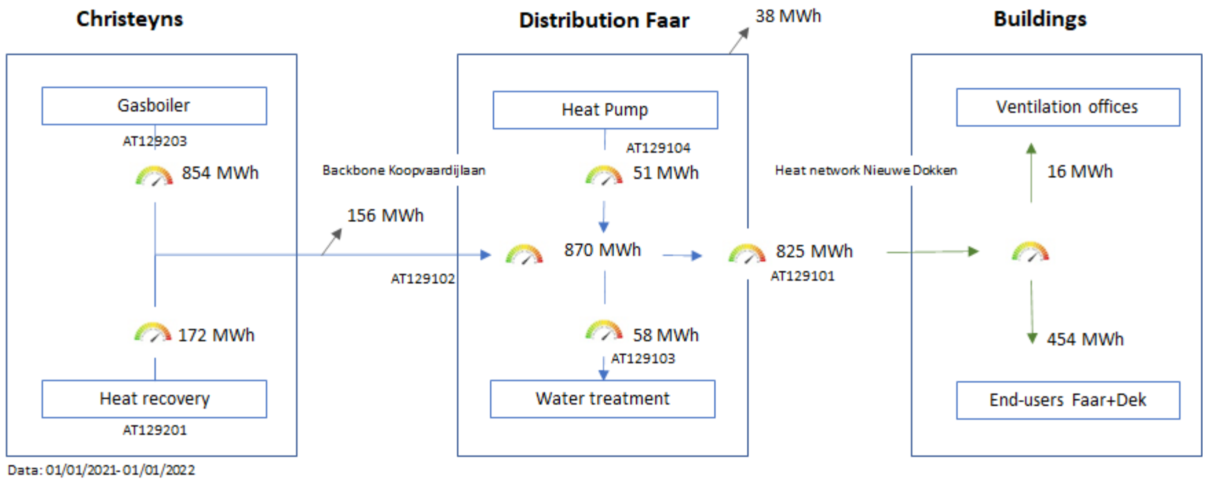


Figure VI-1 Simplified heat network of Ghent use case (DuCoop district heating)

Referring to the deliverable (Demolder Lieven, 2022), the DuCoop district heating network has been exclusively designed for the Nieuwe Dokken project, based on the availability of industrial waste heat at a nearby industry site, Christyens (Christeyns, 2022), a factory that produces soap products, disinfectants, and surfactants. Apart from this, DuCoop is also valorising waste heat from residential wastewater, using an aqua thermic heat pump in combination with a very innovative water treatment system in the basement of the buildings in central area (Middenveld). Using a 4th generation district heating system, DuCoop aims at creating the ability to provide space heating (SH) and sanitary hot water (SHW) from a DH network operating at minimal temperatures (about 55°C) to be able to reutilize waste heat that is usually discharged (convector cooling) in industry or dissipating in the sewer network (in the case of residential wastewater). In 2018, a district heating connection was created between Christyens and the central area of the Nieuwe Dokken (approximately 1000m). From there, the heat is distributed to the buildings of the central building area (’Middenveld’) and the other developments (’Noordveld’, and in the future (2025) also Southfield (’Zuidveld’)). Since 2019, the system was activated and is supplying heat to the public building ’Melopee’ (School and sport complex) and the residents of the ’Middenveld’ (spring 2020).

Thereafter, the different calorimeters and actual values to track the thermal loads and their distribution as well as establishing the link with the values on Grafana dashboard are added. Afterwards, checking and understanding the numbers in relation to the calorimeters’ locations together with deciding upon the granularity in which the technical thermal KPIs could reflect the performance of the energy island is performed. In Figure VI-2, the same heat network is enriched with the existing calorimeters.

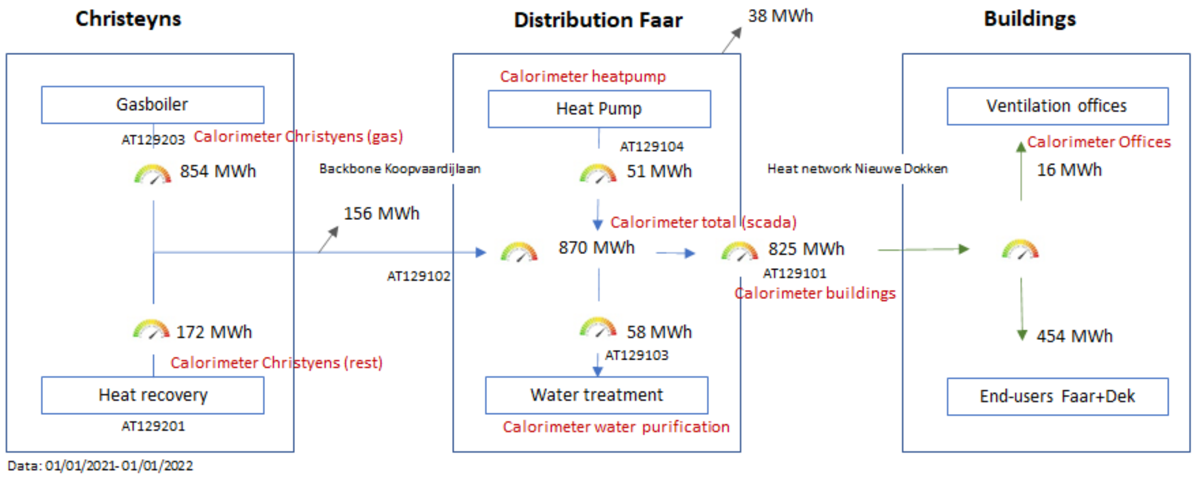


Figure VI-2 Calorimeters on the Ghent Heat Network

In the next stage, a bilateral discussion about the relevant KPIs selection resulted in picking the shortlist defined earlier (the five technical KPIs). In detail, these discussions addressed the description of the heating network and its numerous properties including the components focussing notably on the heat provision resources, the heat consumers, the heat losses, the heat excess, and the classification of certain loads as RES or non-RES. Thereafter, the shortlist of technical KPIs dedicated to assessing the heat performance was validated. In fact, the goal of such an exercise is to reveal the gaps existing within the heat network by calculating the defined technical indicators.

Intending to calculate the different KPIs, monthly data figures related to the heat were provided.

In the next subsections, the details of calculation for each of the technical KPIs are shown.

VI.2.1. Self-sufficiency or autarky indicator for Ghent

As a first point of interest concerning the assessment of the heat network in the New Docks pilot in Ghent, we want to understand to what extent this heat network can really function as an energy island (only focussing on heat for the time being). This means that we want to assess to what extent the system can sustain itself without external support. For that purpose, the self-sufficiency KPI (autarky indicator) is specified earlier and then calculated.

The formula to calculate this KPI is given in the following and is specific to the Ghent case for the heating energy vector.

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

Where:

$E_{Consumed}^{T}$ represents, based on the network nature, the total amount of thermal energy consumed by the district according to the following formula:

$$\begin{aligned} E_{Consumed}^{T} = {} & \text{Water Purification consumption} \\ & + \text{overall district consumption (Faar + Desk + Central)} \\ & + \text{offices ventilation over time horizon T} \end{aligned}$$

In fact, this value is crucial for all the KPIs identified. For Ghent heat use case, it represents the quantities of thermal energy in KWh that is consumed by the different heat consuming units which are namely the water purification/treatment in combination with the aqua thermic heat pump that is considered as a heat supplying device, the ventilation of the offices, and the end-users' thermal consumption in the buildings listed earlier.

E_{losses}^{T} represent, based on the network features, the total amount of thermal energy lost or wasted in the local district heating network of New Docks-Ghent. In fact, the energy losses are dependent upon the number, performance, and where the calorimeters (energy heat counters) are placed.

In this context, three types of losses are identified and two out of them are accounted in the calculations of the selected KPIs.

E_{losses}^{T}:

- First type of losses represents the losses when conveying the heat from the factory and from the gas boilers to the central calorimeter. The following equation clarifies the heat pathway and the first amount of loss:

  E_{loss1}^{T}= *(Calorimeter Christyens (gas) + Calorimeter Christyens (rest)) - Calorimeter total (scada)*

- Second type of losses represents the heat losses occurred within the distribution building (Faar) from the heat pump and the already collected heat to the buildings.

E_{loss2}^{T} =(Calorimeter total (scada) + Calorimeter heatPump - Calorimeter WaterPurification) - Calorimeter Buildings

- Another type of losses was not taken into account which is the losses inside the building due to the data unavailability about the actual consumption of the buildings.

$E_{missing}^{T}$represents the total amount of energy imported by New Docks energy island and/or the direct and/or indirect thermal energy produced locally based on fossil-fuel resources to meet the heat requirements of the different units.

For Ghent use case, it is expressed as follows:

$$E_{missing}^{T} = \text{heat generated by the gas boilers} \\ + \text{HP heat produced by electricity grid consumption}$$

The missing energy over a time horizon T, $E_{missing}^{T}$ destined to provide the heat is the energy produced in KWh by fossil-fuel resources, notably, the gas boilers converting the natural gas imported in cubic meters are the main appliances providing the thermal energy for the district heating for Ghent. This energy is considered as missing in the formula since it is imported externally in terms of natural gas drawn from the grid to generate the required heat for the entire energy island or from the electricity grid to produce the heat by the HP in an indirect way. In short, the thermal energy supplied by non-RES is classified as energy missing. In this regard, the classification of the HP indirect thermal energy produced could be considered as fully RES-based heat like in (European Commission, 2002). However, to better represent the actual use case study, the classification is twofold. The heat generated by the HP based on the grid is classified as non-RES, and the remaining part based on PV- based heat production is considered RES-based.

E_{excess}^{T} as defined earlier, is the excess amount of heat/electricity at some time interval T but cannot be nor consumed neither stored thus injected to the public heating network/electricity grid. In this regard, it is assumed that the E_{excess}^{T} is accounted for the electricity network as injections to the grid, and for the thermal energy volumes, it is negligible.

The assumption concerning $E_{excess}^{T}$is written as follows:

For all the months of the observed period T, we assume $E_{excess}^{T} = 0\ KWh$.

The results of the period spanning from January 2021 until December 2021 are shown in the Figure VI-3.

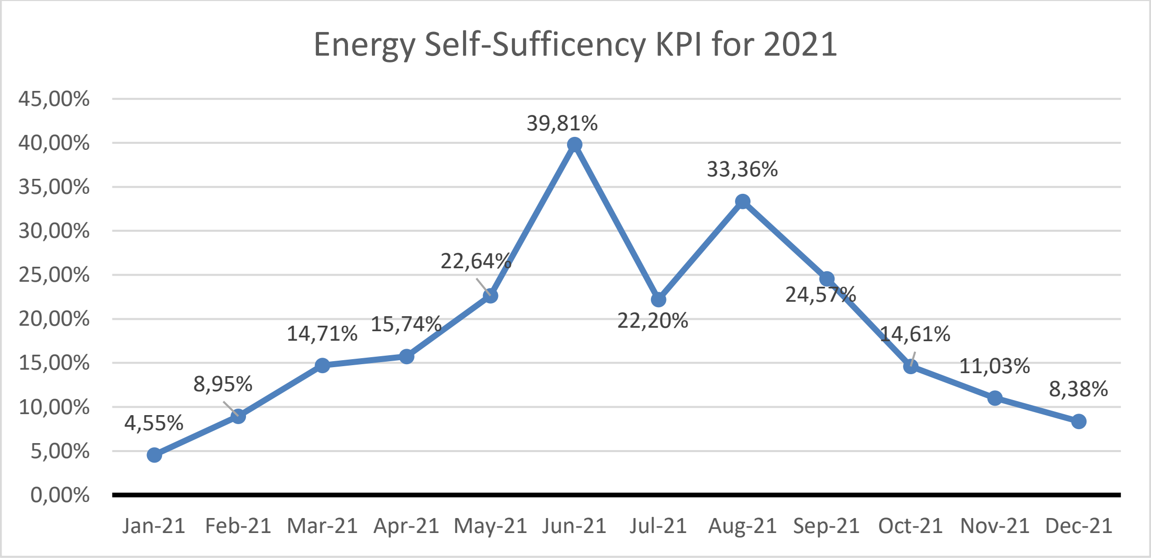


Figure VI-3 Energy self-sufficiency indicator for the heat sector of Ghent (DuCoop district heating)

Observing the temporal evolution curve of the self-sufficiency KPI, we first notice that there is a monthly shifting in the values. Hence, there is a monthly or seasonal variation that can be explained by Figure VI-4 which depicts both influential aggregated metrics ($E_{consumed}^{T} + E_{losses}^{T}$ and $E_{missing}^{T} - E_{excess}^{T}$) yielding these technical KPI values.

The sought value to reach for the energy island to be successful and self-sustainable is the 100% values of self-sufficiency or even to exceed it due to heat energy exports E_{excess}^{T}. What is depicted in Figure VI-3 reveals that the energy island of Ghent pilot is not self-sufficient with regards to the thermal energy since the values of this KPI do not reach the 100% for it to be considered self-independent in that specific energy-vector over the observed period T (2021).

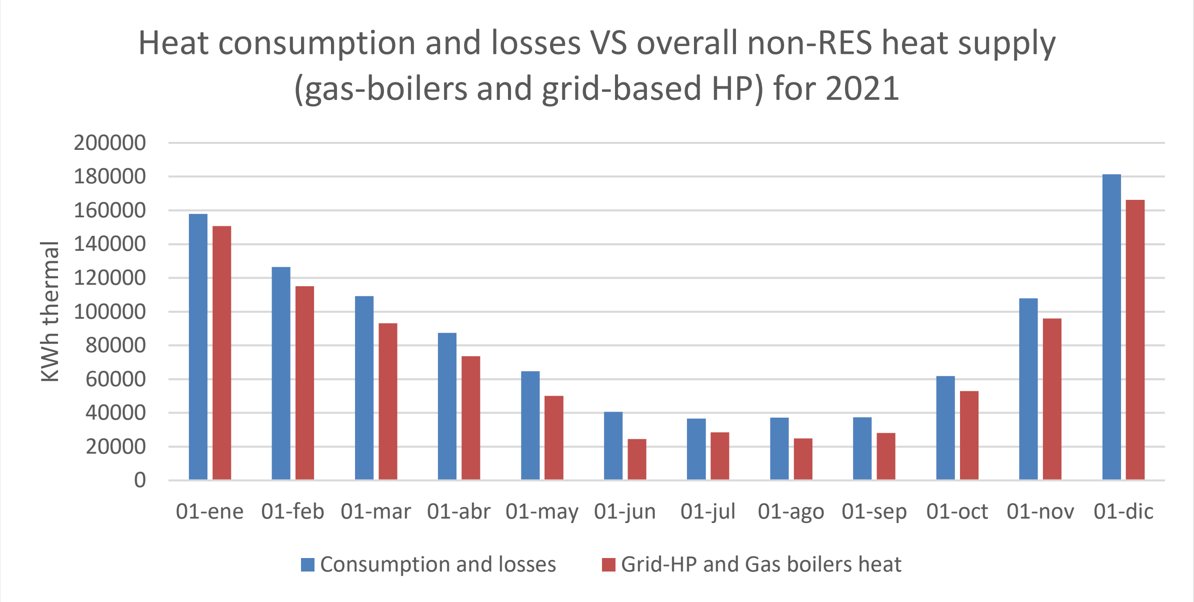


Figure VI-4 Heat energy consumed and gas energy supply.

In fact, we notice that there are months in which the self-sufficiency value goes close to zero which is an unsatisfactory energy island situation. The purpose is to reach higher levels of self-sufficiency by re-using recovered heat and optimizing the heat flows to be available for consumption at the right moment to balance out the demand and supply curves of thermal energy and adjust ideally both measures in the same periods of time along with decreasing the losses that occur over time.

In this case, we can observe that for all the months the loads of fossil-fuel based supply and entire consumption (actual consumption and losses) are comparable in ranges with a difference that is highlighted by the self-sufficiency KPI. Indeed, the self-sufficiency is ensured when the energy island sustains its heat requirements from locally produced thermal energy from RES sources or heat recovery techniques together with smartening the end-users' heat consumption behaviour such as the automation of the heaters and binding them to the thermal energy optimization algorithms.

Based on the values obtained of self-sufficiency during the year 2021, there is a seasonal prominent effect translated by the Figure VI-4 and reflected in the self-sufficiency measurements. As a matter of fact, the external temperature factor plays a fundamental role in defining the different amounts of heat that the energy island entirely consumes where we can observe that the volumes are less important during the summer months (e.g., June, July, August, and September). During these months, the altogether thermal energy consumption undergoes a significant decline since the actual consumption of the end-users of the heat is limited to hot water usage for showering and dishwashing in certain cases. It is then logical that the value of self-sufficiency during these months improves significantly in comparison to the other months.

In line with the results obtained, several recommendations concerning the heat management could be proposed to optimize certain aspects and improve the self-sufficiency indicator.

For instance, the gas supply for the gas boilers can be curtailed during the months of summer (less heating demand). That way, we can reduce the term $E_{missing}^{T}$ and thus reach higher levels of energy sufficiency.

Another more radical recommendation consists in shutting down the gas boilers and rely on the RES-based thermal energy from the Heat Pump and the heat recovered along with lowering the heat usage and losses. This radical shift is challenging to implement in practice, especially, during the cold season, because of the insufficient amount of PV power generated and its intermittency. Additionally, shutting down the gas-fired boilers will be questionable depending on the definition of the energy island borders in the sense whether we turn off the gas boilers within the energy island's boundaries or the ones that belong to the factory from which the heat is recuperated. The remedy to this issue could be dedicating a seasonal storage module (BESS) fed with PV power to ensure the functioning of the HP in an indirect thermal energy generation fashion. This can be penalizing particularly that the several energy conversion steps result in increasing energy losses. More in detail, these conversions concern the solar energy conversion to electrical (maximum of 20% for the most efficient PV panels according to (Jason Svarc, 2022)) and also the electricity to thermal by the HP which can depend upon the COP factor. However, this endeavour could counter the financial goals of the energy island because of the prohibitive costs of storage systems and the weather conditions long-term forecasting uncertainty notably in the last years.

Another technique might be promising with regards to the direct heat energy storage strategies such as the latent-heat storage techniques based on salt (Koenig et al., 1988), and sand heat battery heated with solar and wind power as in Kankaanpää, Finland destined for a later use (Murray, 2022). In such radical scenario, the amount of energy originating from non-renewable sources is avoided or considerably reduced which will significantly improve the current technical KPI value.

Aiming to reflect the numbers' disparity between the different heat supply sources, the Figure VI-5 highlights the numbers of the amount of heat being supplied by the different sources (HP, natural gas, and recovered heat from Christyens) and the amount being consumed.

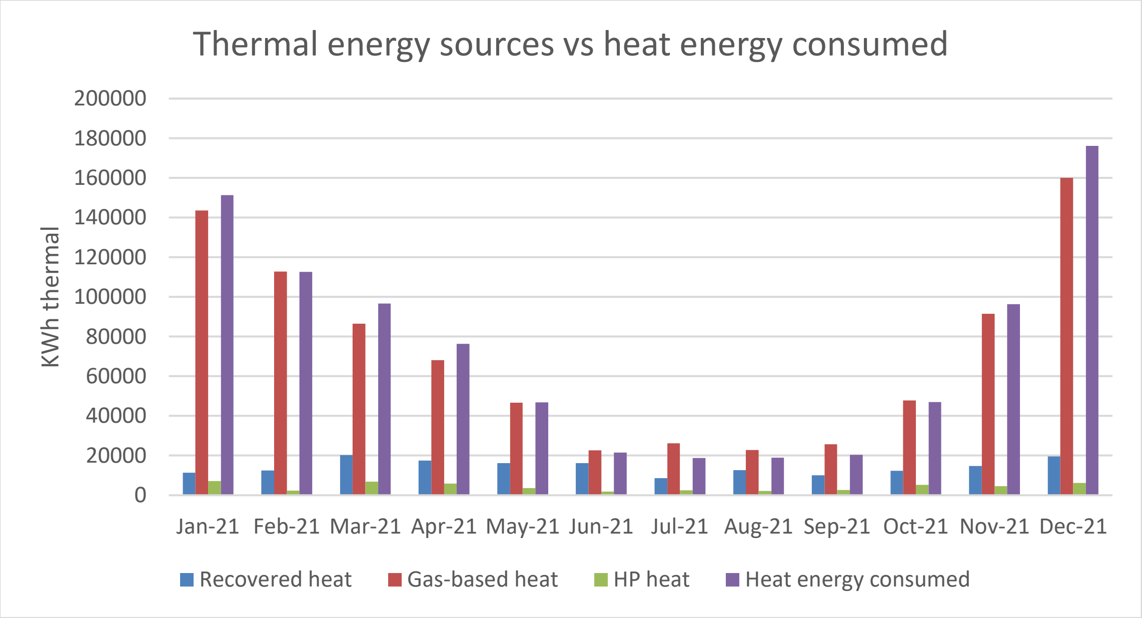


Figure VI-5 Graphical representation of the heat consumed and the different thermal supplying sources.

One more alternative after warrantying the self-independency is to render the energy island thermally net exporter through injecting the excess heat power stemming from the RES to the public grid. This step can be guaranteed by several means including the thermal smartening techniques together with investing in promising heat technologies.

VI.2.2. Energy efficiency indicator for Ghent

This technical KPI, as discussed in section III.2.2. , reflects the effectiveness of dealing with the heat energy losses in comparison to the actual heat demand. It translate the potential of consuming effecively all the supplied heat energy (imported and locally generated)

Recalling the formula to calculate this KPI values, the E_{losses}^{T} are described earlier in the section VI.2.1.

$$E_{eff}^{T} = 1 - \frac{E_{losses}^{T}}{E_{Consumed}^{T} + E_{losses}^{T}}$$

The assessement of the energy efficiency KPI are given in

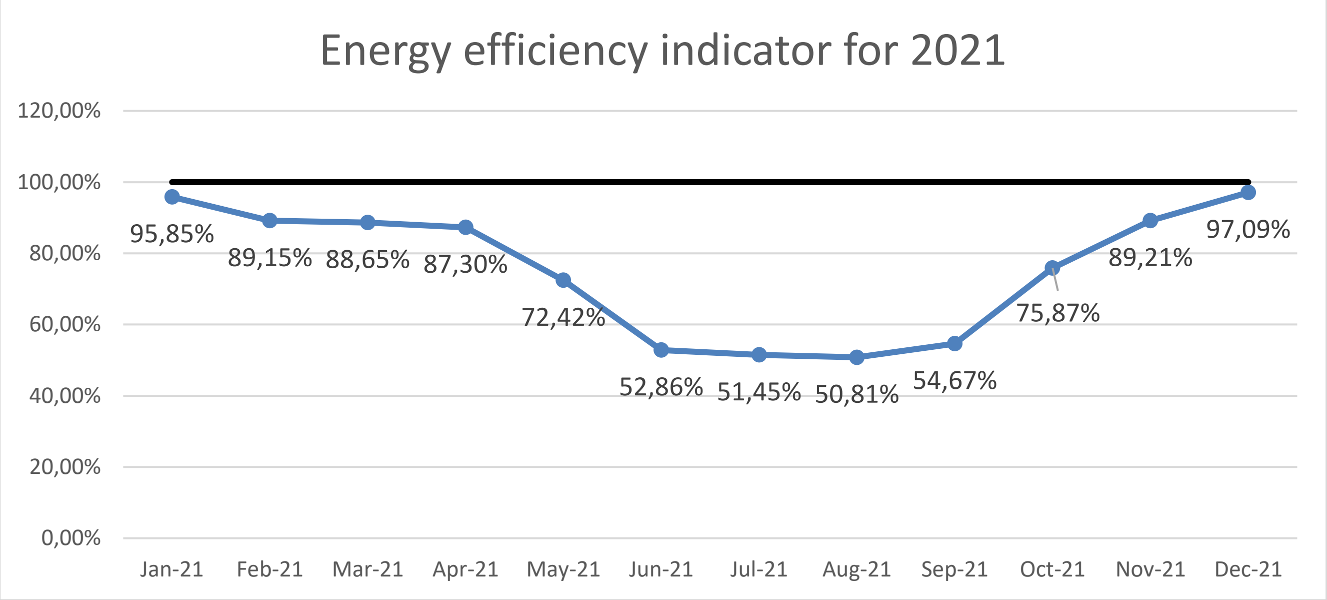


Figure VI-6 Energy efficiency indicator for the heat sector of Ghent (DuCoop district heating)

The efficiency values of heat energy are complementary to those of self-sufficiency indicator. In this regard, we aim at reflecting the capability of the heating district system to retain the supplied heat over the period of 2021 in an effective manner through conveying it to the consumption sinks.

In this context, the energy island seeks to be fully efficient and thus to reach the 100% energy efficiency levels. By observing Figure VI-6, the monthly measures show that the efficiency levels are lower during the summer months implying that the losses are more substantial in relation to the real end-users consumption. This observation can be further emphasized in Figure VI-7.

This phenomenon can be explained through the intention to maintain a high thermal comfort level during the summer by keeping the hot water accessibility instantaneous through the heat exchanger warming up and circulating it in the building pipes. During the winter months, the pipes can serve for the space heating, and therefore the heat actually consumed is accounted as effective since it is destined for the heating purpose. In fact, the heat demand during the cold months is more substantial and more or less continuous as opposed to the heat demand during summer which is reduced to showering and in some cases warm-water dishwashing which is more unpredictable, discrete, and discontinuous. Hence, even though the warm water is available at some temperature inside the pipes, its utilization is minimal compared to the winter months, and therefore, the heat energy losses are translated by the heat leakage because of remaining longer inside the pipes without any significant usage, then the loss replaces the actual consumption. As a result, the volume of thermal losses is more substantial in relation to the real heat consumption.

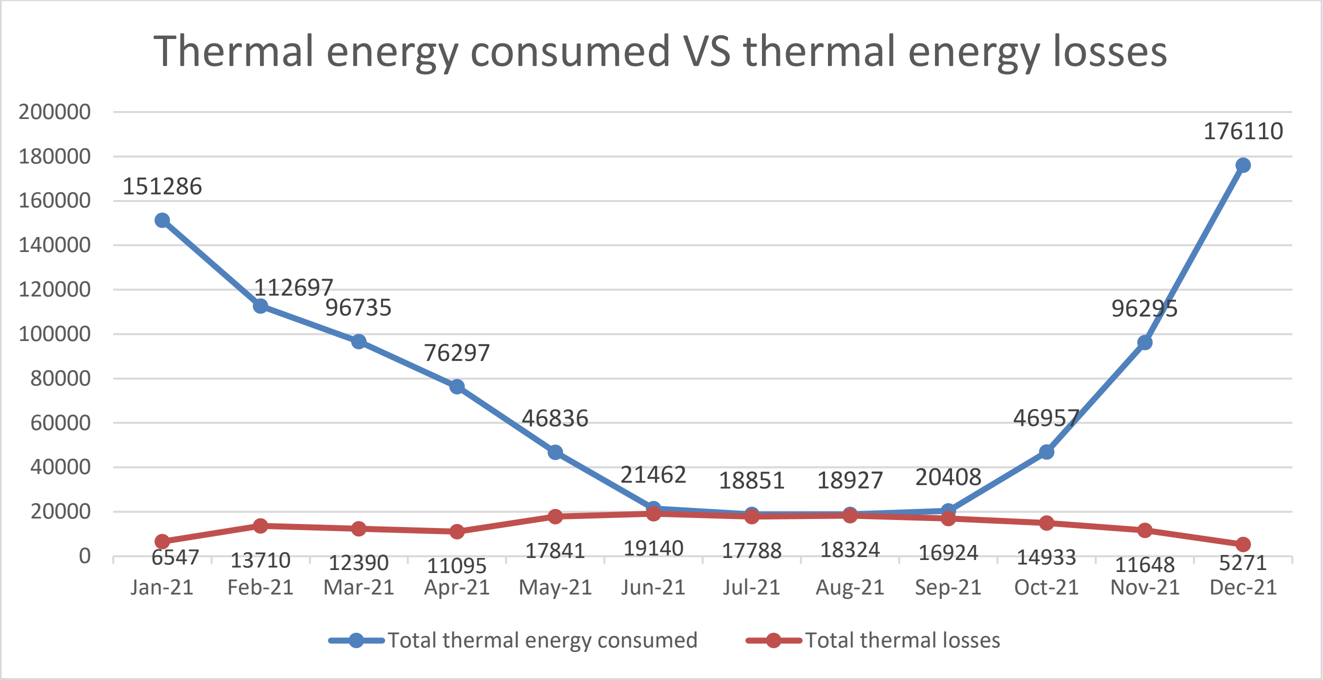


Figure VI-7 Thermal energy consumption VS thermal energy losses

VI.2.3. Energy Potency indicator for Ghent

Going a bit further than the previous analysis, we would like to understand how efficiently the heat network for New Docks can integrate variable renewable energy sources (RES), so we will calculate the energy potency KPI.

The formula to compute this value is shown below for the specific case of Ghent for the heat energy vector.

$$E_{Pot} = \frac{E^T_{missing} + E^T_{excess} + E^T_{losses}}{E^T_{Consumed} + E^T_{losses}}$$

Where:

The results of the period spanning from January 2021 until December 2021 are shown in the Figure VI-8 below.

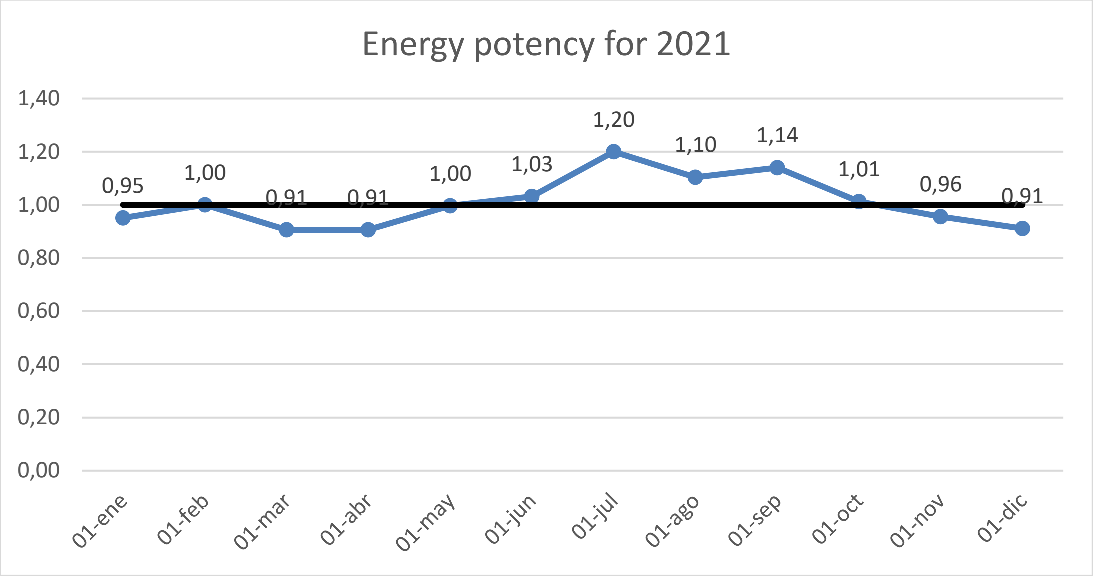


Figure VI-8 Energy potency KPI for the heat sector of Ghent (DuCoop district heating)

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 graph in the Figure VI-9 that depicts the different influential terms namely the energy consumed, the sum of energy losses, and the energy provided by non-RES including the gas boilers as well as the grid-based heat from the HP impacting the evolution of that technical KPI.

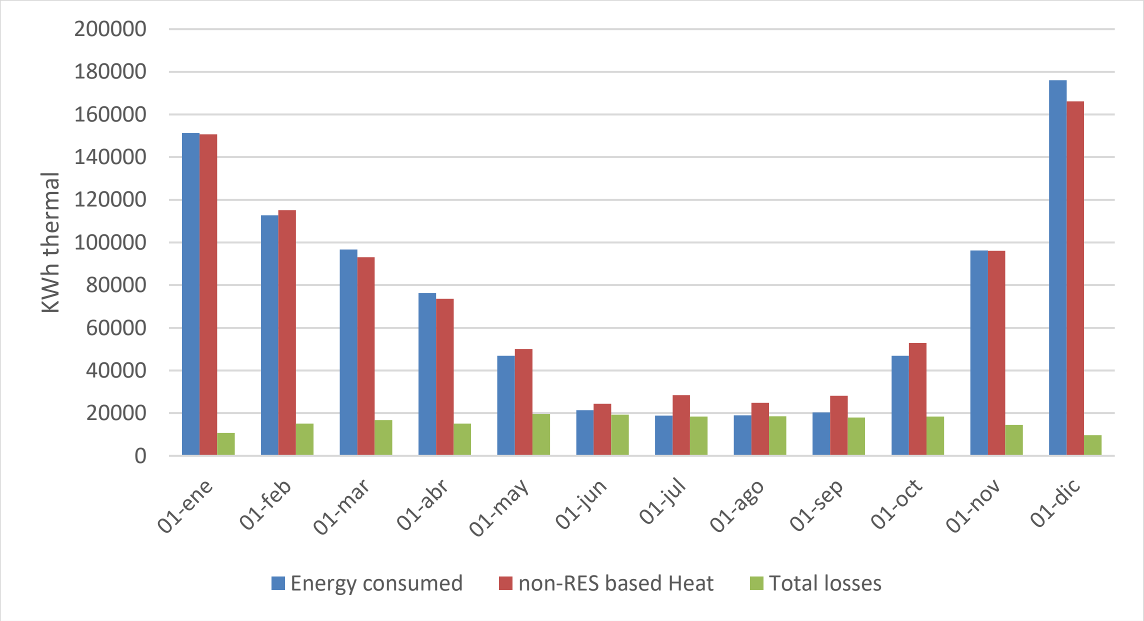


Figure VI-9 Column graph of the total heat energy consumed, natural gas supplied energy, and the amount of total heat losses in Ghent heat network

The column graph gives us an idea about the significant shares of non-RES thermal energy provided throughout the year of 2021 regardless of the season or the month. Indeed, this thermal energy amount is always almost comparable to the amount that is being consumed by the energy island. On the other hand, the amount of heat energy losses is minimal during the months of winter proportionally to the overall amount of heat consumed because it is clearly not comparable with the ranges of the other two columns ($E^T_{missing}$and $E^T_{consumed}$) during the winter months, but it is during the warm months as explained due to the fact explained earlier in section VI.2.2. As a matter of fact, the optimal value of energy potency levels is zero. Thus, in Ghent use case, there is always a room for optimizing the heat network management (supply and demand patterns) to push it to the envisioned zero-value.

Bearing in mind that the larger share is always to the natural gas energy, a recommendation from a technical KPI perspective is to promote more investment in other HPs coupled with RES to assist in reducing the amount of thermal energy originating from fossil fuel resources since it is the main barrier to reach minimal value of energy potency.

In the same vein, intending to diminish more efficiently the thermal energy losses, the upgrading of the pipes' insulation system for the heat recovered and the heat transit infrastructure is another way to retain more thermal energy and improve the overall heat network functioning.

Finally, the seasonal heat storage can potentially minimize the energy potency values by sparing the energy island of importing gas in the wintertime and exploiting the abundance of solar power during summertime.

VI.2.4. Share of fossil fuel for Ghent

In order to get a good view on the importance of renewables for the heat network in New Docks-Ghent, we calculated both the portion of energy from fossil fuel sources being injected in the Ghent energy island and the portion of renewable energy sources, both of them relative to the total energy consumed. That is exactly what is represented by the KPIs shared of fossil fuel and share of RES, calculated in the current and subsequent section respectively.

The share of fossil fuel represents the amount of thermal energy stemming from non-renewable resources (non-RES) from the overall thermal energy provision. Figure VI-10 depicts the monthly average percentages of the fossil fuel provision for Ghent use case spanning from the January 2021 until December 2021.

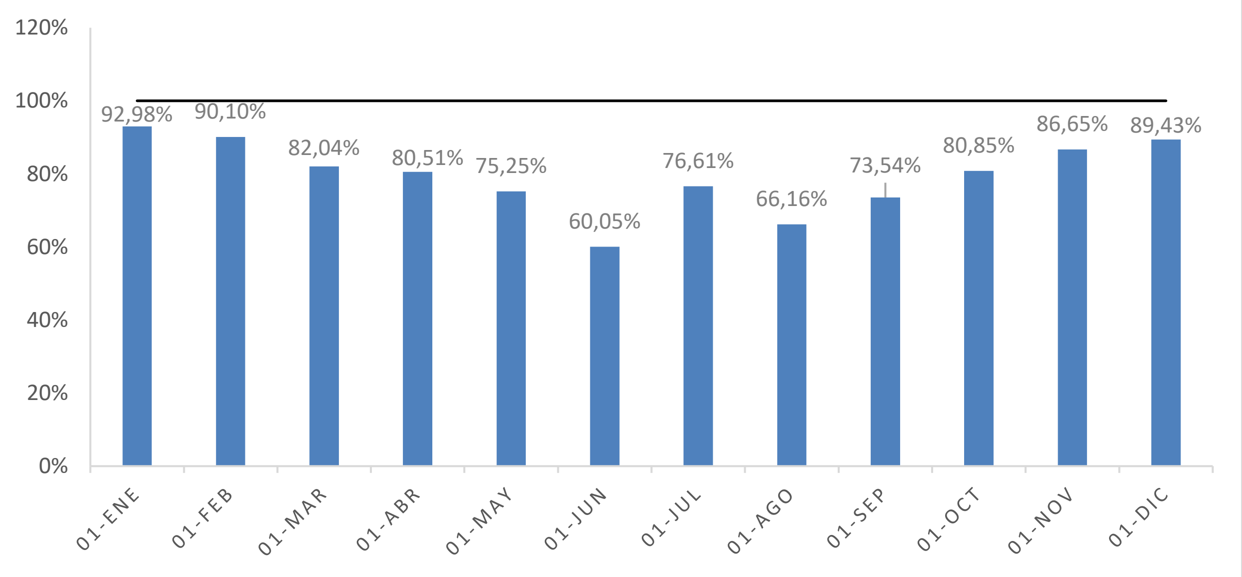


Figure VI-10 Share of thermal non-RES in the heat network of Ghent-New Docks Energy Island

By observing the previous figure, it is noted that the share of fossil fuel in the thermal energy povision of the energy island is utterly large. In the observed period, the shares are always above the 60% regadless of the season.

It is clear that the outside temperature (seasonality impact) is correlated with the share of non-RES. Indeed, the lowest values are occurring in summer because the provision in fossil-fuel based energy is less important following the thermal consumption pattern.

VI.2.5. Share of RES for Ghent

As defined earlier, the share of RES is a KPI that defines the portion of the renewable energy being injected into the energy community originating from renewable energy sources concerning the entire energy provision over some time T. In this case, we are referring to the thermal energy consumed by the entire heat network of Ghent energy island in addition the incurred heat losses.

Let us recall the formula for calculating the share of RES KPI.

$$Share_{RES}^{T} = \frac{E^{T}{}_{RES}}{E_{Consumed}^{T} + E_{losses}^{T}}$$

For New Docks-Ghent use case, $E^{T}{}_{RES}$ is considered as the total of energy generated by renewable energy sources.

In this regard, two assumptions are adopted together with the system engineers what resources could be considered as RES-based heat. The first assumption concerns the heat recovery that is reused due to the link to the factory. The second assumption is that the heat produced indirectly by the HP based on PV power is considered for the renewability. For that purpose, the RES-based electricity flowing in the energy island network is assumed to be the same flowing to all the connected appliances and thereafter, the heat energy is inferred as a function of the coefficient of performance (COP) of the HP and the shares of RES, essentially, the PV power.

For Ghent use case, it is expressed as follows:

$$E_{RES}^{T} = \ heat\ recuperated\ from\ the\ factory + E_{HP}^{T} * COP_{HP}^{T} * Share_{electricity}{}_{RES}^{T}$$

Where:

- $heat\ recuperated\ from\ the\ factory$ is an input data
- E_{HP}^{T} is the heat provided by the HP over the observed time period T
- COP_{HP}^{T} is coefficient of performance (COP) of the HP over the observed time period T
- $Share_{electricity}{}_{RES}^{T}$ represents the share of RES in the electricity produced with regard to the final electric energy consumption.

Indeed, the main barrier is the classification of the thermal energy as part of the renewable or non-renewable while considering the origins of its generation especially in the case of the energy transformation processes (e.g., the electric heat pump) and the purpose of the use whether it is a second-use or an avoidance of heat wastage and a valorisation benefit. As a matter of fact, the heat recovery technique consisting of recuperating the wasted heat from the neighbouring factory is not fully green since the original production of the heat is due to natural-gas combusting, but it could be classified as green depending on the energy island boundaries and whether our goal is greening all the pathway or delimited greening. However, for the sake of representing the effort of that heat recovery and instead of releasing it into the atmosphere, it would be re-used for better purposes, it is recognized as a renewable energy source heat.

In the following figure, a representation of the share of RES of the heat consumed is provided for the period January 2021 until December 2021.

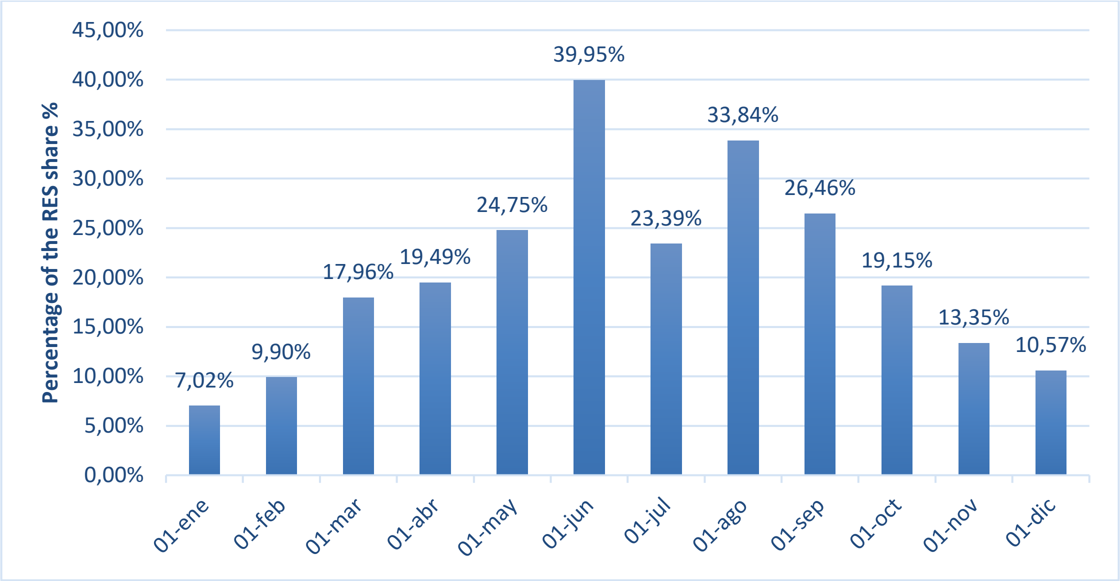


Figure VI-11 Share of thermal RES in the heat network of Ghent-New Docks Energy Island

By observing the percentages of RES, we note that there is a similar monthly pattern to the non-RES KPI is depicted. This could be explained by the amounts of the heat waste that is being recovered which is nearly constant over the months in comparison with the overall heat that is requested which is less important during the summer months.

This idea is better explained by representing simultaneously both values of heat energy consumed and the one being recovered (assumed as RES).

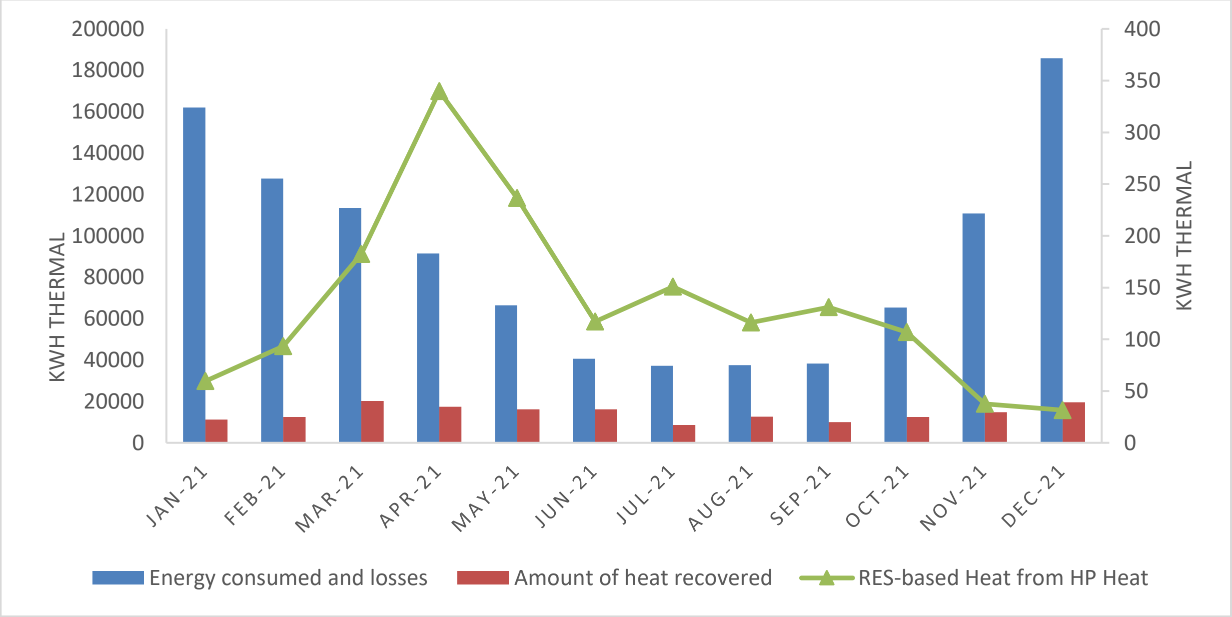


Figure VI-12 Thermal energy consumption and losses VS thermal energy recovered VS Amount of HP PV-based heat

In that respect, a recommendation could be drawn is that a large share of heat recovery available during the months of summer could spare Ghent energy island of operating gas boilers during that period. Also, the operation of the HP could be better enhanced to meet the heat requirements especially during the summer season. In this graph, since the scales of both values are not comparable, we added a secondary axis to depict the RES-based heat provided by the HP even though its values are significantly lower in relation to the energy consumed, losses, and heat recovery volumes. In this context, introducing extensively more RES in the whole electricity network and consequently to the HP seems to be a good remedy to increase the RES-based heat values.

VI.2.6. CO_2 intensity

The KPI CO2 intensity represents the amount of CO2 emissions released by the production and consumption of heat-wise energy divided by the overall consumed energy. This KPI is computed for the specific case of Ghent Energy Island for the energy vector of heat by applying the following formula.

$$CO_{2}{}_{intensity}^{T} = \frac{CO_{2}{}_{prod}^{T} + CO_{2}{}_{missing}^{T}}{E_{Consumed}^{T} + E_{losses}^{T}}$$

Where:

$CO_{2}{}_{prod}^{T}$ represents the amount of CO_2 released while meeting the end-users' requirements of thermal energy by local heat production. In the Ghent use case, the heat pump non-RES based electricity consumption to provide heat over a time horizon T is considered as $CO_{2}{}_{prod}^{T}$. Thoroughly, building on the same values of shares of RES and non-RES in the electricity supply, the amount drawn from the grid and consumed by the HP to provide heat is regarded as CO_2 releasing source. The quantity of CO_2emitted is computed as function of the average CO2 released in Belgium of 1 KWh of electricity found in (Our World in Data, 2022)

Additionally, $CO_{2}{}_{prod}^{T}$ entails the natural gas imported from the grid and serving for the heat production by the gas-boilers within the energy island. This values is based on the assumption that combusting 1 cubic meter of natural gas for heat generates 1.89 KgCO2 (‘impact of 1m3’, n.d.)

$CO_{2}{}_{missing}^{T}$ is assumed to be 0 since not direct heat from the grid is flowing to the energy island.

In the figure below, the monthly CO_2intensity is calculated based on the input data from both sides (the grid-based heat from the HP and gas boilers data).

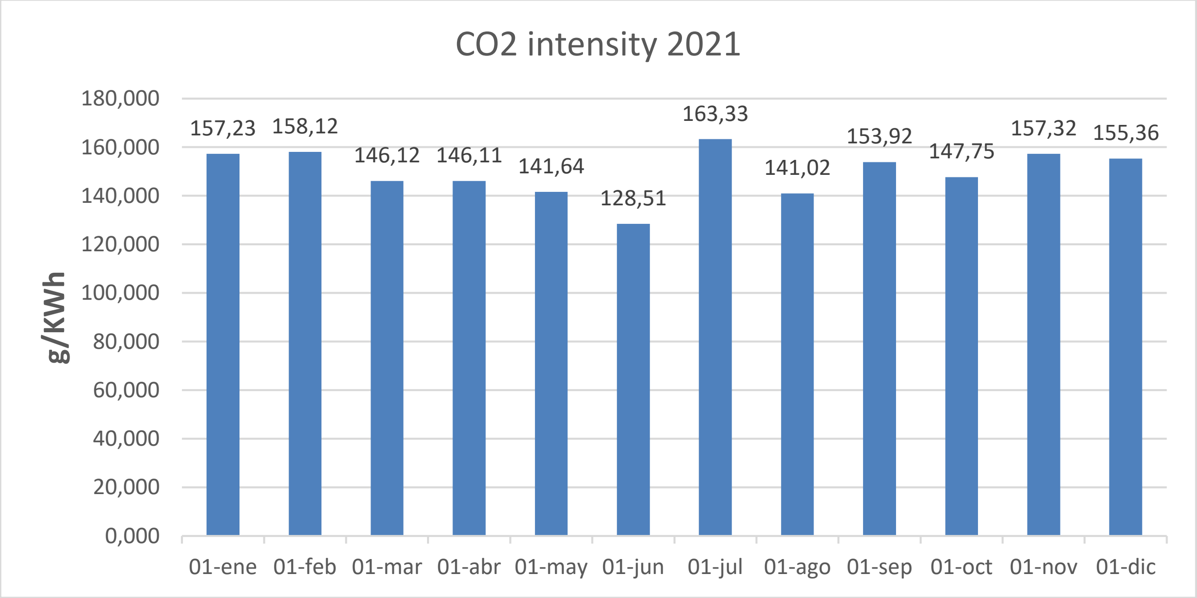


Figure VI-13 the CO2 intensity caused by the thermal energy consumption and production.

The different numbers calculated indicate that the monthly upper limit as prescribed in the EU CO2 emissions’ threshold is exceeded. The CO2 intensity limit is set to 100 gCO2/KWh (‘EU limit').

The details of calculations are clarified in Figure VI-14 by spotting separately the origins of each of the emissions.

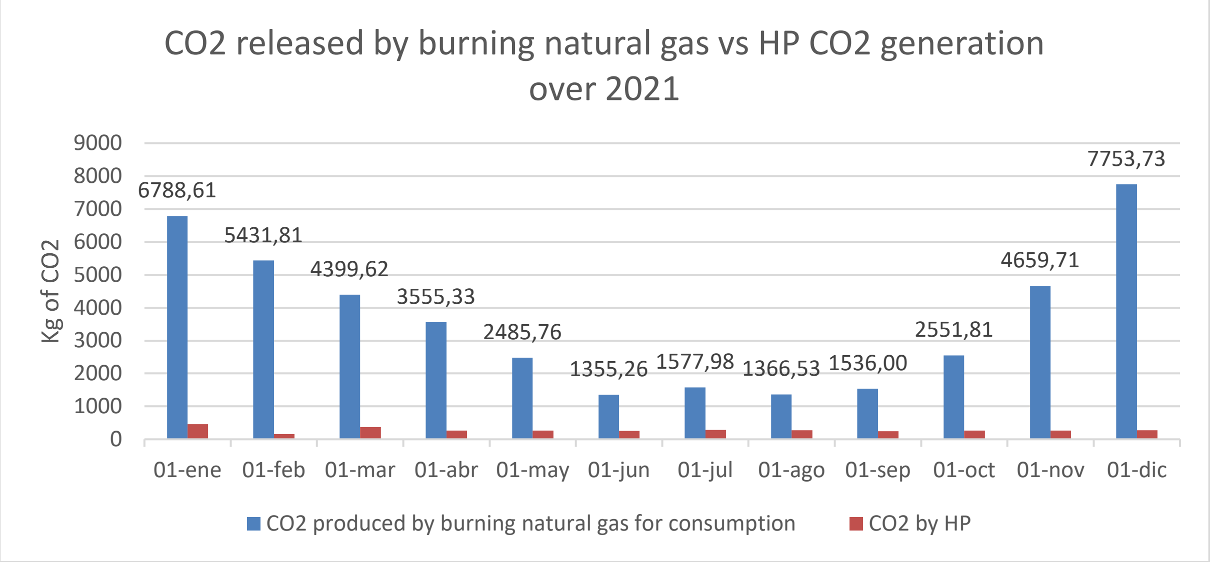


Figure VI-14 CO2 emissions released by Ghent energy island.

It is clear that the emissions stemming from the gas boilers thermal energy generation is more important than those provided by the HP due to the difference of the production potential from one side.

On the other hand, the calculation adopted to quantify the CO2 emissions released by the consumption and production operations is assuming that the amount of CO2 dismissed by one Kilowatt-hour of heat is dependent upon the natural gas quality (e.g., the coefficient of performance of the gas being combusted to generate heat, the degree of pollution incurred by producing 1 KWh thermal by that natural gas, the pressure settings). displays the monthly amounts of gas consumed by Ghent energy island.

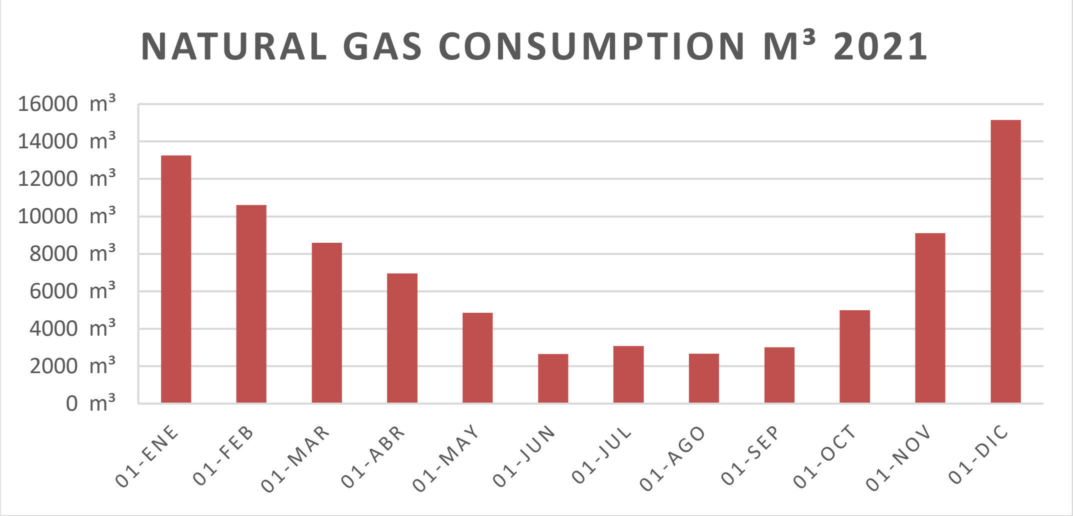


Figure VI-15 Natural-gas consumption amounts for the heat network of Ghent-New Docks Energy Island

It is noticeable that in the summer months, the gas supply is considerably less than in the other months. However, since the consumption is also much lower, then the ratio can yield high CO2 intensity values penalizing the overall picture of "less consumption, less CO2 impact". This is highlighted, for example, in the case of July 2021, where the intensity of CO2 is the highest even though the heat consumption is not that large (among the lowest). Undoubtedly, the magnitude of pollution is less, but the intensity is still high due to the proportionality between heat consumption and supply.

VI.3. Social assessment New Docks energy community

In Ghent, the New Docks community is already rather established. A first assessment related to social KPIs was already done, as indicated in the information card below.

General question(s) to be answered	What positive impact does the formation and development of an Energy Island and its associated community have on residents?	
KPIs	Domain	Social
	Individual KPIs of interest	Social cohesion; Social identification, Efficacy-beliefs (individual; collective), Attitude towards system (individual, others), Thermal comfort; Participation rates; demographics (as proxy for social inclusion)
Scope of the assessment	Pilot	New Docks (Ghent pilot)
	Considered subpart	Heat demand response
Data source	method	mail surveys amongst New Docks residents
	Time period	01/22 - 03/22

Table VI-3 information card for the social assessment performed for New Docks community.

The survey of social KPIs in Ghent was conducted together with a trial of Heat DR. In addition to the survey and the insights gained from it, the acceptance and participation rates for such a technological innovation in the New Docks community could also be measured. A pre-selection of suitable KPIs for the Ghent setting was made in advance through close collaboration with the pilot partner. Here, the focus was placed on social identification and affiliation, reflected in social cohesion, identification with community and beliefs about others. Furthermore, we particularly examined the significance of efficacy beliefs, both individually and collectively, as indicators which could be influenced positively through the intervention, also with regards to future interventions. Thermal comfort was also included in the study to ensure that potential interventions did not have a negative impact on this social factor. As the trial was framed as a 'community collective action', the aim was also to strengthen community-related KPIs through participation.

The trial of heat demand response, to which the social KPI survey was connected, was conducted in the New Docks from end of January to end of March 2022. Before beginning of the trial action, we sent around mails with the survey link to N = 48 households. We further contacted the tenants in successive weeks (steps = 12 households in each week for four weeks) with the flyer for trial participation, which also led to the online survey through a QR Code. Additionally, further tenants were contacted after the trial for a second wave of survey participants.

Overall, this led to a participation rate of N = 21 participants in the first wave, and N = 13 participants in the second wave of data collection. For both surveys, the majority of participants were male and household size varied between one to four (first survey) and one to five (second survey) inhabitants per household.

For the social KPI scales, both surveys showed a similar pattern, depicted in Figure VI-16 and Figure VI-17.

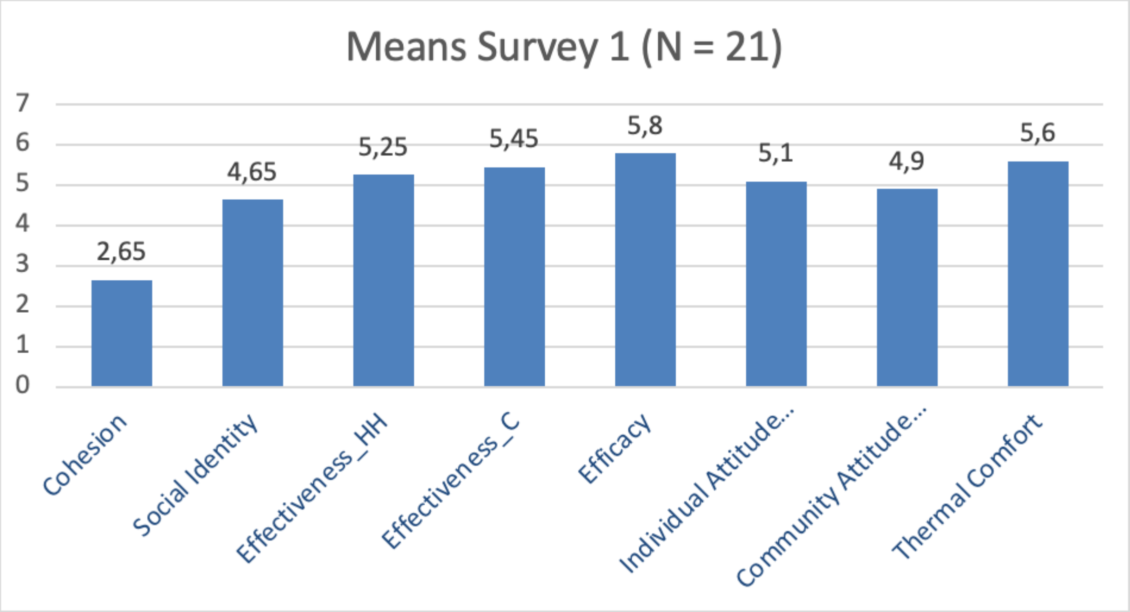


Figure VI-16 social KPI evaluation for New Docks energy community from first survey

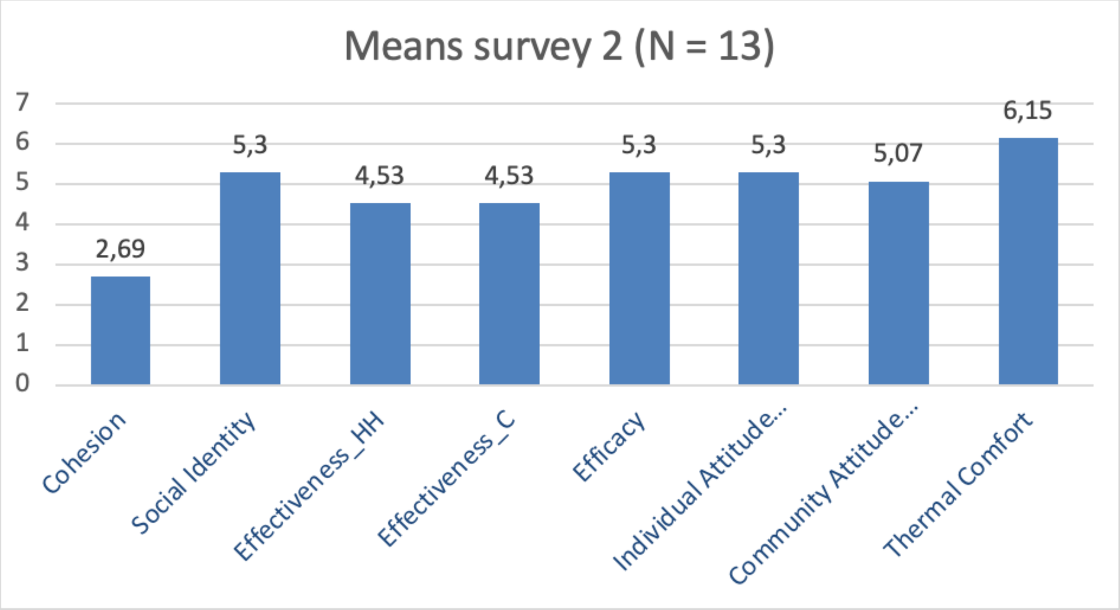


Figure VI-17 social KPI evaluation for New Docks energy community from first survey

Notably, in terms of perceived effectiveness, an interesting tendency in the first sample (N = 21) emerges regarding the relevance of the action as a 'community' action: perceived effectiveness, i.e., the extent to which participants believe that (1) they as a community can actually make a difference by participating in Heat DR, is slightly higher than the belief that (2) they as an individual household can make a difference. This descriptive plot is shown in Figure VI-18.

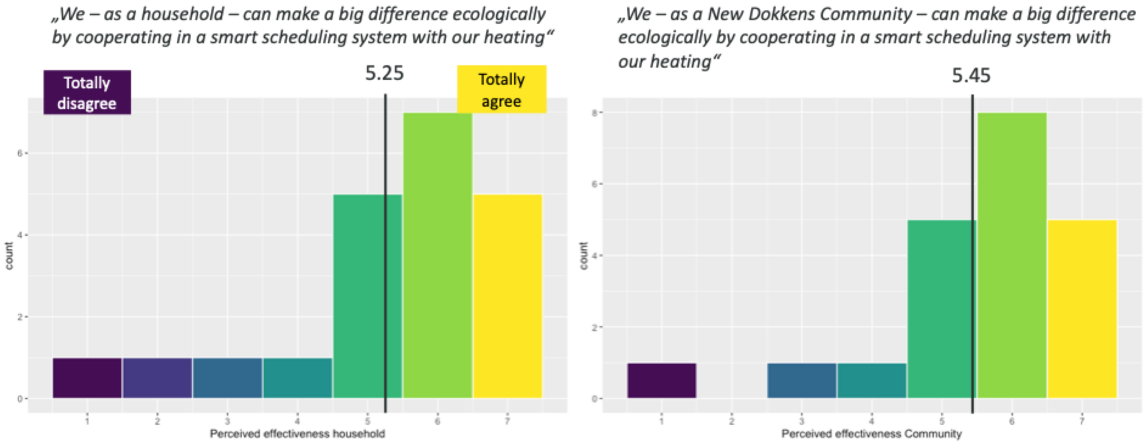


Figure VI-18 descriptive plot for perceived effectiveness New Docks

Another trend evolving in both samples was the difference between the own attitude towards the system vs. the expected attitude of others. Here, the mean values of one's own attitude tend to be slightly higher than the mean value of other people's attitude in the community. Figure VI-19 shows this exemplary for survey 1. Based on the higher variation in values, this could also indicate that people feel more unsure about how others in their community see such a system.

Figure VI-19 own attitude towards the system vs. the expected attitude of others New Dockx

Overall, the data analysis of the first social KPIs in Ghent conveys an optimistic picture with regard to their descriptive values: For example, the average social identification with the community is quite high in both samples (*M* = 4,65 in survey 1, *M* = 5,3 in survey 2). In order to draw further conclusions, additional measurement points and more specific analyses of the individual households are needed.

VII. RELEVANCE OF KPI EVALUATION FOR REPLICATION

The pilot sites Poznan, Ghent and Segrate each have their specific goals and are demonstrating specific solutions to specific challenges for an Energy Island starting from a different initial situation. Trying to replicate the pilot's approaches "as implemented" is likely to fail, as any potential follower sites will likely lack the precise technical, economic, and social context of the pilot. Before deploying a RENergetic software solution, any follower EI therefore needs to make sure that the frame conditions, the context, of their site are in place to meaningfully deploy the RENergetic software solutions.

The goal of the RENergetic replicability package to be developed in WP8 is to allow other Energy Islands with similar initial situations, goals and challenges to employ methods and solutions that have been developed in the pilot sites for their own case. In order to succeed with the replication effort, RENergetic will deliver a methodology to prepare the needed context at any follower Energy Island, in order to meaningfully deploy the RENergetic software modules. These methods address technical and IT infrastructure, economic and legal frame conditions as well as social and behavioural. This means as a first step the specific pilot's context is replicated to the follower EI. With the frame conditions properly in place, any follower EI can now choose the various RENergetic software modules, that provide solutions to their specific goals, and that can now be used as is. This approach aims to replicate the pilot's context for any other Energy Islands to reproduce the results achieved with the RENergetic software modules.

The RENergetic replication package is structured along so called "Transformation Pathways", which are defined as the sum of all interventions needed in order to achieve a specific sustainability goal of an Energy Island.

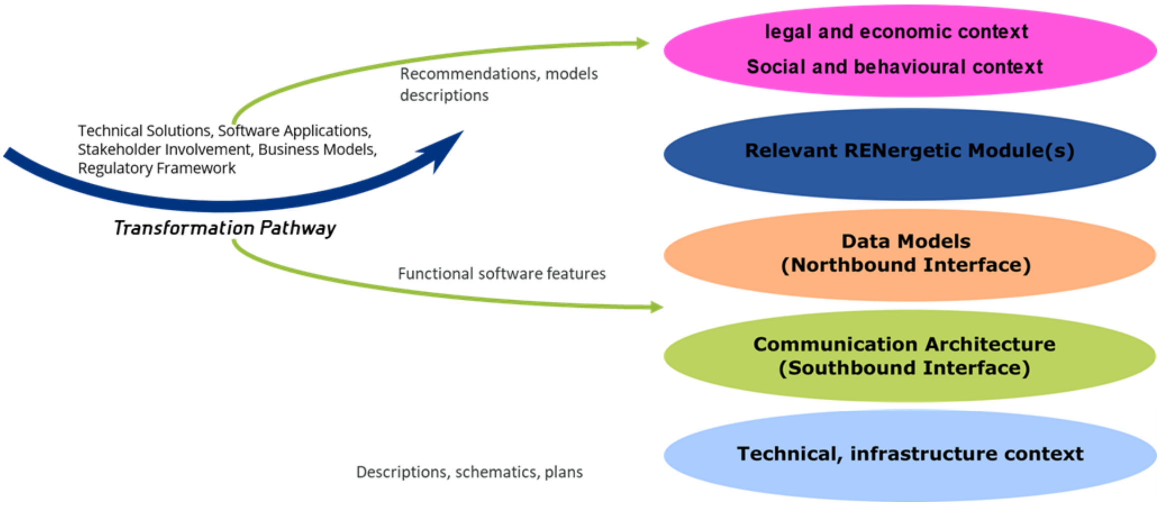


Figure VII-1 Schematic representation of the Transformation Pathway

The KPI as developed in the RENergetic project will serve three major goals in the replication package: assessing the initial situation of a follower EI, identifying a potential transformation pathway, and assessing the progress made along that pathway.

The details of this methodology are outlined in the deliverables D8.1 and D8.2

VII.1. Assessing the initial situation of a follower EI

As already mentioned above, before choosing and settling on specific interventions for a Transformation Pathway any potential follower site needs to assess their respective initial situation compared to the RENergetic pilots.

The technical, economic and social KPI as defined in chapter III, IV and V respectively will be utilized in the replication package to provide a methodology for the assessment of the initial situation and frame conditions at the follower EI. However, rather than comparing the raw values of these KPI, which might not yield meaningful results in many cases, relations between KPI will be used to provide a relative assessment of the initial situation compared to a specific RENergetic pilot.

VII.2. Identifying the Transformation Pathway

Once the initial situation of a potential follower EI is assessed, the interventions that will make up this site's Transformation Pathway need to be defined.

The set of RENergetic KPI will also provide a useful guideline for this step, by allowing to identify the areas that have the relative worst performance or least contribution to the EI's sustainability goals.

Technical, economic, and social KPI will be used at this step to identify the most critical interventions and the interventions that will yield the most impact towards the Energy Islands sustainability transformation. The sum of these interventions will make up this EI's Transformation Pathway.

VII.3. Defining progress milestones and measuring the impact

It is critical to know if each intervention has the desired impact. Therefore, once the interventions to be implemented are settled upon, milestones along this Transformation Pathway need to be defined. As part of their implementation plan, each follower EI will choose the specific KPI they want to monitor and use as performance indicators to assess their respective progress.

While it is not intended for most KPI to be used to compare one site to another (as the different frame conditions make such comparisons problematic or even meaningless), each KPI provides the sites with an internal "measuring stick" to assess their own performance. As such, the RENergetic KPIs will be utilized to assess a site's progress along their own transformation pathway and as indicators if the milestone targets have been reached.

VIII. SUMMARY

The current deliverable describes the key performance indicators (KPIs) selected for the evaluation of energy island actions and how they can be calculated based on metrics (data), These KPIs allow to evaluate (in a quantitative way) the impact generated by the considered actions. The approach contains the evaluation of KPIs (based on metrics) in 3 different domains (technical, economic, social) Those KPIs can be applied for evaluation of RENergetic pilot actions, as well as actions at replications sites and even beyond those.

First, we have sketched the importance of common evaluation of actions and the need to develop a multidisciplinary approach to that. We emphasized the fact that the KPIs are not intended to simply compare different energy island or local energy communities with one another, but rather to truly understand what aspect of the energy island is being evaluated and appreciate the reasons of different metric values for different setting.

In the main sections of the deliverable, the selected KPIs in the technical, economic, and social domain are introduced one by one. For each domain, we start by shortly sketching the scene based on literature references, then the selected KPIs are defined one by one, afterwards a generic procedure is defined for how to actually evaluate those KPIs (get to numbers) and finally some potential pitfalls in the application of the KPIs are given.

In the technical domain the selected KPIs are the self-sufficiency indicator (the degree at which the system can sustain itself without external support), the energy efficiency indicator (the ability of consuming efficiently the energy produced without losses), the energy potency indicator (how efficiently the energy island can integrate renewable energy sources), the share of RES (share of renewable energy sources in the energy provision portfolio), the share of fossil fuel (amount of fossil-fuel based energy provided in the energy island) and the CO2 intensity (amount of CO2 released by the energy island per kWh.

In the economic domain, the selected KPIs are the levelized cost of energy (LCOE), the net present value (NPV, sum of discounted cash flows), the internal rate of return (IRR), the (undiscounted as well as discounted) payback period (PP), the load purchasing from the grid and the energy sold to the grid.

In the social domain, more KPIs are selected in order to adequately grasp all relevant concepts. The selected social KPIs are the share of local ownership in energy infrastructure equipment, the share of local participation in energy system related orders, high acceptance of the community hubs reflected in increasingly positive attitudes, self-identification with community, self-identification with local energy production and usage, social Inclusion, energy behaviour intentions, individual sustainable energy behavior, communcal sustainable energy intentions, social cohesion, job creation through EI, thermal comfort, evaluation of the performance of the heating solutions proposed, democratic participation, behavioral intention to become active, preference of participation and collective efficacy beliefs.

After defining all selected KPIs, some first evaluation results are included. They consider the evaluation of technical KPIs for the heat network in New Docks (Ghent) as well as the evaluation of the social KPIs for the New Docks energy community with respect to demand response. Note that these results are included here for illustrative purposes on how to use and interpret the KPIs, as the actual common evaluation of demonstration results follows in a later project stage and in Deliverables D7.3 and D7.5.

Finally, the relevance of the KPIs for the replication package is described.

IX. APPENDIX ON AUXILIARY ECONOMIC FACTORS

IX.1. Capital Recovery factor

The capital recovery factor is a factor that is used to express the upfront investment cost by an equivalent series of recurring annual investments. This process takes into account the time value of money (expressed by the MARR i) and does “annualize” the investment costs by using the investment lifetime T_{Il}.

In general, this factor is defined as the ratio between the annuity A (period payment in a uniform series of equal end of period payments) and the cumulative present value of equal payments P (Zayed et al., 2020). This CRF can also be expressed as a function of the interest rate i and project’s lifetime n.

Indeed, CRF can convert a present value into equal annual payments flow at a specified discount rate (the MARR i) in a certain period of time n and can be calculated by equation:

$$CRF_{i,n} = \frac{A}{P} = \frac{i(i+1)^n}{(i+1)^n - 1}$$

IX.2. Expenses Levelizing Factor

As indicated in the previous section, we the CRF can be used to get from a one-time investment to an equivalent recurring cash outflow. This concept is not relevant as such for OA&M costs as those are already recurring cash-flows. However, the situation gets more interesting if we consider also inflation (where we actual recurring revenue does not stay constant given the impact of inflation). Let me get back to that in a minute.

First, let’s introduce the present value (PWF) factor. PWR is used to derive the present value of a (single) spending or receipt of cash on a future date. The PV factor is greater for cash receipts scheduled for the near future, and smaller for receipts that are not expected until a later date. The factor is always a number less than one. The formula for calculating the present value factor is:

$$PWF = \left(\frac{1}{1+i}\right)^n$$

When taking into account an inflation rate (IF) as well, the present worth factor (PWF) would be calculated according to the next formula based on (Cusano et al., 2019) and (Soteris Kalogirou, 2014, p.12).

$$PWF = \frac{1+IF}{i-IF} * (1 - \left(\frac{1+IF}{1+i}\right)^n)$$

with project lifetime (n), the inflation rate (IF) and interest rate (i=MARR).

So, this updated PWF formula can be used to get the PV from a (single) future cash flow considering inflation. When applying the CRF on this, we can get to an Expenses Levelling Factor (ELF) calculated as follows:

$$ELF = PWF * CRF_{i,n}$$

This ELF is the recurring cash-flows that is representing the recurring cash-flows but taking into account the impact of inflation.

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