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D4.2 Guidelines to calculate the annual energy balance of a PED

WP4, Task 4.1

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Abbreviations and acronyms

Acronym	Description
%PED	Percentage of total net energy needs covered by resources coming from outside district boundaries
%RES	Percentage of the total net energy needs (thermal or electric) covered by local RES
CO_2eqB	Net carbon dioxide equivalent emissions
FWC	Follower City
LHC	Lighthouse City
PEB	Primary Energy Balance
PED	Positive Energy District
PEE	Exported Primary Energy
PEF	Primary Energy Factor
PEI	Imported Primary Energy
RES	Renewable Energy Systems/Sources
SET	Strategic Energy Technology

Executive Summary

Calculation of energy balance in positive energy districts is complex since it includes several parameters regarding RES on-site, primary energy factors, deciding if a resource is an input or not for calculation and so on. In order to reach an annual positive energy balance, buildings involved in the district have to manage their energy consumption and the energy flow between them and the wider energy system. The system and the interaction between the buildings should make optimal use of elements such as advanced materials, local RES, local storage, smart energy grids, demand-response, cutting edge energy management (electricity, heating and cooling), user interaction/involvement and ICT. Calculation methodology for annual balance may be generated following a few steps. First, energy sources and resources within the limits of the district need to be studied. Once both analyses are done, an iterative process and examination of energy balances will result in different alternatives for the district. In order to assess how positive a certain district is, the balance is made in primary energy terms, as it compares different type of energy and considers the benefits within and beyond the limits of the district. To calculate energy balance, the appropriate assumptions need to be realized (i.e. primary energy factors, average efficiencies of the systems, etc.).

Keywords

Positive Energy Districts, Annual Energy Balance, PED Calculation, Energy Use, Energy Need, Energy Delivered, Primary balance, Primary energy factors

1 Introduction

According to the EU directive 2010/31/EU, buildings in the European Union account for 40% of the total energy consumption. Thus, the building stock offers a huge energy saving potential. Urban planning has been performed without considering mixed-use districts and buildings have been built individually, irrespective of the surrounding buildings. Nonetheless, these heterogeneous districts and RES local energy production need to be seen as the key element contribute to sustainable cities, once both are locally interconnected and managed (Monti, Pesch, Ellis, & Mancarella, 2016). Therefore, an interdisciplinary design process is needed, in order to not only reduce consumption of those districts but also to allow an interchange of energy flows within the limits or even export energy outside its limits.

MAKING-CITY project aims to achieve evidences about the actual potential of the PED concept, as foundation of a highly efficient and sustainable route to progress beyond the current urban transformation roadmaps.

The main objective of this deliverable is to provide guidelines for the calculation of a positive energy district, following the process that was performed during the initial state of MAKING-CITY project. The development process of this document has been based on a continuous process fed by lessons learnt from other work packages and experiences specifically from the demo sites.

The document initially focuses on identifying state of the art methodologies trying to identify any elements that could interact with the current efforts of defining a guideline within the scope of this document. Later, framework of PED concept and definition is identified also addressing definition of calculation terms and how to represent them in an efficient manner. Energy balance and calculation procedures for PEDs are described in detail providing a step by step approach including defining the boundaries, calculations of energy needs, uses and on-site productions. Primary energy factors and calculations are also explained under this document.

The document also tries to answer the role and inclusion of flexibility concept in PED definition and its energy balance as well as what would be the next steps moving from the concept of PED to even bigger scales such as Positive Energy Neighbourhoods or Regions.

1.1 Purpose and target group

The main purpose of Guidelines to calculate the annual energy balance of a PED is to provide an approach for a unified calculation method of PEDs. Calculation of energy balance in positive energy districts is complex since it includes several parameters regarding RES on-site, primary energy factors, deciding if a resource is an input or not for calculation and so on. MAKING-CITY project follows and makes a synthesis of Guidelines – EU Directives 2012/C 115/01 and ISO 52000, which methodology was developed for calculating the energy performance of buildings rather than districts. Main aim of simplifying the existing procedures is for interpreting these methods to be applicable in district scale. Since SET Plan has the ambition to support the planning, deployment and replication of 100 'Positive Energy Districts' across Europe by 2025, the calculation method should be general and simple enough to be adopted in different geographies citing different resources, infrastructures and primary energy calculations.

The target group of the proposed PED method is mainly the municipalities; nonetheless the process defined in this report covers energy planners and engineers, as well. FWCs will apply this methodology to design PEDs in their cities next year.

1.2 Contribution partners

The following Table 1 depicts the main contributions from participant partners in the development of this deliverable.

Table 1: Contribution of Partners

Partner nº and short name	Contribution
25-DEM	Literature review on PED definition and framework, identification of PED calculation guidelines
01-CAR	Main contributor for developing PED calculation methodology, literature review in reference methods and synthesis of method based on identified phases
02-TEC	Contribution to PEF identification and types, Integrated tools for PEB/PED framework calculation
04-TNO	General review of the method and contributions to all sections

1.3 Relation to other activities in the project

The following table depicts the main relationship of this deliverable to other activities (mainly deliverables) developed within the MAKING-CITY Project and that should be considered along with this document for further understanding of its contents.

Table 2: Relation of the report to other deliverables and activities

Deliverable / Task nº	Relation
T4.1/D4.1	PED Methodology Phase V adopts Guidelines to calculate the annual energy balance PED (demand, consumption, Energy flows, storage, RES) to verify if the selected boundary and solutions already provide surplus in energy balance.
T 4.3/D4.17, D4.4	Calculation methodology will be followed and tested for technical design of PED in FWCs (Bassano, Kadikoy, Leon, Vidin, Trencin, Lublin)

2 Reference Methods – State of Art (for calculations)

The Positive Energy Block concept is already integrated in the Action 3.2 Smart Cities and communities of the Energy Union and Set Plan that aims at net–zero-energy/emission districts (ZEED) that will strongly contribute to COP21 targets. A further step to this ZEED concept is the consideration of "positive energy districts (PED) or positive energy blocks (PEB)[1]". These districts consist on delimited areas of buildings and public spaces where the total annual energy balance is positive, therefore the area will deliver, in average, an energy surplus to be shared with other urban or peri-urban zones. To that aim, these districts need to be designed with local RES generation systems in order to not only be able to cover its own needs but the needs of their surrounding limits.

This new terminology regarding PEBs, PEDs and how the concepts are evolving into these trends are also being discussed in D4.1 Methodology for PED design, Section 2.1 from smart cities to PEDs.

During the design process, a previous analysis of the current demand of the district is needed. After that, the energy sources and resources within the limits of the district need to be studied. Once both analyses are done, an iterative process and examination of energy balances will result in different alternatives for the district. In order to assess how positive is a certain district, the annual balance is made in primary energy terms, as it compares different type of energy and considers the benefits within and beyond the limits of the district. To do that energy balance, the appropriate assumptions need to be made (i.e. primary energy factors, average efficiencies of the systems, etc.)

As Primary Energy Factors used for energy balance calculations differ substantially depending on the framework, Building Energy Specification Tables (BEST 2018) were defined in order to calculate the energy balance, evaluating the energy needs, the Renewable Energy Production on site, and the energy flows through test site boundaries. The MAKING-CITY follows the European Directive "Guidelines 2012/C 115/01 accompanying Commission Delegated Regulation (EU) 244/2012 supplementing Directive 2010/31/EU on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building" to perform the energy balance calculation and BEST tables calculation. Although the BEST tables procedure does consider electric appliances as energy needs, the BEST calculation that was performed in MAKING-CITY did not take them into account as the procedure in Directive 2010/31/EU and Guidelines 2012/C 115/01 was followed. Besides electric appliances, any other electrical equipment within the building (auxiliaries for the heating system such as pumps, electrical resistances, etc.) and lighting should be included in the balance, whereas the mobility or lighting of the street is not considered, unless the mobility hub is owned by the community.

Other standards are available to calculate primary energy balances where a similar procedure to the EU Guidelines is followed. For instance, the Umbrella Document V7 (prCEN/TR 15615) provides an outline of the calculation procedure for assessing the energy performance of buildings (and by extension, neighbourhoods or districts). It includes a list of the European standards, both existing and those that are being written, which together form the calculation methodology. But CEN/TR 15615 was withdrawal on july 2017, and replaced by CEN ISO / TR 52000-2: 2017 that is nowadays in force. ISO 52000-2 refers to the EPB-standard overarching, ISO 52000-1, and it contains information to support the correct understanding, use and national implementation of ISO 52000-1, including *explanation on the procedures and background information and justification of the choices that have been made; reporting on validation of calculation procedures given in the standard; and explanation for user and national standards writers involved with implementation of the EPB standards, including detailed examples*. Both documents, Guidelines 2012/C 115/01 and ISO 52000, follow a similar approach.

[1] According to EIP-SCC, Positive Energy Block (PEB) is a group of at least three connected neighbouring buildings producing on a yearly basis more primary energy than what they use.

Table 3: References for current standards

EN number	Content	Status
EN ISO 52000:2017	Assessment of overall energy use of a building, by measurement or calculation, and the calculation of energy performance in terms of primary energy or other energy-related metrics.	In force
EN ISO 52003:2017	Indicators, requirements, ratings and certificates for energy performance of buildings.	In force

According to this, PED claims for an extensive demonstration and validation action to consider this innovative concept as a reference to guide the energy transition in cities. A lot of cities are joining the concept. The project Hunziker Areal, from Zürich (Switzerland) defined their newly built neighbourhoods as PEDs, integrating concepts such as affordable housing, jobs on-site, citizen participation, energy efficiency, RES production and sustainable materials. +CityxChange H2020 project defines a positive energy district in a similar way as the SET-Plan Implementation Working Group 3.2 on Smart Cities and Communities (IWG 3.2) emphasizing energy retrofitting, RES on-site, active management, mobility, social aspects, and flexibility, among others. SPARCS project defines a positive energy district with virtual boundaries, where the energy management, storage, e-mobility, RES production, NZEBs and retrofitted buildings concepts are integrated (among other characteristics). Even COOPERaTE project has developed fined an open, scalable neighbourhood service and management platform that provides services and energy management towards energy positive neighbourhoods and it was tested in two demo sites.

Although in principle a PED approach seems a solid and ambitious strategy, this should be complemented with long term urban planning to ensure upscaling and fostering higher impacts. Currently city energy plans are starting to be designed with a 2030 horizon, according to the standard city commitments, as for instance those reflected in the SECAPs and other more specific city plans (e.g. Sustainable Urban Mobility Plans, Digital Agendas….). The projects will face a huge challenge, consisting on developing not only a 2030 approach but a longer term 2050 city vision that guarantees a seamless city transformation from planning to implementation and further upscaling as will be explained below.

3 Concepts and calculation terms for PEDs

3.1 PED Framework

One of the most important aspects to be considered is the ANNUAL ENERGY BALANCE calculation procedure. This is the subtraction of the surplus of energy produced on-site minus the energy requested from outside the district boundaries. Since all energy carriers have to be considered, **only primary energy units are able to make a suitable calculation merging energy flows**, therefore a PED should deliver a positive non-renewable primary energy outside the defined district boundaries whatever the carriers involved.

The district boundaries that content the PED are defined in several ways (detailed explained in section 4.1). They can be geographical, virtual or functional and with a continuous or discontinuous border.

EU definition: *"Positive energy districts consist of several buildings (new, retro-fitted or a combination of both) that actively manage their energy consumption and the energy flow between them and the wider energy system, have an annual positive energy balance, make optimal use of elements such as advanced materials, local RES, local storage, smart energy grids, demand-response, cutting edge energy management (electricity, heating and cooling), user interaction/involvement and ICT. They are designed to be integral part of the district/city energy system and have a positive impact on it. Their design is intrinsically scalable and they are well embedded in the spatial, economic, technical, environmental and social context of the project site. Assessing Positive Energy Blocks/Districts: as Primary Energy Factors used for energy balance calculations differ substantially depending on the framework, we evaluate energy need, RES produced locally and energy flows through test site boundaries"*

Discussion within the SET-Plan Implementation Working Group 3.2 on Smart Cities and Communities in Vienna in April 2019, the **IWG 3.2 defined PEDs as** "*Urban neighbourhood with annual net zero energy import and net zero CO_2 emissions working towards a surplus production of renewable energy, integrated in an urban and regional energy system*". In June 2019, the last SET Plan short definition: "*Positive Energy Districts (PED) are energy efficient districts that have net zero carbon dioxide (CO_2) emissions and work towards an annual local surplus production of renewable energy (RES)*." They require interaction and integration between buildings, the users and the regional energy, mobility and ICT system, while ensuring social, economic and environmental sustainability for current and future generations.

According to the latest discussions, four types of PEDs are being defined, according to the way the energy balance is achieved, and thus provide for system flexibility and operational optimization potential:

- **Auto-PED (PEDautonomous):** 'plus-autarkic', net positive yearly energy balance within the geographical boundaries of the PED and internal energy balance at any moment in time (no imports from the hinterland) or even helping to balance the wider grid hinterland outside
- **Dynamic-PED (PEDdynamic):** net positive yearly energy balance within the geographical boundaries of the PED but dynamic exchanges with the hinterland to compensate for momentary surpluses and shortages
- **Virtual-PED (PEDvirtual):** net positive yearly energy balance within the virtual boundaries of the PED but dynamic exchanges with the hinterland to compensate for momentary surpluses and shortages
- **Candidate-PED (pre-PED):** no net positive yearly energy balance within the geographical boundaries of the PED but energy difference acquired on the market by importing certified green energy (i.e. realizing a zero-carbon district)

JPI Urban Europe defined PEDs and Neighborhoods *"are an integral part of comprehensive approaches towards sustainable urbanisation including technology, spatial, regulatory, financial, legal, social and economic perspectives. They require interaction and integration between buildings, the users and the regional energy, mobility and ICT system. In this sense, a Positive Energy District is seen as an urban neighbourhood with annual net zero energy import and net zero CO_2 emissions working towards a surplus production of renewable energy, integrated in an urban and regional energy system. Active management will allow for balancing and optimisation, peak shaving, load shifting, demand response and reduced curtailment of RES, and district-level* *self-consumption of electricity and thermal energy. A Positive Energy District couples-built environment, sustainable production and consumption, and mobility to reduce energy use and greenhouse gas emissions and to create added value and incentives for the consumer. Furthermore, implementation has to come with a high and affordable standard of living for its inhabitants."* According to the latest update in February 2020, A framework for PEDs could be defined as follows: *"Positive Energy Districts are energy-efficient and energy-flexible urban areas which produce net zero greenhouse gas emissions and actively manage an annual local or regional surplus production of renewable energy. They require integration of different systems and infrastructures and interaction between buildings, the users and the regional energy, mobility and ICT systems, while optimizing the liveability of the urban environment in line with social, economic and environmental sustainability."*

Other definitions have been found in the latest PED projects, such as SPARCS and +CityxChange, as mentioned in section 2.

In general, the following characteristics for a PED have been found in all the different sources:

Table 4: Quantitative and Qualitative Characteristics of a PED

QUANTITATIVE CHARACTERISTICS	QUALITATIVE CHARACTERISTICS
Several buildings (New, retrofitted, combination of both, mixed-use) Positive Energy Balance Scalable Optimal use of systems Active management Energy Efficiency Net CO2 emissions Surplus of RES	Integrated building Positive impact Interaction between buildings/users/systems Synergically connected Role model Innovative Sustainable urbanization User added value Affordable, high standard living Sustainable Mobility, consumption and production

Positive total primary energy balance evolves from net zero energy districts but can obtain better impacts, since intensive use of local RES and high energy efficiency can achieve very high reduction of CO2 emissions. **Locality,** in terms of technical solutions, new business models, individuals and communities should be compatible to the scalable logic from PEDs to PENs. Positive Energy Neighbourhoods are, at first sight, scaled up versions of PEDs and as identified earlier, involve much larger areas of the city in the form of whole neighbourhoods. PENs thus get closer to the urban reality in terms of the complex dynamics that begin to involve land use patterns, public space, urban energy infrastructure and most importantly larger populations that may have conflicting socio-technical visions of the urban future. On the other hand, possibilities for positive energy balance may contain opportunities not present in PEDs in that RES resources may become diversified and heat and power exchanges increase in number, creating more **opportunities for flexibility**. In order to pursue these opportunities however, PEN concept definitions must be developed aligned with mid to long-term planning process (WP1) of the cities concerning liveability, spatial quality, biodiversity, quality of life, affordability and inclusiveness parameters for the design of buildings and public spaces for extended boundaries.

Thus, according to these discussions on the PED definition and characteristics, as well as considering the urban contexts of the Lighthouse cities of Oulu and Groningen, **MAKING-CITY** adopts the following definition of a Positive Energy District:

"A Positive Energy District is an urban area with clear boundaries, consisting on buildings of different typologies that actively manage the energy flow between them and the larger energy system to reach an annual positive non-renewable primary energy balance"

3.2 Definition of calculation terms

The terms used for the definition of the PED calculation procedure developed in MAKING-CITY project are based on the ISO52000. In following table, most relevant ones have been described and their measuring units identified.

Table 5: Calculation terms definitions

Name	Acronym	Description	Units
Positive Energy District	PED	Urban area with clear boundaries and annual non-renewable primary positive energy balance. Non-renewable primary energy imported to the district is lower than the equivalent avoided non-renewable primary energy (due to RES exports outside the district limits).	-
Renewable Energy Sources	RES	Systems using solar energy, wind farms (owned by the district), geothermal, hydropower, heat pumps (with COP>2.5), and systems using local biomass or biogas are local on-site renewable energy sources. Waste heat facilities are considered as local on-site renewable sources that reduces the amount of thermal energy needs to be covered by non-renewable sources (from outside the PED limits). In the case of biogas and biomass, a non-renewable primary energy factor is used to transform the biogas/biomass energy delivered to primary energy, i.e. account for the energy needed to process and obtain these fuels.	-
Thermal Energy needs (heating and cooling)	$TEN_{H\&C}$	Heat to be delivered to or extracted by emitters (radiators, fancoils, etc.) to cover the energy demands of the buildings and thermal conditioned spaces, to maintain the intended space temperature conditions during a given period of time[2]	kWh_{th}/yr
Thermal Energy needs (domestic hot water - DHW)	TEN_{DHW}	Heat to be delivered to the needed amount of domestic hot water to raise its temperature from the cold network temperature (usually known as tap water) to the prefixed delivered temperature (different for each country and system) at the delivery point accounting the losses[3]	kWh_{th}/yr
Electric Energy Needs	EEN	Electric energy to be delivered to cover the energy demand of lighting and ventilation of a building. Usually electric energy needs and electric energy use by the building for lighting and ventilation purposes are the same (losses can be neglected).	kWh_{e}/yr

[2] ISO52000

		Electrical energy to drive the heating system (such as heat pumps or electrical heaters) and auxiliary elements (pumps, etc.) should be included as energy use	
Thermal Energy Use	TEU	Energy input into the heating, cooling or hot water system to satisfy the energy needs for heating, cooling or hot water respectively. It can also be identified as the useful energy output from the thermal generation systems (E.g. solar thermal collectors, boilers, thermal output from CHP, etc.).	kWh_{th}/yr
Electric Energy Use	EEU	Electric energy Electricity directly consumed by buildings (from grid or local RES as PV, wind…) to be delivered to cover the energy needs (for DHW, heating and cooling when an electricity-driven system is used; and ventilation, and lighting). Only electric energy needs and uses in the EPB standards are considered, therefore the electricity used within the district boundaries for domestic appliances, and mobility (traffic lights, road lights, EV cars etc.) are neglected. In commercial and industrial buildings, the correspondent standards should be considered. Note that electric energy use can also be identified as the useful energy output from the electric generation systems. There might be a slightly difference between the energy use by the building and the electric energy needs by appliances due to the loss of energy by means of heat which is usually neglected as it is smaller than the overall consumption. Electric energy to drive the heating system (such as heat pumps or electrical heaters) and auxiliary elements (pumps, etc.) should be included as electric energy use	kWh_e/yr
Thermal Energy Produced	TEP	Thermal energy generated by the systems located on-site the district. The energy carrier used in these systems should be considered in order to know the amount of delivered energy. Solar, geothermal, local biomass and waste heat facilities are considered as local on-site renewable sources that reduces the amount of thermal energy needs to be covered by non-renewable sources (from outside the PED limits).	kWh_{th}/yr
Electric Energy Produced	EEP	Electricity generated by any system located on-site the district. All the energy carrier used in these systems should be considered in order to know the amount of delivered energy. PV panels, wind farms (owned by the district) or cogeneration systems (using local biomass/biogas) are local on-site renewable sources.	kWh_e/yr
Surplus of Thermal Energy	STE	The thermal energy produced on-site that is not used to cover thermal energy needs and, therefore, is exported outside the district boundaries. It is calculated as the difference between thermal energy produced on-site and thermal energy consumed on-site	kWh_{th}/yr

Surplus of Electric Energy	SEE	The electricity produced on-site that is not used to cover electricity needs and, therefore, is exported outside the district boundaries. It is calculated as the difference between the electricity produced on-site and electricity consumed	kWh_e/yr
Energy Delivered	ED	Energy supplied to the PED (thermal and electricity) that is produced outside the district boundaries. Usually comes from thermal, gas or electric grids and feeds the energy systems available on-site the district. Some of these energy flows can be quantified based on the meters, and in case of gas consumption, it is usually measured in Nm^3,a conversion factor will be needed. (The conversion factors shall be coherent with the choice of referring to gross calorific value or net calorific value.)	kWh/yr
Non-renewable Primary Energy Balance / Total Primary Energy Balance	PEB	Primary energy[3] is the energy that has not undergone any conversion in the transformation process, calculated by energy carrier using non-renewable primary energy factors ((PEFnren) or total primary energy factors (TPEF). The primary energy balance is calculated as the difference between energy delivered to the district (summed by all energy carriers) multiply by the primary energy factor (per energy carrier) and the energy that is exported outside the PED's boundaries multiply by the primary energy factor (per energy carrier). Depending if PEF_{nren} or TPEF are used, the balance will be done in non-renewable primary energy terms or total terms.	kWh_p/yr
Non-renewable primary energy factor	PEF_{nren}	It demonstrates how much primary energy from non-renewable sources is used to generate a unit of final energy through the use of consumption indicators.	-
Renewable primary energy factor	PEF_{ren}	It demonstrates how much primary energy from renewable sources is used to generate a unit of final energy through the use of consumption indicators.	-
Total primary energy factor	TPEF	It demonstrates how much primary energy from renewable and non-renewable sources is used to generate a unit of final energy through the use of consumption indicators.	-
Non-renewable Primary Energy Exported / Total primary energy exported	PEE	Surplus of primary energy delivered by the PED that is used outside the district boundaries. It is calculated as the summed of surplus of thermal energy multiply by primary energy factors (taking into account the different energy carriers) and the surplus of electric energy multiply by primary energy factors (taking into account the grid electricity factors). The total or non-renewable primary energy factors of the grids (gas, electric, fuels, etc.) are used in order to take into account the "avoided" energy of the system beyond the boundaries.	kWh_p/yr

[3] Article 2(5) of the Energy Performance of Buildings Directive 6

		Depending if PEF_{nren} or TPEF are used, the PEE will be done in non-renewable primary energy terms or total terms.	
Non-renewable Primary Energy Imported / Total Primary Energy Imported	PEI	Energy delivered into the PED that is calculated in terms of non-renewable primary energy as the summed of the weighted delivered energy over all energy carriers (electric energy drawn from the grid, heat from a district heating network, gas from the grid, oil, biomass, biogas or any other fuel) multiplied by the primary energy factors of each energy carrier. Depending if PEF_{nren} or TPEF are used, the PEI will be done in non-renewable primary energy terms or total terms.	kWh_p/yr

3.3 How to show the energy balance

Although there are some other ways to represent the energy balance in a PED for summering the energy calculations and highlight the surplus of energy provided by the district, the two main approaches used by MAKING-CITY project are the BEST table and the Energy Flow Diagram (known as Sankey Diagram, based on European guidelines[4]).

The BEST table (Building Energy Specification Table) has proposed by the EU in the Horizon 2020 Programme to collect the performance data in a demo district and summarize the energy values provided by the energy measures of the Lighthouse projects. The energy flow is a common representation of the different supplying energy flows. MAKING-CITY project has prepared BEST Table at the proposal stage to present calculations of Oulu and Groningen Lighthouse cities but BEST table will not be used in PED calculation methodology since they are not user-friendly tables for the follower cities. As an alternative, MAKING-CITY tables have been performed (see figures in section 4) as well as energy flow diagrams.

3.3.1 Energy Flow Diagram

This graphical representation shows the energy flows for the different stages of the balance. The energy needs that the district demand, the energy used for covering this demand, the final energy delivered into de district and the previous equivalent primary energy. These four stages cover electric and thermal energy flows. The fifth section of this diagram shows the result of the primary energy balance and represents the surplus of energy that the PED could have (and the CO_2 equivalent related emissions).

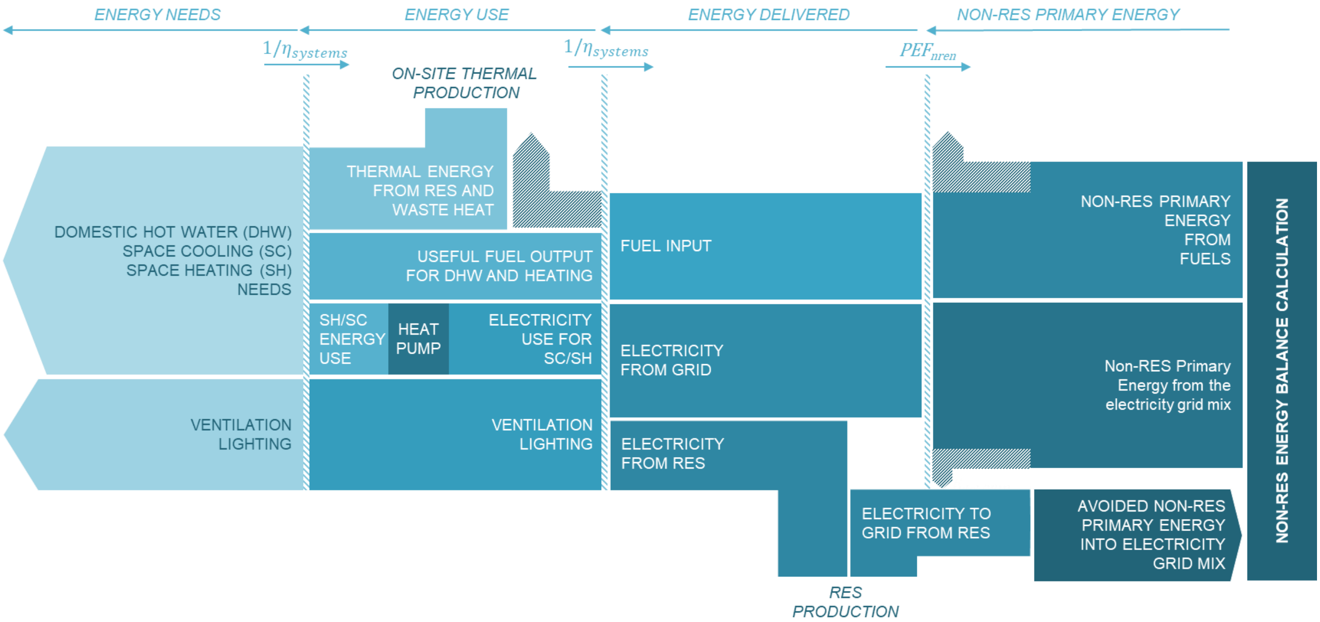


Figure 1: Sankey Diagram for representing Energy Flows. Own elaboration based on (European Commission, 2012)[5]

This schematic illustration has not the intention to cover all possible combinations of energy supply, but only the main ones: on-site energy production and energy use. Energy produced on-site (thermal and electric) are considered to cover part of the energy demand reducing in this way the energy needs of the district, and in fact the energy delivered on it in terms of final and primary values. Loses due to systems efficiency and those related with the primary energy transformation are also represented in this diagram.

[4] European Commission. (2012). Guidelines accompanying Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings. Official Journal of the European Union

[5] European Commission. (2012). Guidelines accompanying Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings. Official Journal of the European Union

The calculation of the weighted primary energy from outside and within the system boundaries needs to be performed from the left to the right in this diagram in order to account for the losses along the whole system, i.e. from energy needs to primary energy. Primary energy instead of final energy is used to make adjust the balance, as different energy sources are assessed (i.e. thermal and electrical)~~,~~ and losses in the overall process can be accounted. This consideration also allows taking into account the benefits of exporting energy out of the limits of the PED, which can be evaluated and compared with the internal use of energy coming from outside the district boundaries.

4 Energy balance and calculation procedure for PEDs

In this chapter, the procedure to calculate the primary energy balance (PEB) within a Positive Energy District (PED) has been explained. As mentioned before, the European Directive Guidelines 2012/C 115/01 have been followed within MAKING-CITY project to perform the PEB calculation. Calculation goes from net energy needs to primary energy use and different steps have been identified for making easier the following of the energy calculations.

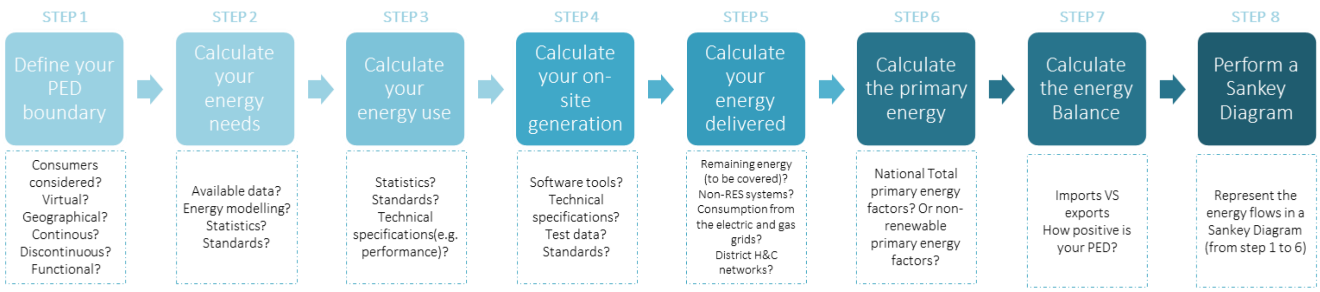


Figure 2: Steps of the calculation procedure

4.1 Decide the district boundaries

The first step of the procedure will be to define the boundaries of our PED. A system boundary can be defined as "a borderline that includes several systems, installations, facilities and/or buildings that are interconnected somehow between each other, either with some energy infrastructures, grid or virtual/contractual connection".

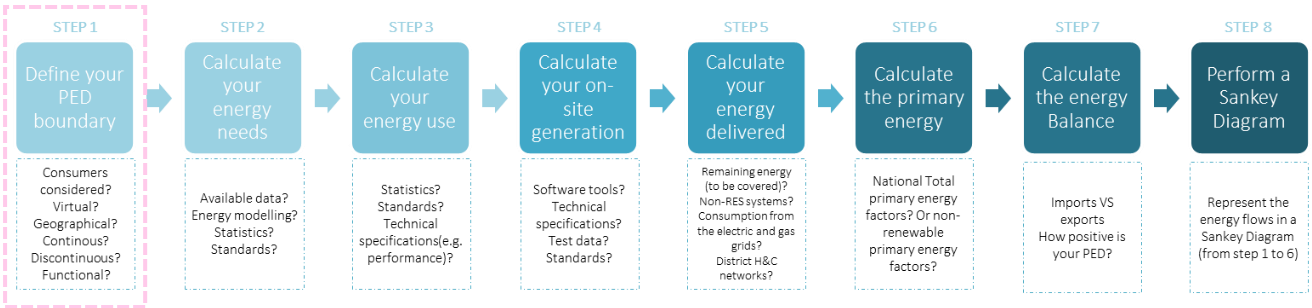


Figure 3: Calculation procedure (step 1)

System boundaries delimit a group of blocks that share a common functionality (e.g. energy system, information system, etc.). From a technical point of view a PED is characterized by achieving a positive energy balance within those given boundaries. Boundaries of a PED can be geographical, functional or virtual, attending on energy systems connected, and continuous or discontinuous according to the configuration of detached patches[6].

PEDs can be delimited by spatial-physical limits including delineated buildings, sites and infrastructures. Therefore, the PED will be characterized by geographical boundaries (Figure 4).

[6] According to the latest discussions of the SET-Plan Implementation Working Group 3.2 (IWG 3.2) on Smart Cities and Communities

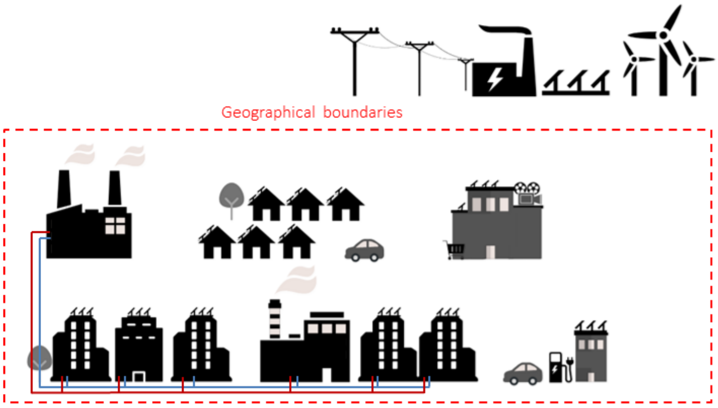


Figure 4: Example of a potential PED with geographical boundaries

Furthermore, it might be possible that the district has several buildings within a district or city interconnected with each other in terms of energy grids. This is the case of a district with a district heating or cooling system. A definition of a PED with a "functional boundary" can be taken from this as the buildings are interconnected by means of the pipes, and buildings are supplied by the same service. A gas network grid or an electric grid will follow the same approach, as an electricity/gas grid behind a substation can be considered as an independent functional entity serving the PED, even if the mentioned service areas are substantially larger than the energy sector of the PED in question.

But, what if an energy generation infrastructure own by the community is located outside the geographical boundaries of the district? Then, a virtual boundary could be defined, where the momentary energy produced and consumed is compared guaranteeing that, when a district demands, that RES energy is purchased to the grid. This is the case of a community that has the resources to own a windmill which are not usually located close to the city (See Figure 5). When the district cannot afford to own an energy infrastructure but can contract their RES energy with an Energy Trading Company or can buy green energy certificates, it can be debatable to consider it as a PED or not. According to the latest discussions in different platforms (JPI Urban Europe, IWG 3.2), this type of district will be named as "pre-PED" as it cannot be guaranteed that this energy will be purchased and, also, it is not actively managed by the district.

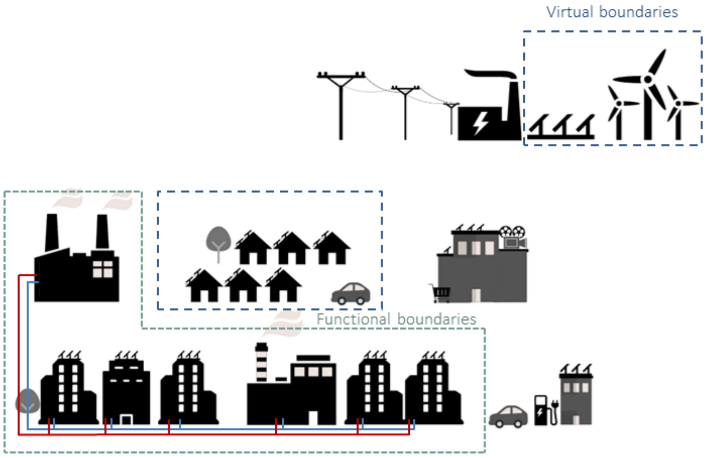


Figure 5: Example of potential PEDs with a functional boundary (within a district heating system) and a virtual boundary (RES infrastructure owned by the PED outside the geographical boundaries).

As mentioned before, district boundaries are important for the evaluation of the performances of the district and the calculation of the annual primary energy balance. When deciding the district boundaries, the specific typology of the district must be taken into account. Boundaries can be defined according to political reasons, city priorities, or land planning. Anyhow, it is recommended to specify the reasons and methodology followed by the city (or district) to decide the borders.

To illustrate an example, Figure 6 shows a district that consists of an apartment block, 3 detached houses and one school. A district heating facility, nearby the district, supplies heat to both: apartment blocks and detached houses, whereas the school has a heat pump to provide all the thermal needs of the building. All buildings have installed photovoltaic panels in their roofs and the school electric batteries installed allowing to share P2P the electricity that the district needs when there is no sun. Furthermore, when electricity production exceeds the demand, the surplus is exported and when lower, electricity from the grid is is imported to the district. The district heating facility is powered by natural gas, and it also supplies heat to the surrounding buildings outside the PED district boundaries. It can be debatable whether the PED should include the district heating facility within their boundaries or not. Is it a PED even though natural gas is feeding the district heating facility? It is a matter of making the annual energy balance, city priorities (e.g. city wants to expand the district heating network, and decarbonise it by including renewable energy sources such as biogas from municipal waste), or the company's willing (if the district heating is not owned by the municipality): the district heating facility does not want to be included within the PED.

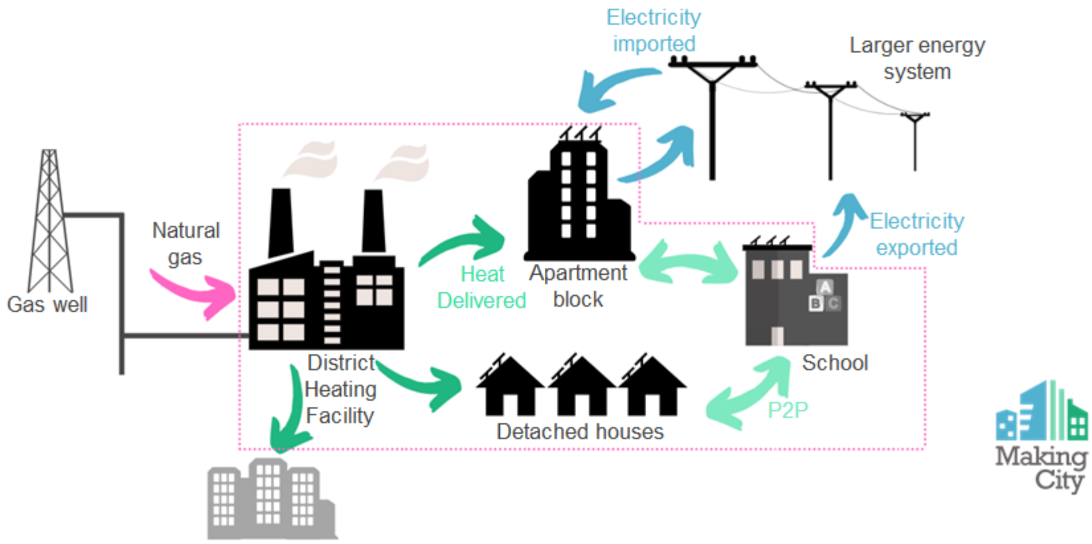


Figure 6: Illustration Example 1

In the calculation table below building definition delimitate the district boundaries (Figure 7), meanwhile in the energy flow diagram these boundaries cover the energy need and use stages (Figure 8).

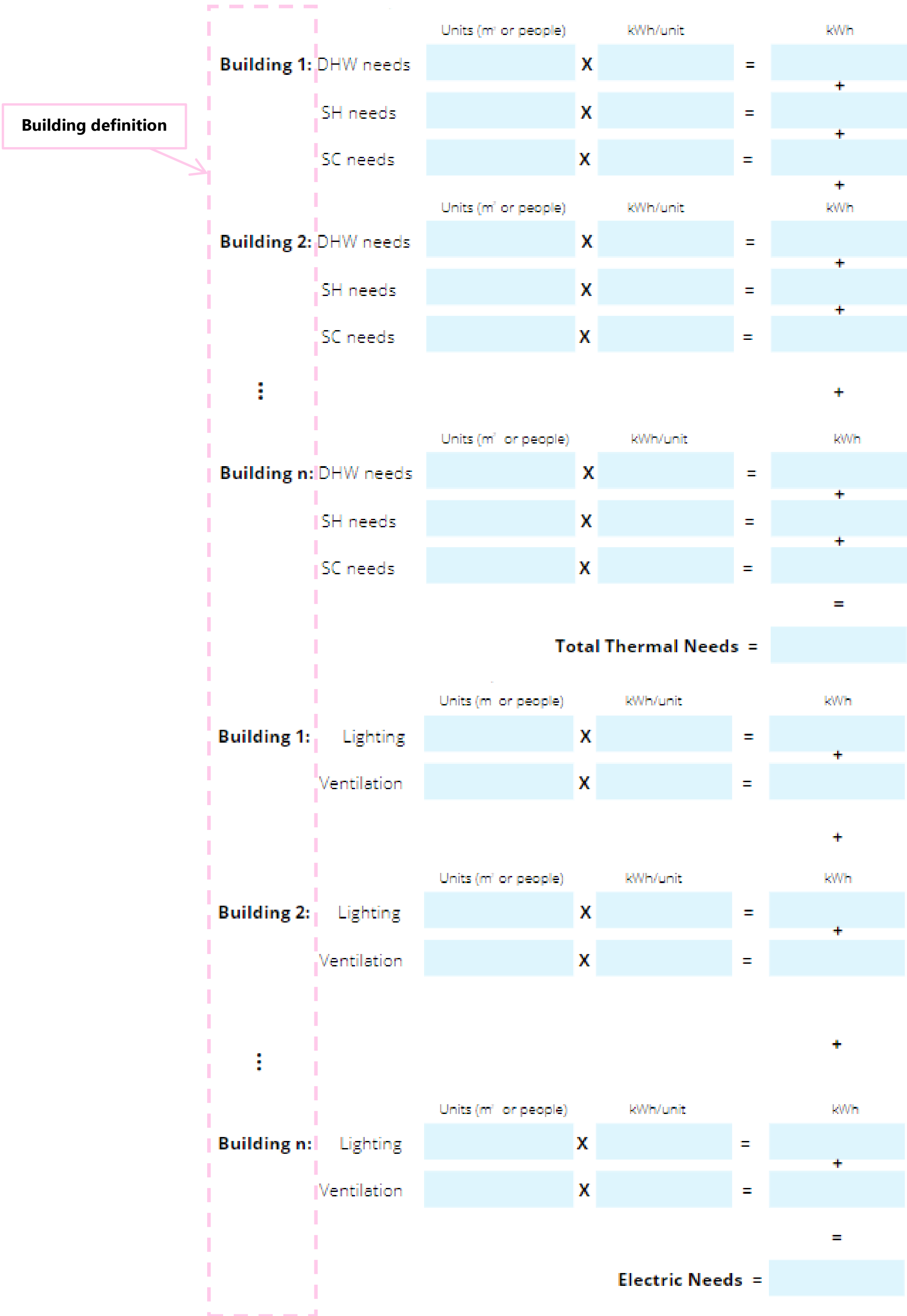


Figure 7: Calculation table (Building definition - boundaries)

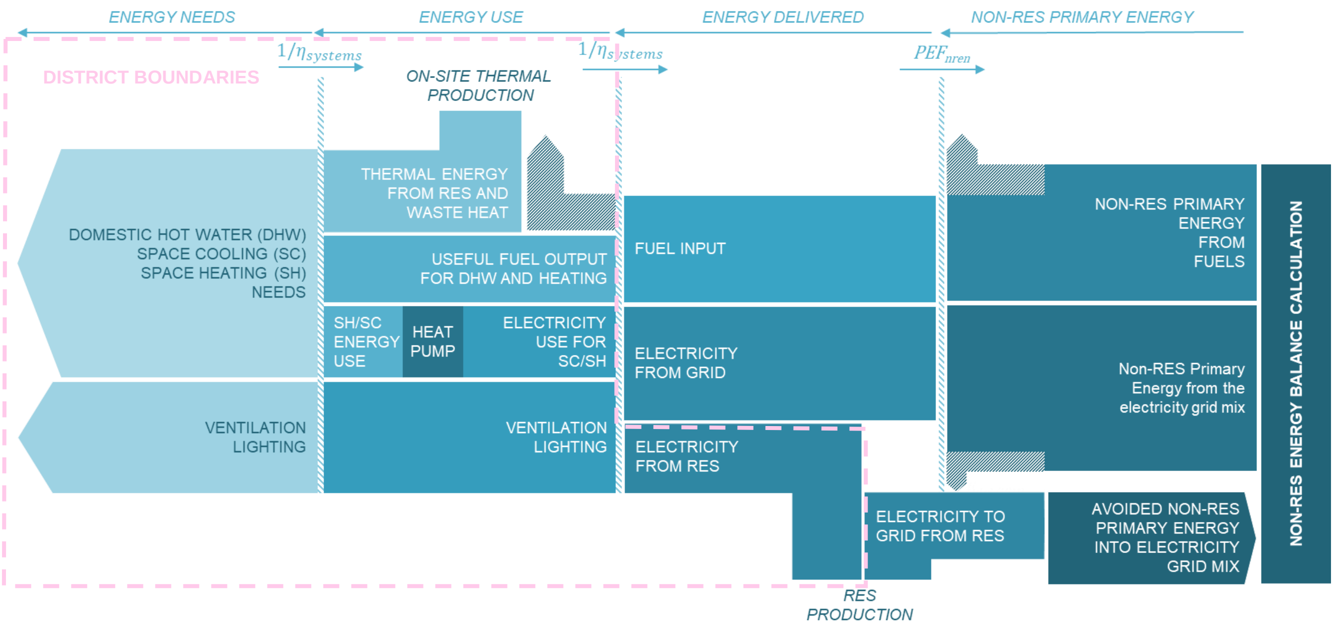


Figure 8: District boundaries in the Sankey Diagram

4.2 Calculate the energy needs inside the boundaries

The second step of the procedure is to estimate the energy need by the PED taking into account the different energy demands.

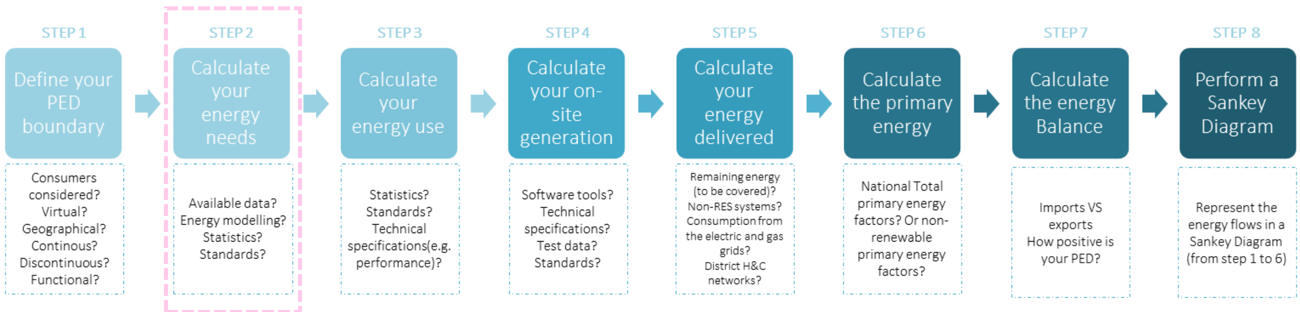


Figure 9: Calculation procedure (step 2)

To calculate the user's requirements for heating, cooling, domestic hot water preparation and electric needs (lighting, ventilation and others), different calculation methods can be used, depending on the accuracy needed, the cost effectiveness (of gathering the inputs), or the complexity of the type of buildings. National standards, national statistical data (with estimated energy demand per square meter dependent on the climate zone of the area, etc.), measured data (if available), or bills can be used to calculate the demand. Furthermore, when structural data of the building and data from the existing system are available, an energy modelling tool can be useful to estimate the demand. Careful should be taken, as the heating demand of the building will be lower than the heating needs from the emitters (e.g. radiators, fan coils, etc.) as part of the energy is lost in the process. The later one should be used for the assessment. For instance, once the heating demand is calculated it can be divided by the performance of the emitters (available in technical specifications or manuals) and that is the energy needs of the buildings to be met. Also, ISO standards could be followed which defines two routes, simplified and detailed numerical calculations (See Table 6).

There are also some tools that allow calculation of energy needs at district or city scale, based on GIS models or alternatively replicating reference buildings etc. Detailed information may be found in Chapter 7.

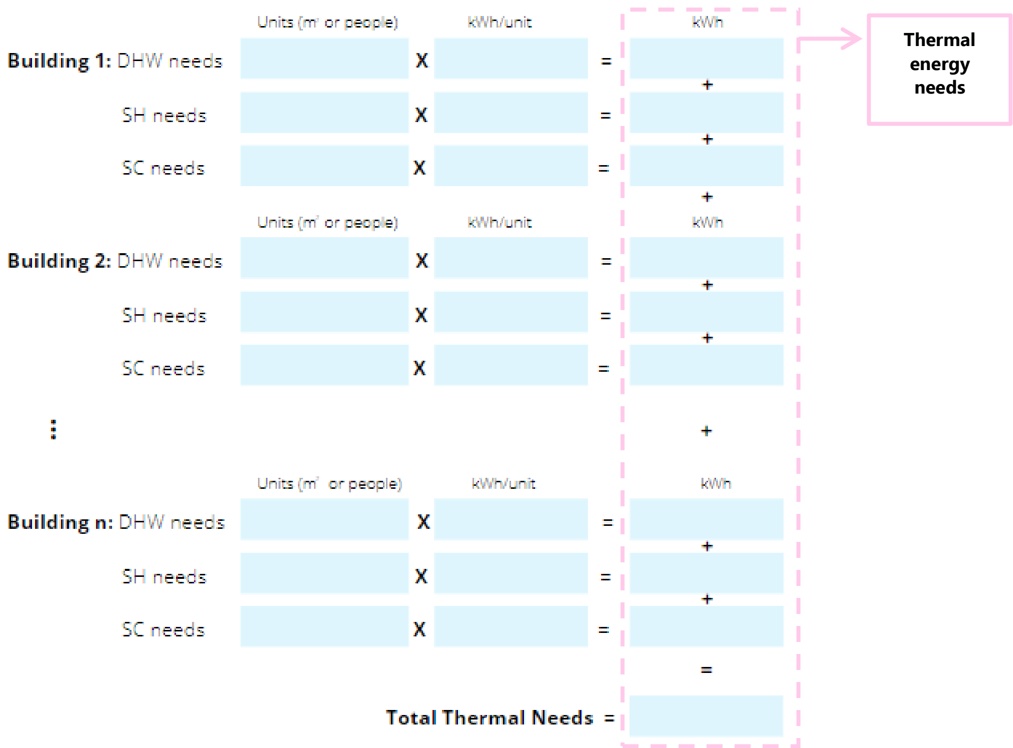
When calculating the electric energy needs, simultaneity coefficients should be considered. Appliances are hard to estimate as it depends mainly in the user's behaviour. But if possible, standards or public free tools like CREST or LPG can be used to generate electricity profiles beyond HVAC systems. Depending on the EU Directive or EPB standards, appliances are not considered (such as in the ISO 52000). **If they are not considered, then, during the evaluation period of the PED, an estimation of the appliances will be needed to subtract them from the overall energy consumption.**

Once the method to calculate it is chosen, **the overall energy needs are calculated and separated by thermal and electric energy needs**. The energy can be expressed in energy units (kWh, etc.) or per unit area (kWh/m^2, etc.) or volume (kWh/m^3, etc.), as long as the units and area or volume thermally conditioned are specified. If the buildings require too much heating and cooling needs, it is recommended to improve the dwellings, include retrofitting measures or change the emitters to more efficient ones in order to reduce it, as has been explained in deliverable D4.1.

Table 6: Existing standards to calculate the energy demand

Standard	Description	Status
EN ISO 52016:2017	Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads	In force
EN 15316-3-1:2018 EN 12831–3	Energy needs for domestic hot water preparation	In force
EN 15193-1:2019	Energy requirements for lighting	In force
EN 16798-5-1/2:2018	Calculation methods for energy requirements of ventilation and air conditioning systems	In force
EN 15232-1:2018	Impact of Building Automation, Controls and Building Management	In force

Now the energy needs can be added to the MAKING-CITY Tables (Figure 10). The total energy needs can be summed up and separated by total thermal net energy needs (TEN) and total electric net energy needs (EEN).



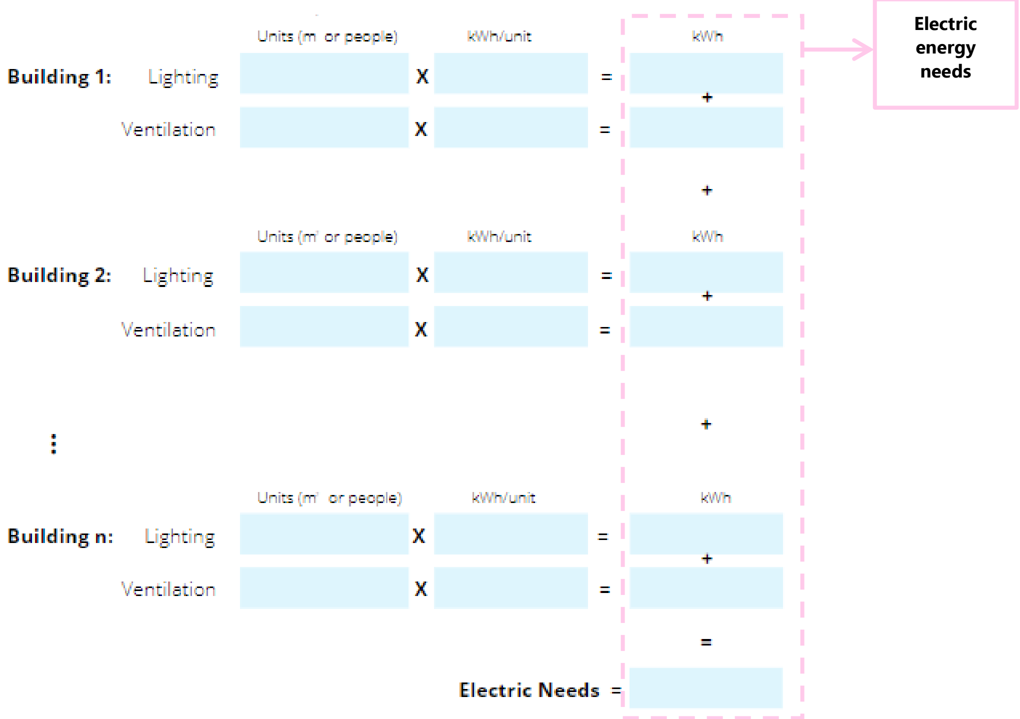


Figure 10: MAKING-CITY Table (Thermal and Electric Energy Needs)

Then, the corresponding energy flows will be:

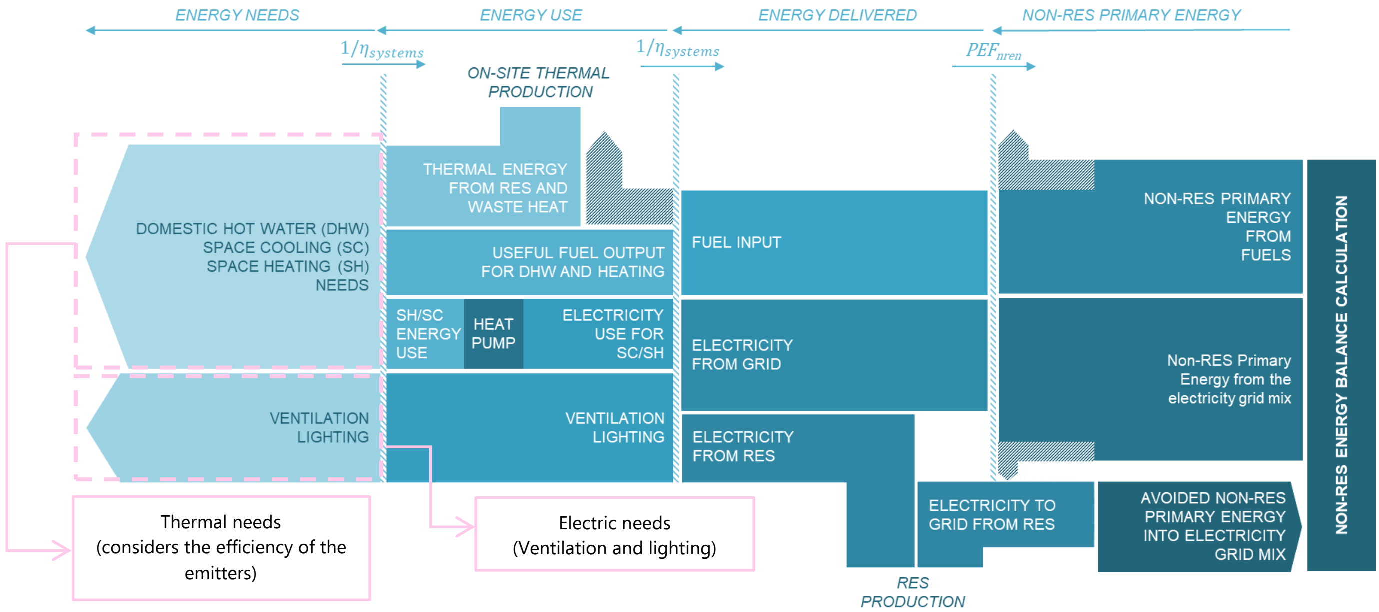


Figure 11: Energy needs in the energy flows Diagram

4.3 Calculate the energy uses

The third step of the procedure is to calculate the energy uses by the PED taking into account the above energy needs and the efficiency of the distribution systems.

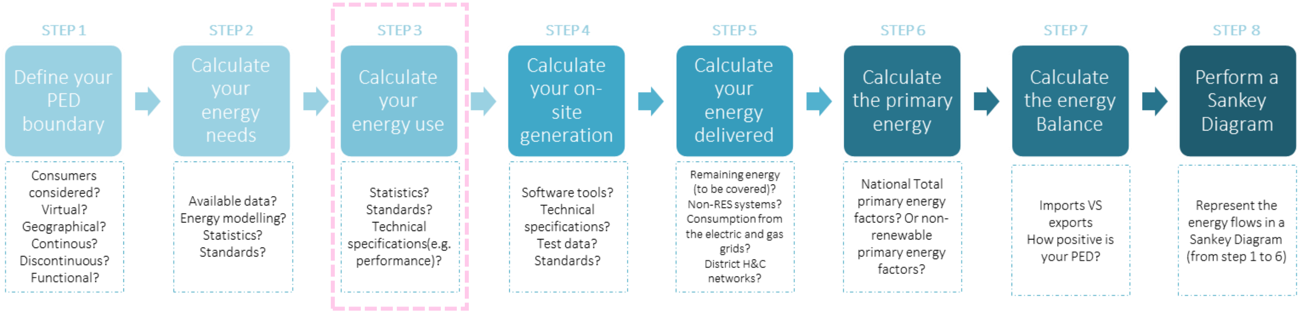


Figure 12: Calculation procedure (step 3)

Energy use can be divided in:

- TEU: Thermal Energy Use (on-site) is the energy input into the heating, cooling or hot water distribution systems to satisfy the energy needs for heating, cooling or hot water respectively. It can be also considered as the useful energy output from the thermal generation systems (E.g. solar thermal collectors[7], boilers, thermal output from CHP, etc.) that will be used by the heating, cooling or hot water system to satisfy the thermal energy needs.
- EEU: Electric Energy Use (on-site): Electricity directly consumed by buildings (from grid or local RES as PV, wind…) to supply the electricity needs (heating, cooling, ventilation, lighting and domestic hot water). It can also be identified as the useful energy output from the electric generation systems. Only electric energy uses in the EPB standards are considered[8], therefore the electricity used within the district boundaries for domestic appliances, and mobility (traffic lights, road lights, EV cars etc.) are neglected. In commercial and industrial buildings, the correspondent standards should be considered. There are slightly differences between the energy use on the appliances and lighting, and the electric energy produced (or measured at the bottom of the electric panel), as part of the electricity will be lost in the form of heat, but generally this part can be neglected as it is smaller than the overall consumption.

In a general way, the energy use can be summarized in the following formula:

$$Energy\ Use\ = \frac{Energy\ needs\ covered\ by\ the\ system\ (Section\ 5.2)}{Performance\ of\ the\ distribution\ system^{9}} \quad (Eq.\ 1)$$

For ventilation and lighting it could be said that:

$$EEU\ (Ventilation + Lighting) \cong \text{Electric energy needs} \quad (Eq.\ 2)$$

Furthermore, if a heat pump or an electric resistance is used to cover the SH/SC needs and/or DHW, its coefficient of performance could be used to estimate the electric energy use. Thus, the total electric energy use of the district will be the summed of the ventilation, lighting and electricity required for SH/SC and DHW:

$$\begin{aligned} &EEU\ (Ventilation + Lighting + Heat\ pumps) \\ &\cong Electric\ energy\ use\ (Ventilation + Lighting) + \frac{SH + SC + DHW\ needs}{SCOP} \end{aligned} \quad (Eq.\ 3)$$

[7] For instance, part of the solar thermal collectors output can be stored in a tank, but the useful output supplied to the buildings will be. In the design process, this cannot be estimated (unless some online simulations are performed), but needs to be taken into account in the evaluation part of the PED.

[8] ISO 52000-1 (2017)

[9] Typical losses in the distribution systems: 5-10%. When heat exchangers are included, the number is up to 15-45% of overall losses (depending on the efficiencies of each heat exchanger, number of heat exchangers, distance from the energy generation to the emitters such as radiators, fan coils, etc.).

4.4 Calculate on-site production

The identification of RES resources forms the second phase of the methodology of the PED design developed in MAKING-CITY project and reported in the deliverable D4.1.

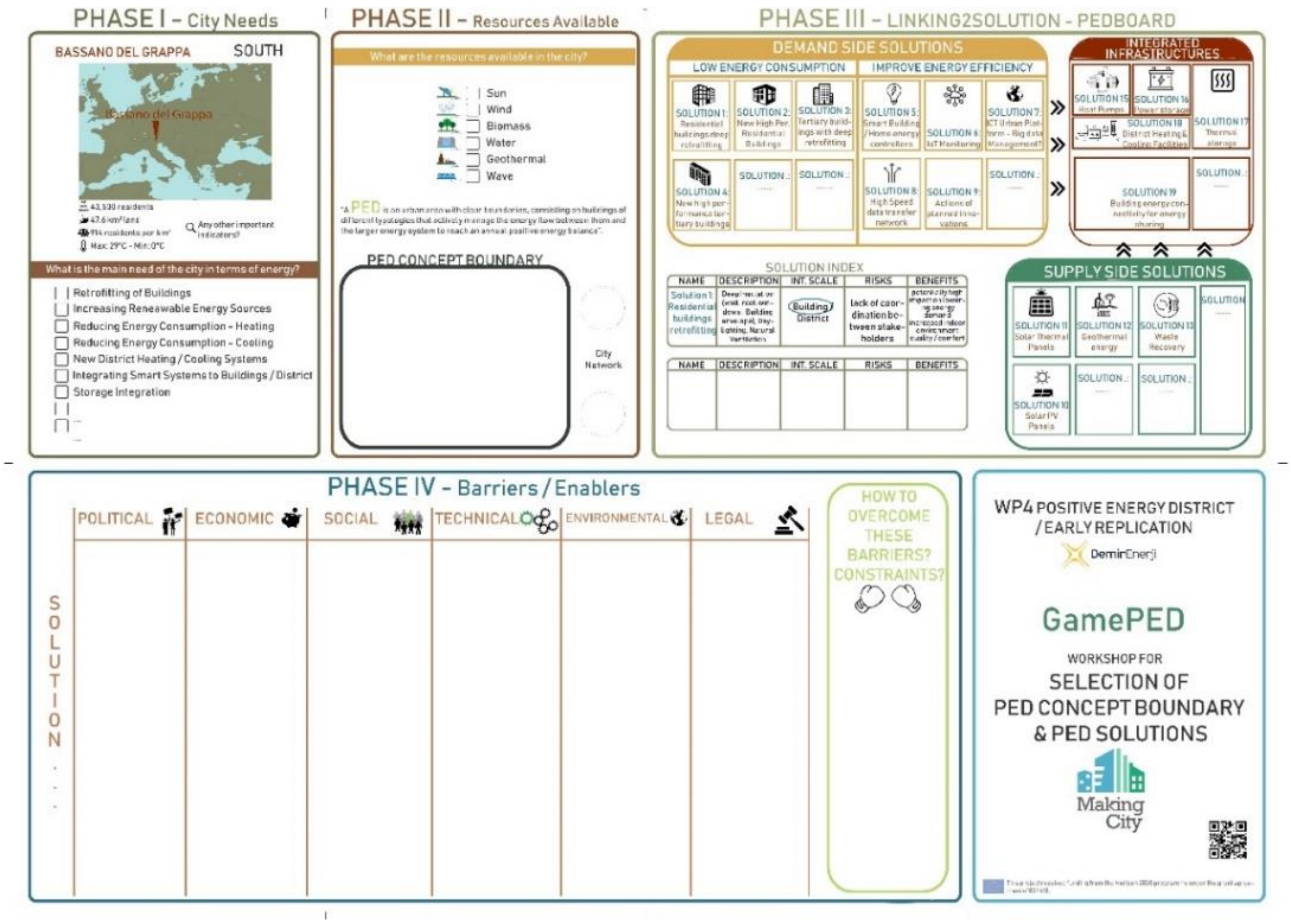


Figure 13: PED design methodology (Deliverable D4.1)

How to do this identification has been widely described in that deliverable, but in this case, for the calculation procedure, as there are necessary to evaluate all the energy systems.

When part of the district already exists, part of the district demand could be covered by existing systems. In that case, it can be identified beforehand which systems will remain and which ones will be substituted by new solutions. This information can be obtained by means of interviews to the different buildings involved; by obtaining the district drawings and schematics of the buildings or, if any of that is possible, some assumptions can be made based on national regulations.

After identifying which solutions will be considered for a certain district, energy systems can be listed and the connections between each other (schematics) and the energy source that is supplied to it (biogas, natural gas, solar, wind, electricity from the grid, etc.) can be identified. As an example, a certain district might be using individual or collective boilers for DHW needs and the boiler can be fuelled by biomass, natural gas, oil, among others. The connections will give information about the energy coming from outside the district boundaries and the energy losses in the whole system. The most common systems are listed in Table 7 meanwhile additional solutions can be found in Figure 13 (Phase III).

Table 7: Energy systems on-site[10]

Feature	Data requirement, parameters	Energy sources
Heating systems Boiler CHP Heat pump	Schematic Technical specification of heat generators	Fossil fuels or biogas, biomass, biofuels, etc. Electricity Solar

[10] See more info in ISO 52000-2 Annex L.

Electric resistance Solar thermal panel		
Cooling systems (Reversible) Heat pump (HP) Other cooling system: adsorption HP, absorption HP, compression HP, etc. Storage (ice tanks, etc.)	Schematic Technical specification of heat generators, storage and emitters	Compressor driven: Electricity Thermal driven: solar or boilers run by fossil fuels, biomass, biogas, biofuels, etc.
Photovoltaic (PV) installation	Total installed power and area Location and inclination of panels.	Solar
Electric grid	Topology, cable type and load profile	Several sources: primary energy factors gives you information of the percentage of non-renewable and renewable sources that are used
Wind turbine	Rated power. Technology Wind velocity data	Wind

When a GIS based district model is used for the energy assessment, the energy systems used in each building can be associated with the boiler that is actually being used, since the georeferenced information related to the equipment and the supplied energy source can be obtained from various sources, such as municipal databases or Energy Performance Certificates.

The input and output of the different generation systems (identified above) will be calculated in step 4 of the calculation methodology. Energy input to the generation system can be identified as the energy delivered (as has been named in Figure 1). Energy delivered is considered as the energy consumed by the generation systems to produce energy that will be used by the PED to cover the energy uses– in other words, the energy contained in the energy carrier that is used to produce useful energy. Each generation system will cover part of the amount (or total in some cases) of the energy uses calculated in section 4.2. Depending on the characteristics of each system, the energy carrier can be identified (for instance, a solar thermal collector will use as energy carrier the sun). The size of the systems (capacity) will give information of how much of the useful energy is produced by these systems (output), considering its efficiencies. Output energy from the generation systems will be the energy use (Figure 1). The summary of the local RES generation systems can be introduced in the MAKING-CITY Table (**Figure 18**Figure 17)

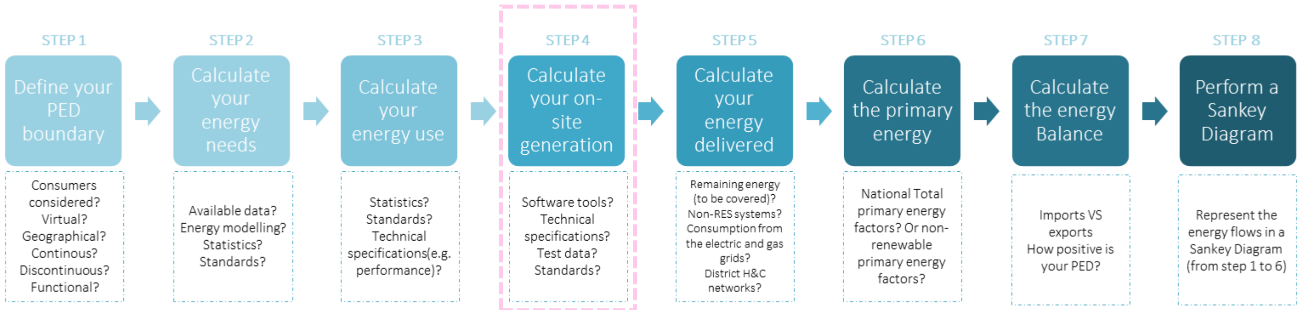


Figure 14: Calculation procedure (step 4)

Several different systems could be used in combination with other systems for a single demand, so the different energy flows should be considered. The energy carrier fed into the generation systems can come from on-site renewable energy sources (within the boundaries) or also from the outside (incoming energy) when electricity from the grid or biomass is consumed. RES are considered local (or on-site) generation in MAKING-CITY calculation methodology (i.e. within the boundaries of the district, see section 3.9 for more details). Heat pumps with a SCOP higher than 2.5 are considered as a renewable source according to ISO52000. Waste heat is also considered a renewable source in most of the literature, as this heat would otherwise be wasted (Assefa, Eriksson, & Frostell, 2004). To calculate the energy production, seasonal efficiencies of generation, distribution, emission and control systems in the district need to be taken into account. The seasonal efficiencies can be found in the technical specifications of the systems (See Example I below). When these are not available, overall national performances, monitored data, or statistical data can be used to estimate the energy output and input of the different systems – both depend on the efficiency and capacity of the system. ISO standards (Table 8) or existing national standards in the country can also be used to estimate it.

Example I: Seasonal efficiencies in the technical specifications of the systems

A building has 5kWh of heating needs, and these needs are covered with a heat pump. In Figure 15 can be seen, the technical specification of a heat pump with a capacity of 6kW (heating). Its COP is 4.2 (at 7ºC/35ºC conditions), meaning that it will produce 6kWh of heating at 35ºC consuming 6/4.2=1.5kWh of electricity. The useful energy is the 6kWh that are used to heat up the storage tank. The storage tank losses are 1kWh. From the COP can be known that 1.5kWh is the input electric energy to the HP, and it can come from PV or wind on-site production, or the hinterland. In this case, 1.5kWh will be delivered to the PED from the electric grid.

	Model HPI Evolution 6 MR-2
Thermal power capacity (in heating mode, for +7°C on the evaporator and 35°C supplied)	5.87 kW
COP at 7°C/35°C	4.18
Electrical power absorbed at 7°C/35°C	1.41 kW

Figure 15: Technical characteristics of a HPI Evolution Air water heat pump model 6MR-2

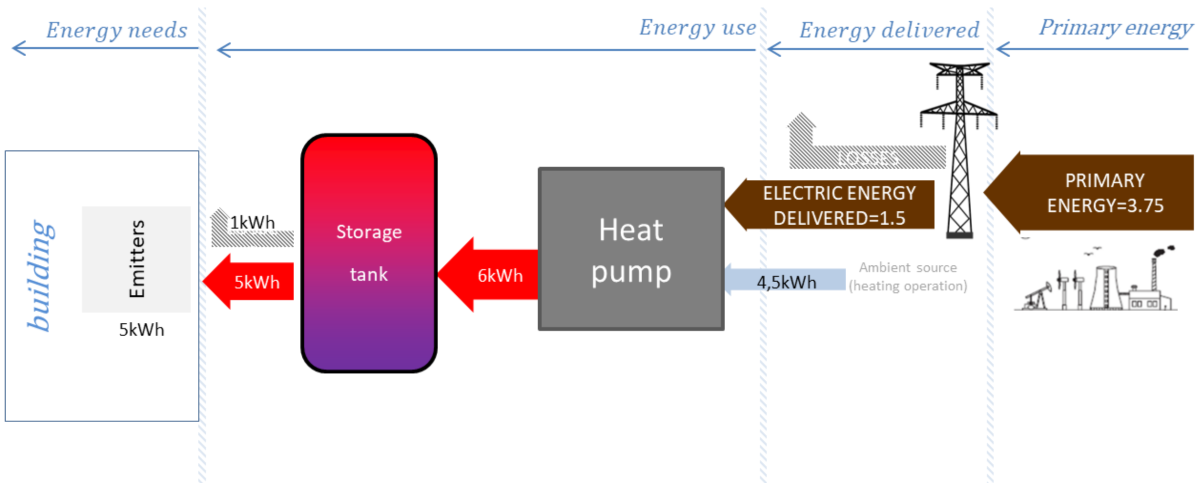


Figure 16: Energy flows in example 1

Table 8: Standards to calculate the energy performance of the systems

EN 15316:2018	Methods for calculation of system energy requirements and system efficiencies Part 1: General Part 2: Heating and cooling Part 3 : Space distribution in H&C and DHW system Part 4-1: Combustion systems (boilers, biomass) Part 4-2: Heat pumps Part 4-3: Heat generation systems, thermal solar and photovoltaic systems Part 4-4: Cogeneration Part 4-5: District heating and cooling Part 4-6: Electric generation coming from RES Part 4-7: Biomass Part 4-8: Air heating and overhead radiant heating systems, including stoves (local) Part 4-9: Direct electrical heater Part 4-10: Wind Part 5: Storage	In force

For active solar, wind or water energy systems, the assessment boundary is the output of the solar panels, solar collectors or electric generation devices. Weather data will need to be considered to calculate the solar and wind production. Software tools like PVsyst software, PVgis tool[11], WAsP, TRNSYS, among others, can be used to estimate the useful outputs of solar and wind systems for a given location and climate data.

For heat pumps the energy use will be the thermal output (cooling or heating) and the energy delivered to the heat pump will be electric energy coming either from on-site renewable energy sources or the electric grid. In case of boilers, CHP, etc. the energy use will be the thermal output and the energy delivered to it is the equivalent fuel energy. The energy can be expressed in energy units (kWh, etc.) or per unit area (kWh/m^2, etc.) or volume (kWh/m^3, etc.), as long as the units and area or volume thermally conditioned are specified. For existing systems, some of these energy flows can be also quantified based on meters (e.g., gas, electricity, district heating). In the case of a GIS model being used to assess district energy demand, and when energy systems are integrated in the GIS model (from example gathered from a database of building energy certificates), district energy use can be calculated based on the energy needs and the energy system for each building.

Once the useful output is calculated, they can be introduced in the MAKING-CITY Table as shows the Figure 17.

The useful energy (output) from renewable energy sources is calculated:

	PV	PVT (el/th)	Solar thermal	Biomass	Geothermal	Heat pump
Building 1						
Building 2						
....						
Building n						

Total Energy from RES (electric) =

Total RES (thermal) =

Figure 17: MAKING-CITY Table (useful output = "energy use")

The energy outputs and inputs of each system have been identified Now the different connections between the systems and the energy flows need to be linked. The amount of energy supplied by each system can be known by subtracting from the energy needs the useful energy outputs from the different systems (for thermal and electric separately). **If the amount of RES energy produced on-site is higher than the energy consumed, a surplus of energy is identified (which will be exported). This is known as "energy surplus"**. If the amount is less, this "remaining" energy needs to be covered by on-site non-renewable systems such as gas boilers, low-efficiency heat pumps, CHP, etc. or heat coming from a district heating network, which will give information about the energy coming from outside the boundaries (fuels, electricity, heat, etc.).

Remaining (Thermal) = Total Thermal Use - Total RES Thermal =
(Surplus if negative, remaining to be covered by external sources if psotive)

Remaining (Electric) = Total Electric Use - Total RES Electric =
(Surplus if negative, remaining to be covered by external sources if psotive)

Figure 18: MAKING-CITY Table (remaining energy, when negative there is more energy produced than it is consumed, and when positive there is still energy to be covered by non-renewable energy systems)

The idea in this phase is to identify which energy uses will be covered by RES (number 1 and 2 in Figure 5) and maximize its capacity to cover as much as possible with it. As Figure 5 shows, the higher the thermal energy coming from RES and waste heat, the lower the dependency from a non-RES system such as a boiler. If the later one is used, a fuel input will be required (number 4 in Figure 5) that can come from a non-RES source (such as

[11] Available online in: http://re.jrc.ec.europa.eu/pvg_tools/en/tools.html#PVP

natural gas). In the case of electricity, the energy uses can be covered by electric RES, a CHP and/or the electricity from the grid (number 2 and 3 in figure 5, respectively).

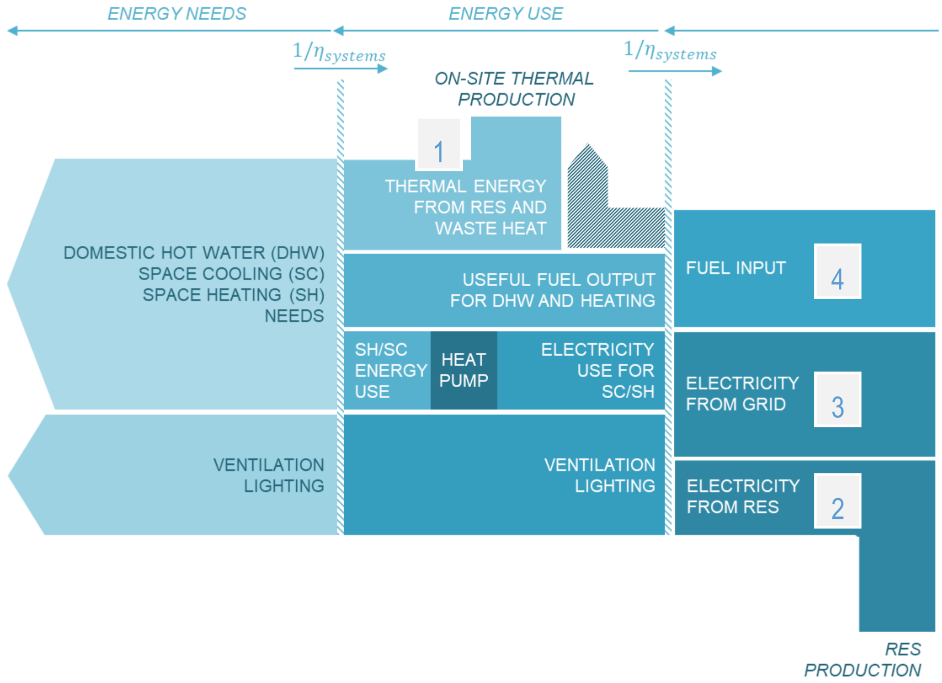


Figure 19: Energy Flows in a Sankey Diagram illustrating the difference between energy needs, energy uses and energy delivered.

4.5 Estimate your energy delivered

The energy delivered is known as the energy supplied to the PED (per energy carrier) that is produced outside the district boundaries. Usually, it comes from thermal, gas or electric grids and feeds the energy systems available on-site the district.

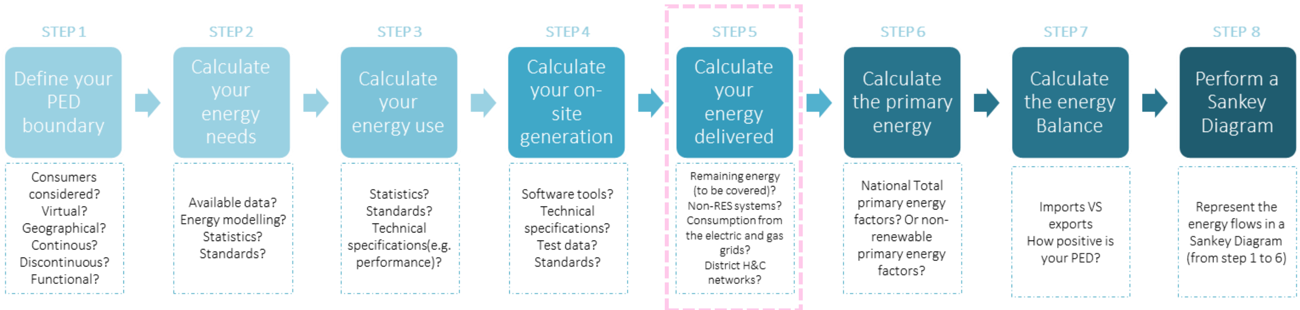


Figure 20: Calculation procedure (step 5)

With the useful outputs calculated in step 4, the remaining energy to be covered by non-renewable energy sources (e.g. natural gas-driven boilers) or by external grids (e.g. electricity or DHN) has been identified. The incoming energy to boilers or CHP system that use biomass is usually considered as a renewable source coming from outside the boundaries (thus, it is delivered to the PED). That incoming energy (to be used by biomass boilers or CHP boilers) needs to be accounted for as well. Both the output and input of each system are linked with a source of energy inside or outside the boundary for each energy carrier. Greater energy consumption over a renewable energy generation within the boundary indicates an import (in) from outside the boundary. **A greater renewable energy generation within the boundary over energy import from outside the boundary indicates an export (out) to outside the boundary (Energy surplus)**. The imported and exported energy is then transformed to primary energy in step 6.

Now, the energy in/out through district boundaries can be introduced in the MAKING-CITY Table:

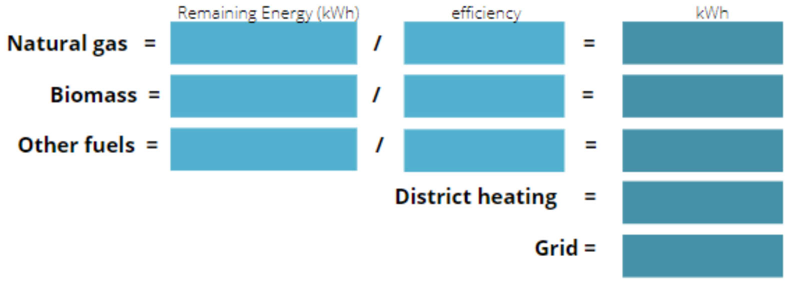


Figure 21: MAKING-CITY Table (Energy in/out through district boundaries "known as energy delivered").

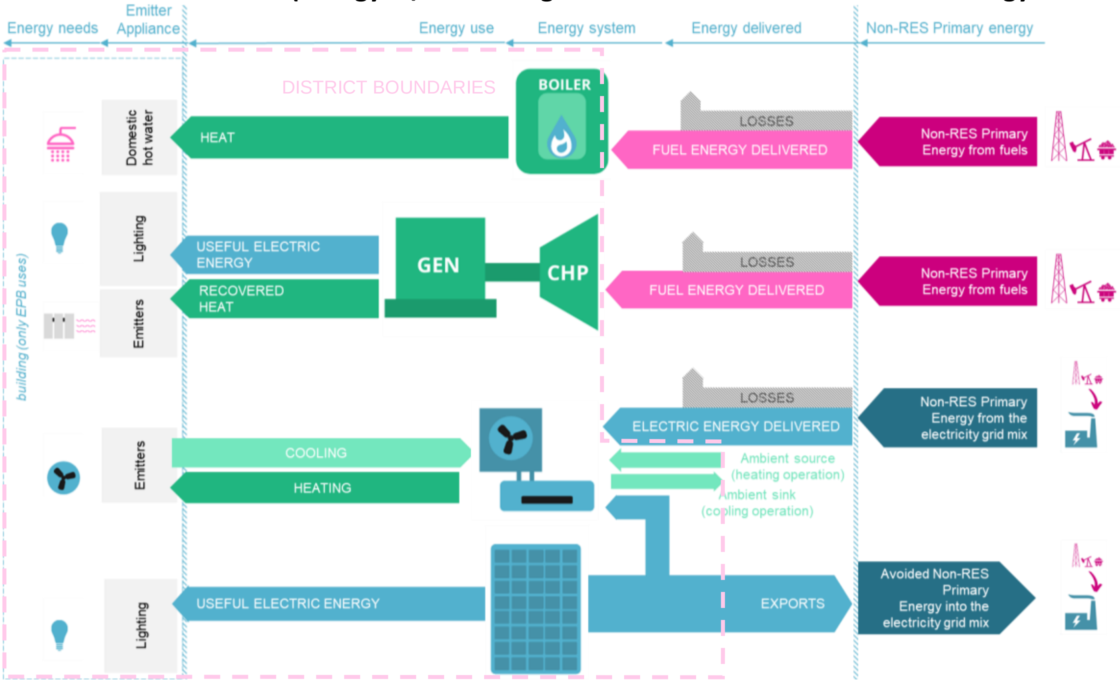


Figure 22: Steps of the calculation procedure in a diagram showing the different emitters and appliances at the buildings, energy systems providing the energy uses, and non-RES energy systems in the external grids[12]

4.6 Calculate the primary energy

At a step 6 the energy delivered to the PED is transformed into equivalent primary energy terms (using primary energy factors, explained in section 4.6.1.).

In MAKING-CITY methodology non-renewable primary energy factors (PEF_{nren}) are used. Usually, the non-renewable primary energy factor for the electricity exported energy is something similar to the grid's non-renewable primary energy factor, since by exporting it, this amount of energy is avoided. The same thing happens with the heat exported to a district heating.

[12] Useful electric energy from a RES generation can be considered as "energy use" when supplied directly to the building or as "energy delivered" if it is supplied to the generation system to indirectly cover energy needs of the building (e.g. PV connected to the heat pump that covers heating needs of the buildings).

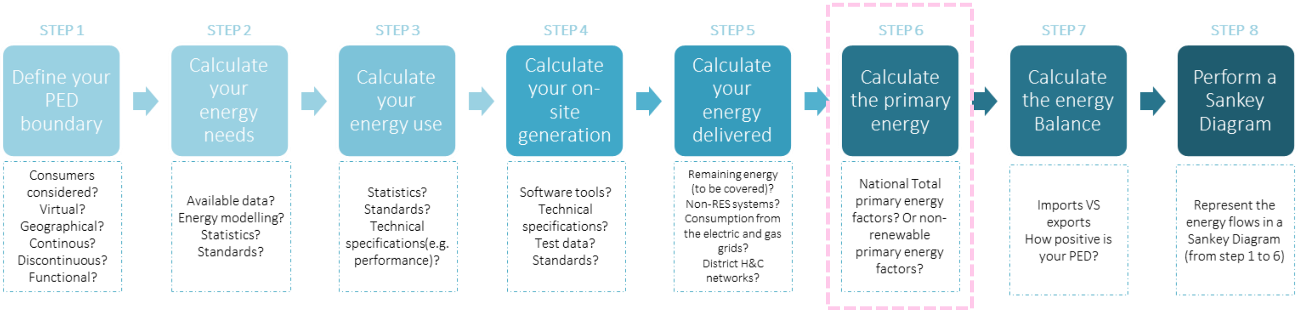


Figure 23: Calculation procedure (step 6)

4.6.1 Primary energy factors

Primary energy is defined by Article 2(5) of the Energy Performance of Buildings Directive 6 as *'the energy that has not undergone any conversion in the transformation process, calculated by energy carrier using a primary energy factor'*. In order to calculate it, primary energy factors (PEF) are used to transform the energy incoming and outgoing to/from a PED to primary energy. This way, all the losses in the grids (thermal and electric grids) and the energy use at the power stations can be taken into account. In ISO52000-2:2017, PEF are defined as "*Primary energy factor indicates the associated primary energy to each delivered kW·h"*, and it can be illustrated as follows:

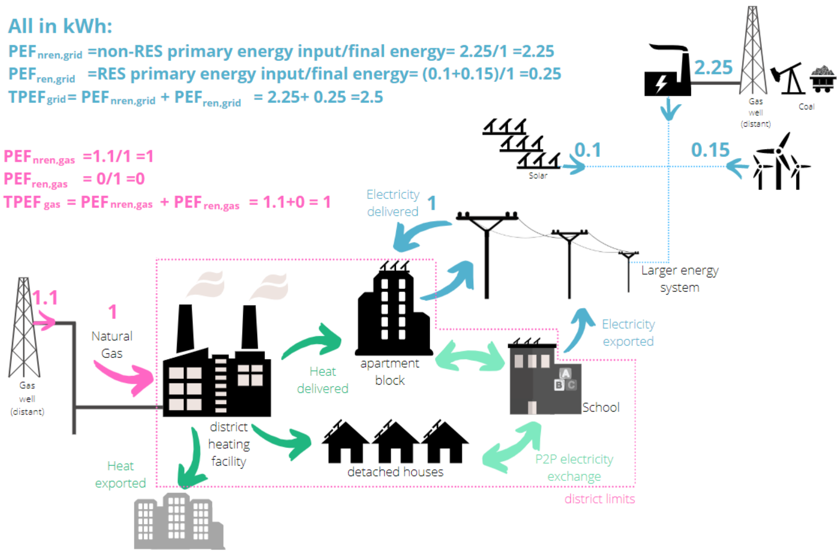


Figure 24: Illustration of the meaning of primary energy conversion factors (based on ISO 52000-1:2017)

Figure 24 shows how the primary energy factors can be calculated. In this example, it has been necessary 2.25 kWh of fossil fuels and 0.25 kWh of renewable energy (solar + wind) to provide 1 kWh of electricity to the final user. Thus TPEF is 2.5, the PEFnren is 2.25 and the PEFren is 0.25. The values depend on the energy mix (how much percentage comes from a source or another) and the losses of the electricity grid. In a similar way, for the natural gas grid it was needed 1.1 kWh of gas coming from the well to provide 1 kWh to the final user. In this case there is no portion of renewable energy, but if biogas or hydrogen produced from a renewable source is injected into the natural gas grid, the PEFren can be higher than 0. This methodology might change from country to country, and a study (Esser, (FhG-ISI), Amann, & Iñarra, 2016) evaluates different options following the Eurostat methodology, the IEA method and the Finish method. Generally, it can be said that "the primary energy factors are the ratio of a given type of primary energy (renewable, non-renewable, and total) to the actual energy amount". Thus, the total PEF (TPEF) can be calculated as the summed of the non-renewable primary energy factor (PEFnren) and renewable primary energy factor (PEFren):

$$\mathrm{TPEF} = \mathrm{PEF}_{\mathrm{nren}} + \mathrm{PEF}_{\mathrm{ren}} \qquad \text{(Eq. 4)}$$

TPEFs are usually a constant national value, and do not depend in time or geographical location. However, TPEFs depend on the specific mix of primary energy sources and the efficiency of the processes of transformation, generation, storage and transportation, which are factors temporal dependent. In the article proposed by Tranberg et. al, (Tranberg, y otros, Real-time carbon accounting method for the European electricity markets, 2019) a methodology for real-time carbon accounting method for the European electricity markets is presented. A similar methodology could be followed to consider the instantaneous variation of the TPEFs. Another option could be to follow the methodology proposed by Willby et. al (Richard Wilby, Rodríguez González, & Vinagre Díaz, 2014), which considers the temporal moment and local characteristics.

For the present methodology, as the balance is calculated in annual basis national annual primary energy factor are recommended. For example, for UK natural gas coming from the pipe has a TPEF of 1.02, and LPG from a bottle has a TPEF of 1.06 (SAP, 2009). For Poland mains gas has a TPEF of 1.10, whereas its electricity mix has a TPEF of 3. Default values of PEF can be taken from ISO 52000-1:2017 table B.16. It should be consider that PEFs are not based entirely on scientific arguments and clear algorithms, and issues such as inclusion of the primary energy associated to the different stages of the supply chain are considered very differently between countries. For example, in EU countries mains gas has an average TPEF that goes from 1 to 1.26; LPG TPEF varies from 1 to 1.26; oil goes from 1 to 1.23; coal goes from 1 to 1.46.For biomass, there are also large differences on calculated TPEF between countries, as a very wide range of feedstock can be used. For electricity, the TPEF varies the most between countries, from 1.5 to 3.45 (Papaglastra, 2018), as it depends on the country specific electricity mix. Given the significant changes that lie ahead for electricity supply, the TPEF for electricity should be revised regularly and its method of calculation clearly documented and eventually harmonized. Electricity mix TPEF from seven countries have been found in the national building regulations (Table 9).

Table 9: Total Primary factor for Electricity mix in different countries (Molenbroek, Stricker, & Boermans, 2011)

	EU-28 (Fritsche & Greß, 2015)	FRANCE	GERMANY (Horst, Schettler, & Ahlke, 2018)	NETHERLANDS	POLAND	SPAIN (IDAE, 2016)	FINLAND (Saprunov, 2017; Haakana, 2016)	UK
TPEF,grid	2.460	2.58	2.800	2.56	3	2.403	1.200	2.92
PEFnren,grid	2.060	-	1.800	-	-	2.007	1.200	-
PEFren,grid	0.360	-	1.000	-	-	0.396	0.000[13]	-

Sometimes the TPEF factor does not contribute in a positive way of the use of electricity, that is the case of France that has been using a TPEFel of 2.58 (Observatoire de l'Industrie Electrique, 2020), although the power grid carbon intensity factor is lower than 100 kg CO_2eq/MWh (Tranberg, et al., Real-time carbon accounting method for the European electricity markets, 2019). This high TPEFel is due to the fact that nuclear production has an important weight in the calculation of the TPEF, as each unit of electricity (kWh) needs a factor of 3 (1/ 0.33 = 3) of nuclear fuel input. In the case of Finland, the TPEFel is low as a value of zero is assumed for PEFren,el, while in the ISO52000-1 standard PEFren,el is 0.2 (value that depends on the generation power mix). This problematic has led to MAKING-CITY project to choose PEFnren as the ones for designing and evaluating the positive energy balance of PEDs.

Primary energy factors for renewable sources are a bit more intricate. For example, in the case of biomass, it has a TPEF around 1.05-1.1, where, generally, PEFren=1 and PEFnren=0.05 to 0.1, to account for the non-renewable energy use for processing and transporting the biomass. But, what if the biomass extraction rate

[13] The PE for electricity or heat from non-combustible renewables (hydro, wind, solar, geothermal) is accounted as zero by definition

were higher than the regrowth rate? Then, it could be considered that this biomass is a non-renewable source. This is what happens with peat, which is considered a non-renewable source due to its low regrowth rate (Clarke & Trinnaman, 2004). Peat is actually considered as dead organic matter, since it accumulates on the land with a low carbon sequestration yield (20 to 50 kg/ha per year) (Change, I. P. O. C., 2006). Therefore, it is advisable that, in the case of peat or biomass with an extraction rate higher than the regrowth rate, its primary energy factor is allocated to the PEFnren and not to the PEFren (generally: PEFnren =1.05 and PEFren =0). For renewable sources such as PV or Wind, some countries consider the non-renewable energy used in the entire supply chain, therefore PEFren =1 and PEFnren =0.05.

Waste heat can be seen as a renewable source (with a PEFren of 1) that is used to reduce the heat input, as this heat would otherwise be wasted. But what if this heat comes from an intensive energy industry that emits a lot of greenhouse emissions? Is this waste heat still considered clean although the industry is not part of the district? Part of the literature considers that "if everything has been done to optimize the energy usage within the industry, then it can be assumed that the waste heat has zero carbon dioxide emissions", but this affirmation is still under discussion (Assefa, Eriksson, & Frostell, 2004).

Attention, as Primary energy factors (total, non-RES, RES) are country specific, it is advisable to use the ones specific to your country, since the calculation methods and the efficiency of the entire supply change might differ from country to country. Nevertheless, if some factors cannot be found, the ISO 52000 standard provides a table with default total, non-renewable and renewable Primary Energy Factors (Hitchin, Thomsen, & Wittchen, 2018).

Table 10: Default ISO52000-1 2017 primary energy factors (ISO, 2017).

Energy carrier		TPEF	PEFnren	PEFren
Solar (PV, PVT, FPC...)		1.0	0.0	1.0
Environment (Geo-,aero-,hydro-thermal)		1.0	0.0	1.0
Biofuels	solid	1.2	0.2	1.0
	liquid	1.5	0.5	1.0
	gaseous	1.4	0.4	1.0
Fossil fuels	solid	1.1	1.1	0.0
	liquid	1.1	1.1	0.0
	gaseous	1.1	1.1	0.0
Electricity grid (Imported/Exported)		2.5	2.3	0.2
District heating/cooling		1.3	0.0	1.3
Waste heat		1.0	0.0	1.0 (Assefa, Eriksson, & Frostell, 2004)

4.6.2 Primary energy calculation

Using national conversion factors, it can be calculated the primary energy associated with the delivered and exported energy of the district.

Primary Energy Imported (PEI) is calculated as the summed of the weighted delivered energy over all energy carriers (electric energy drawn from the grid, gas from the grid, oil or pellets - all with their respective primary energy conversion factors). It accounts for the energy supplied to the district that is produced outside the district limits.

$$\text{PEI} = \sum \text{Delivered energy per energy carrier} * \text{Primary Energy Factor per energy carrier} \qquad \textit{(Eq. 5)}$$

Primary Energy Exported (PEE) is calculated as the summed of the weighted exported energy over all energy carriers. It is the surplus of energy delivered by the district that is used outside the system boundary.

$$\text{PEE} = \sum \text{Exported energy per energy carrier} * \text{Primary Energy Factor per energy carrier} \qquad \textit{(Eq. 6)}$$

The exported energy will reduce the weighted energy used by grid generators thanks to the exported energy.

The Primary energy factors for exported PV and cogenerated electricity will include the reduction in primary energy consumption of the grid generators thanks to the avoided grid electricity production. Non-renewable primary energy factors (PEF_{nren}) or Total primary energy factors (TPEF) for the substituted electricity mix should be used, according to the type of balance.

The Primary energy factors for exported biogas (or green hydrogen) will include the reduction in primary energy associated to the avoided gas used from the gas distribution grid. Non-renewable primary energy factors (PEF_{nren}) and total primary energy factors (TPEF) of the gas grid should be used (currently most of the gas grids are non-renewable, so total primary energy generally equals non-renewable primary energy)

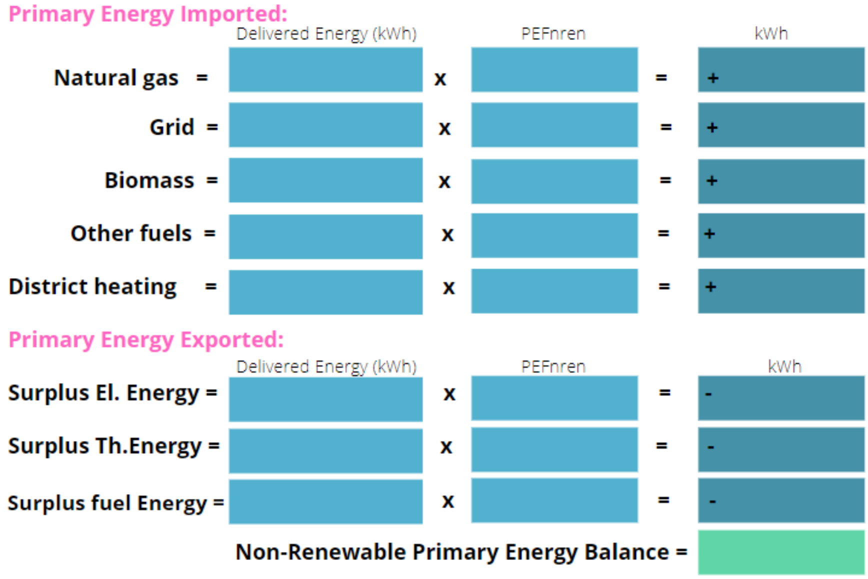


Figure 25: MAKING-CITY tables primary energy (step 6+7)

4.7 Primary energy balance

The primary energy balance (PEB) is calculated as the difference between the weighted energy delivered to the district (summed by all energy carriers) and the weighted energy that is exported outside the PED's boundaries.

$$PEB = PEI - PEE \qquad \textit{(Eq. 7)}$$

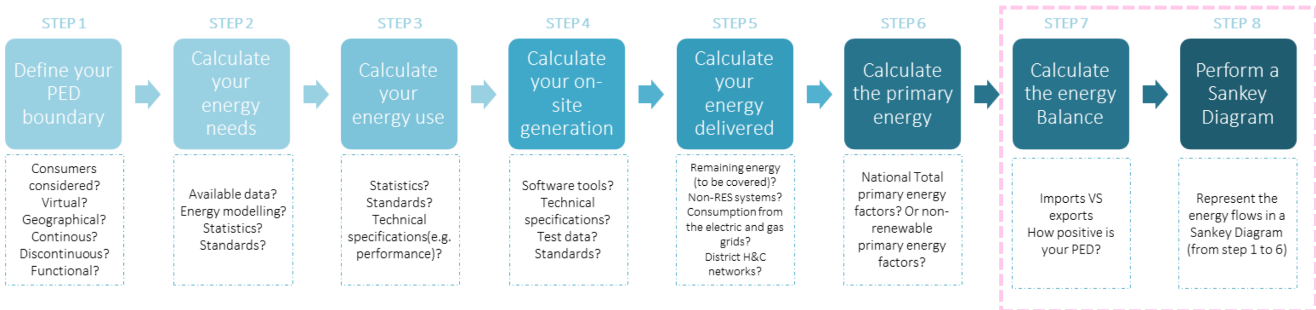


Figure 26: Calculation procedure (step 7+8)

At the end, the overall Sankey diagram can be performed. For the energy flows, energy is separated by energy use (heating, cooling, DHW, appliances, etc.) and energy carriers (delivered energy: fuel energy, electric energy coming from RES, electric energy coming from grid, etc.). The difference between energy needs and energy use is the efficiency in the distribution system (if there is any).

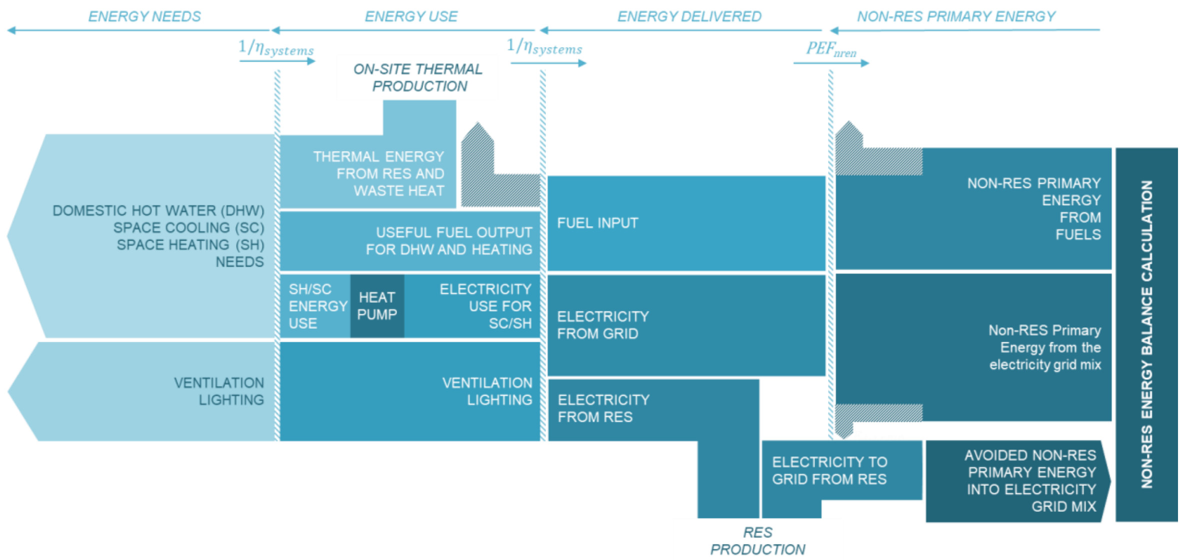


Figure 27: Sankey Diagram of the energy flows in a PED

The MAKING-CITY PED definition is based in a non-renewable PEB. However, some cities might choose to calculate the total primary energy balance, which includes non-renewable primary energy (PEnren) and renewable primary energy (PEren) expressed in net terms as follows:

PEnren is the non-renewable primary energy consumed at the energy facility. It is calculated as the summed of all delivered energy per energy carrier that comes from a non-renewable source weighted using non-renewable primary energy factors ($\mathrm{PEF_{nren}}$). Also, the avoided energy as a result of injecting PV to the grid is considered (using $\mathrm{PEF_{nren,GRID}}$).

$$\mathrm{PE_{nren}} = \sum \text{Delivered energy per energy carrier} * \mathrm{PEF_{nren,ENERGY\ CARRIER}} - \text{Exported energy PV} * \mathrm{PEF_{nren,GRID}} - \text{Exported energy Biogas} * \mathrm{PEF_{nren,GAS}} \ \ldots \text{ETC} \qquad \textit{(Eq. 8)}$$

PEren is the total renewable primary energy consumed at the energy facility. It is calculated per energy carrier. Also, renewables coming from the grid are considered:

$$\mathrm{PE_{ren}} = \sum \text{Delivered energy per energy carrier} * \mathrm{PEF_{ren,ENERGY\ CARRIER}} - \text{Exported energy PV} * \mathrm{PEF_{ren,GRID}} - \text{Exported energy Biogas} * \mathrm{PEF_{ren,GAS}} \ \ldots \text{ETC} \qquad \textit{(Eq. 9)}$$

The summed of the two terms from above will be the TOTAL primary energy balance:

$$PEtot = PE_{nren} + PE_{ren}$$

Calculating the balance in terms of total primary energy can give cities a better understanding on the overall efficiency of the district, as all the energy (renewable and non-renewable) used within the district is considered.

4.8 Additional PED indicators

Besides the primary energy balances used in the PED definition as explained in previous sections, additional indicators can be used to respond to some frequent questions that arise in PEDs:

- How much primary energy is renewable? The amount of primary energy from renewable sources can be calculated by the Renewable Energy Ratio (RER). It expresses how much renewable energy has been delivered to the district, including energy from renewable sources produced on-site (or nearby[14]):

$$RER = \frac{PE_{ren}}{PEtot}$$

- How much renewable energy is produced on-site? The percentage of total net energy needs covered by local RES indicates *how much renewable energy is produced on-site* and it can be calculated as the total thermal or electric energy needs divided by the total on-site thermal or electric local RES production.

$$\%RES_{thermal} = \frac{Total\ Thermal\ Energy\ Needs}{Total\ Thermal\ Local\ RES} \qquad \textit{(Eq. 10)}$$

$$\%RES_{electric} = \frac{Total\ Electric\ Energy\ Needs}{Total\ Electric\ Local\ RES} \qquad \textit{(Eq. 11)}$$

- What are the net CO_2 equivalent emissions? The net carbon dioxide equivalent emissions can be calculated as the difference between the total equivalent emissions of the imported primary energy and the total equivalent emissions that have been avoided by exporting the RES produced.

$$\mathrm{CO_2eqB} = \sum PEI\ per\ energy\ carrier * CO_{2eq}\ \text{emission facto}^{15}\text{r} - \sum PEE\ per\ energy\ carrier * CO_{2eq}\ \text{emission factor} \qquad \textit{(Eq. 12)}$$

[14] In case the energy facility (e.g. wind farm) is outside the city limits but own but the PED neighbors.
[15] Careful should be taken calculating this, as most of the CO2eq emission factors are in terms of final energy (not primary energy). In this case is calculated with the net non-renewable primary energy. Therefore, the emission factor to be used is in terms of non-renewable primary energy too.

5 Assumptions made by MAKING-CITY to perform the PED Energy Balance

The procedure developed in MAKING-CITY project to calculate the non-renewable primary energy balance (PEB) for PED have been inspired in several bibliography documents (section 2) but none of them fits perfectly with the EU call requirements and project considerations about a PED should be and have/or included. So, many assumptions have been taken into consideration for implementing the calculation framework mainly in aspects such as primary energy factors used, which boundaries are considered, consideration of waste heat, and other issues that can be found during the evaluation process.

Firstly, the PEB uses primary energy factors which are different in each country, as can be seen in section 4.6.1. Furthermore, Primary Energy conversion factors are complex to define, for example, how you can guarantee which part of energy coming from outside the boundaries is renewable or not (could be by means guarantee of origin certification?). To solve this issue, country specific primary energy indicators are used. Primary energy factors for exported PV and cogenerated electricity could be something like the grid electricity values (as it includes the reduction in primary energy consumption of the grid generators thanks to the avoided grid electricity production). Primary energy factors for exported biogas could be something like the gas primary energy factor (as it includes the reduction in gas extraction and other productions thanks to the biogas injection into the grid).

Waste heat can be seen as a renewable source (with primary energy factor of 1) that is used to reduce the heat input (same approach as with solar thermal collectors), as this heat would otherwise be wasted. But what if this heat comes from an intensive energy industry that emits a lot of greenhouse emissions? Is this waste heat still considered "clean" even though the industry is not part of the district? Some literature consider that *"if everything has been done to optimize the energy usage within the industry, then it can be assumed that the waste heat has zero carbon dioxide emissions"* but it is still under discussion (Assefa, Eriksson, & Frostell, 2004). To sum up, primary energy factor, when waste heat from an industry or technical building system is used for heating the district is still under discussion.

In terms of limits, during the definition the designer of the PED can think to leave out some energy intensive buildings or industries within the geographical limits of the PED, just to reduce the energy demand of the district and decrease the investment of the project. In order to avoid this issue, the SET Plan Working Group is discussing the procedure to follow in the definition of the limits (See section 4.1). Finally, the aim of the district should be creating a sustainable design that helps to decarbonize the city/region and make it more liveable. Therefore, a minimum requirement of the number of buildings to address, or typology of buildings could help to avoid this situation. Nevertheless, a limited amount of energy needs per district should be required to become a PED, unless everything has been done to lower the energy needs, otherwise can make the households or the investments very expensive. Plus, the inclusion of buildings from different typology, such as buildings with low or near zero consumption and energy intensive buildings, need to be seen as key element as mentioned in (Monti, Pesch, Ellis, & Mancarella, 2016) as it could help in terms of flexibility with the overall energy balance of the district/city.

Other problems derived from the variation in the seasonal energy production and consumption and use together with curtailment issues, can make the calculation challenging. Energy storage and management of the consumption should be always considered, in order to make the district as autonomous as possible.

Also, the accuracy in the calculation of the energy needs and energy use within the buildings and public spaces is debatable, as a lot of estimations are needed, and it can lead to over and under estimations of what it will really being demanded. For instance, the MAKING-CITY project has followed the guidelines (Notice No 2012/C 115/01) of the European Union, where the calculation of energy uses of the building is simplified (and by extension the district). According to the Guidelines 2012/C 115/01, only space heating and cooling, ventilation, domestic hot water and lighting are considered. Nevertheless, these simplifications will be taken into account during the evaluation phase of the demo-sites, carrying out a theoretical analysis of these generation and surpluses to justify properly the achievement of the PED concept, addressing design procedures and simple calculation procedures to foster replication and scalability.

In order to provide a clear calculation procedure, MAKING-CITY has made different assumptions on these technical aspects despite being most of them still under discussion in most of the relevant scientific forums.

5.1 Boundaries of the PED

As has been described in section 4.1, the boundaries of a PED can be virtual, geographical or functional, and continuous or discontinuous. For MAKING-CITY project, and therefore the Oulu and Groningen PED developed on it, the boundaries are geographical and continuous. Boundaries are physically defined around a city district and all the buildings, users or energy producers on-site are within these boundaries.

MAKING-CITY project follows a geographical boundary approach, where all the parties involved agreed to be part of the district boundary, and its limits are enclosed for households and facilities (e.g. commercial, malls, etc.) nearby to each other. It is important to note that, boundaries definition can be flexible and integrate several characteristics, such as the Groningen or Oulu demos where both have a delimited and functional infrastructure (i.e. district heating system) connecting some (not necessarily all) buildings and facilities within the geographical boundaries. Furthermore, both district heating systems are part of a wider district heating grid.

5.2 Appliances for calculation of electrical needs

MAKING-CITY follows the European Directive “Guidelines 2012/C 115/01” (European Commission, 2012), where the appliances are not considered for the electric energy needs calculation. Usually only electric energy needs for lighting and ventilation purposes is used. For thermal energy needs, only the energy to o maintain an intended space at a given temperature (space heating=SH, and/or space cooling=SC) and to raise the cold network temperature to the desired temperature for domestic hot water (DHW) consumption, are considered. Furthermore, the electric energy to drive the heating system (such as heat pumps or electrical heaters) and auxiliary elements (pumps, etc.) is included as energy use. Instead, the space heating and space cooling needs provided by the heat pump is included in the thermal needs (Table above)

Electric energy use, identified as the useful energy output from the electric generation systems, only considers the electric energy uses in the EPB standard. Thus, the electricity used within the district boundaries for domestic appliances, mobility and infrastructure (traffic lights, road lights, EV cars etc.) are neglected. In commercial and industrial buildings, the correspondent standards should be taken into account.

5.3 How to consider RES produced on-site and outside in the calculation of the Energy Used

In the energy balance, the first step is to calculate the energy demand of the district that is directly linked with the energy needs. To cover these needs energy can come from local resources or from outside the district, and can be produced by renewable, provided by a waste heat source or get from the grid if we think in the energy carrier used.

RES produced on-site it is used in the internal balance of the district to reduce directly the energy demand of it, so no primary energy factor (PEF) will be included at this step of the calculation. In case of RES would come from outside the district boundaries, the corresponding PEF would be included in the energy balance as would be done for any other import of energy. As is explained in section 4.6, PEF in some cases would make favourable the import of RES from outside the district, but it is something very specific that should be studied in any particular case.

5.4 How to consider the Waste Heat in the PEB

As it was mentioned in section 5, waste heat usually is considered as RES, as this heat would otherwise be wasted.

5.5 **Energy** Surplus:

Energy surplus produced in the PED is exported outside the district boundaries. This is the main value of the PEB and gives a quantitative consideration in the effectivity of the PED. The way to calculate is has been described in section 4.4 and 4.5, but it is necessary to remark that for MAKING-CITY procedure only a surplus of RES can be considered.

6 MAKING-CITY calculation references

6.1 Lighthouse City - Groningen

In the next sections the results of the reference calculations for the two PED areas (North and Southeast) in Groningen are explained.

The energy balance described in this document corresponds to the original planning. Due to changes in the project, some of the interventions could not be implemented, and are being changed or replaced during the project implementation. The implemented interventions are described in D3.1, and their final energy balance in D3.6

For detailed analysis of the energy simulation for Lighthouse Groningen please look at *D3.14: Simulation models of buildings, energy systems, storage and management of flows algorithms.*

6.1.1 PED boundaries definition

The boundaries for PED North and South are spatial-physical limits. However, in these reference calculations are taken into consideration only the buildings where interventions took place, not the rest of the district. In order to be able to make use of the district utilities (e.g. rest heat, ATES, server park), it only a fraction of the RES production is considered equal to the relative floor area of the intervention buildings compared to the entire PED.

In the next years of the MAKING-CITY project the intention is to perform upscaling calculations considering if all the buildings in the area would undergo PED interventions.

Figure 28: PED areas in Groningen

6.1.2 Energy needs inside PED boundaries

All data related to thermal and electric energy needs are based on the energy calculations presented in the Grant Agreement.

Thermal and electric needs for Groningen North

For the residences, data are based on research on the energy consumption mix in a household performed by Quintel. The table below shows how data were calculated – as a percentage of total use, assuming the gas delivered for heat in 2015.

Table 11 Data for calculation of energy need in Groningen North

Quintel data	TJ	share	TJ	
	2015		2035	difference 2015->2035)
Cooking	0,26	1,57%	0,27	103%
Lighting	0,23	1,39%	0,02	11%
Hot water	2,10	12,71%	2,17	103%
Heat	11,79	71,41%	4,40	37%
Cooling	0,74	4,50%	0,33	45%
Appliances	1,39	8,41%	0,67	48%
Total	**16,51**	**100,00%**	**7,86**	**48%**

The same data relations are used for Nijestee where the data from Enexis (the local Distribution System Operator in Groningen) over the power consumption in the flat are taken into consideration.

ENERGY NEEDS

THERMAL ENERGY NEEDS

		Units (m2 or people)		kWh/unit		GWh (divide by 10^6)
buildings	DHW needs	5463	x	17	=	0.09
						+
	SH needs	5463	x	89	=	0.49
						+
Energy Academy europe	DHW needs	9636	x	13	=	0.127
						+
	SH needs	9636	x	25	=	0.24
						=
				Total Thermal Energy Needs	=	0.951

ELECTRIC ENERGY NEEDS

		Units (m2 or people)		kWh/unit		GWh (divide by 10^6)
buildings	Lighting	5463	x	15	=	0.08
	Ventilation	5463	x	7	=	0.04
						+
Energy Academy europe	Lighting	9636	x	16	=	0.15
						+
	Ventilation	9636	x	4	=	0.035
						=
				Total Electric Energy Needs	=	0.305

Figure 29: Energy needs MAKING-CITY tables for Groningen North in GWh/year

Thermal and electric needs for Groningen South

Data for the sport centre and Powerhouse are based on the related EPC calculations. For Mediacentrale, data were supplied by Waarborg and the effects of all kind of measures or the reduction of heat demand were taken into consideration. The effects of various interventions are taken into account, being: a heat exchanger for ventilation, triple glazing, thermal PVT panels, and optimizing local energy flow.

Subsequently, application of a heat pump (COP: 5 for heating, 3 for DHW preparation…etc.) should allow the mediacentrale to achieve a minimal final energy consumption, which is then electrical (accounted in electric energy use).

ENERGY NEEDS

THERMAL ENERGY NEEDS

		Units (m2 or people)		kWh/unit		GWh (divide by 10^6)
Mediacentrale Offices	DHW needs	10600	x	8	=	0.084
	SH needs	10600	x	85	=	0.901
	SC needs	10600	x	40	=	0.424
Mediacentrale central hall	SH needs	3800	x	39	=	0.148
Powerhouse	DHW needs	7800	x	35	=	0.273
	SH needs	7800	x	37	=	0.289
	SC needs	7800	x	20	=	0.156
Sports Centre	DHW needs	5315	x	2.67	=	0.014
	SH needs	5315	x	10.8	=	0.057
				Total Thermal Energy Needs	=	2.346

ELECTRIC ENERGY NEEDS

		Units		kWh/unit		GWh (divide by 10^6)
Mediacentrale Offices	Lighting	10600	x	14	=	0.15
	Ventilation	10600	x	20	=	0.21
Mediacentrale central hall	Lighting	3800	x	16	=	0.06
	Ventilation		x		=	0.000
Powerhouse	Lighting	7800	x	18	=	0.14
	Ventilation	7800	x	18	=	0.14
Sports Centre	Lighting	5315	x	16	=	0.08
	Ventilation	5315	x	5	=	0.025
				Total Electric Energy Needs	=	0.808

Figure 30: Energy needs MAKING-CITY tables for Groningen South in GWh/year

6.1.3 Energy Use

Thermal and electric energy uses are calculated considering the energy needs but no distribution losses, as done in the proposal phase of the project. The difference between energy needs and energy use are due to heat pumps consumption (accounted in electricity use). In thermal energy uses only the energy provided by the geothermal network is considered.

Thermal and electric <u>use</u> for Groningen North

ENERGY USE

THERMAL ENERGY USE

	GWh	Energy needs		Efficiency of the emitter+distribution losses		GWh (divide by 10^6)
buildings	DHW use	0.094	/	1	=	0.094
	SH use	0.484	/	1	=	0.484
Energy Academy europe	DHW use	0	/	1	=	0
	SH use	0	/	1	=	0
				Total Thermal Energy use	=	0.578

ELECTRIC ENERGY USE	GWh	Energy needs		Efficiency of the emitter		GWh (divide by 10^6)
buildings	SH electric use	0.0028	/	1	=	0.0028
	DHW electric use	0.0001	/	1	=	0.0001
	Ligthing needs	0.08	/	1	=	0.08
	Ventilation needs	0.04	/	1	=	0.04
Energy Academy europe	Ligthing needs	0.15	/	1	=	0.15
	Ventilation needs	0.035	/	1	=	0.03
	SH electric use	0.04	/	1	=	0.04
	DHW electric use	0.02	/	1	=	0.02
				Total Electric energy use	=	0.369

Figure 31: Energy uses MAKING-CITY tables for Groningen North in GWh/year

Thermal and electric use for Groningen South

ENERGY USE

THERMAL ENERGY USE	GWh	Energy needs		Efficiency of the		GWh (divide by 10^6)
Mediacentrale Offices	DHW use	0.03816	/	1	=	0.038
	SH use	0.53	/	1	=	0.530
	SC use	0.424	/	1	=	0.424
Mediacentrale central hall	SH use	0.0836	/	1	=	0.084
Powerhouse	DHW use	0.273	/	1	=	0.273
	SH use	0.1638	/	1	=	0.164
	SC use	0.156	/	1	=	0.156
				Total Thermal Energy use	=	1.669

ELECTRIC ENERGY USE		Energy needs		Efficiency of the emitter		GWh (divide by 10^6)
Mediacentrale Offices	Lighting	0.1484	/	1	=	0.15
	Ventilation	0.212	/	1	=	0.21
	SH and SC use	0.09275	/	1	=	0.09
	DHW use	0.015264	/	1	=	0.02
Mediacentrale central hall	Lighting	0.0608	/	1	=	0.06
	Ventilation	0	/		=	0.00
	SH and SC use	0.016036	/	1	=	0.02
Powerhouse	Lighting	0.1404	/	1	=	0.14
	Ventilation	0.13728	/	1	=	0.14
	SH and SC use	0.0312	/	1	=	0.03
	DHW use	0	/		=	0.00
Sports Centre	Lighting	0.083977	/	1	=	0.08
	Ventilation	0.02524625	/	1	=	0.03
	SH and SC use	0.0143505	/	1	=	0.01
	DHW use	0.00473035	/	1		0.0047
				Total Electric nergy use	=	0.98

Figure 32: Energy uses MAKING-CITY tables for Groningen South in GWh/year

6.1.4 RES production inside the PED

Local generation of renewable heat and electricity Groningen North

The useful energy from renewable heat and electricity takes into consideration renewable sources in place in the PED area. For electricity these are PV panels, BIPV, PVT panels and parking lot PV. RES thermal energy generation comes from geothermal district heating and PVT-H panels. For PVT production, a capacity of 1034 Wp for heat and 250 Wp for electricity has been estimated by TNO based on the generation potential per panel (1x1.66 m). Nijestee is based on 100 panels. The geothermal source comes from 3 km underground and the water is injected in the district heating to about 95°C. For heat, the remaining energy has to be covered by fossil fuels or external sources. For electricity, there is a surplus of energy to be exported outside limits.

The useful energy (output) from renewable energy sources is calculated:

in Oulu

GWh	PV	Geothermal	PVT_el	PVT_th
Total=	0.394	0.431	0.047	0.141

Total energy from RES(electric)		=	0.44
Total energy from RES(thermal)		=	0.57
Remaining (thermal)	**= Total Thermal Use - Total RES Thermal**	=	0.0060
Remaining (Electric)	**= Total Thermal Use - Total RES Thermal**	=	-0.0718

Figure 33: RES production in MAKING-CITY tables for Groningen North in GWh/year

Local generation of renewable heat and electricity Groningen South

The useful energy from renewable heat and electricity takes into consideration renewable sources in place in the PED area. For electricity these are PV panels, PVT panels, parking lot P, floating Pontoons, solar road and solar parks. RES thermal energy generation comes from geothermal district heating and PVT-H panels, and a high pressure digestion.

For heat, there is a surplus of energy to be exported outside limits. For electricity, the remaining energy has to be covered by fossil fuels or external sources.

The useful energy (output) from renewable energy sources is calculated:

in Oulu

GWh	PV	Geothermal	PVT_el	PVT_th	High Pressure Dig	GWh/year
Mediacentrale Offices	0.17763	0.8728	0.0264	0.12216		
Mediacentrale central hall		0.08				
Powerhouse	0.103952	0.5928	0.04658			
Sports Centre	0.499906		0.04658		0.250176	
Total=	0.781488	1.5456	0.11956	0.12216	0.250176	

Total energy from RES(electric)		=	0.901048
Total energy from RES(thermal)		=	1.9179
Remaining (thermal)	**= Total Thermal Use - Total RES Thermal**	=	-0.249376
Remaining (Electric)	**= Total Thermal Use - Total RES Thermal**	=	0.08

Figure 34: RES production in MAKING-CITY tables for Groningen South in GWh/year

6.1.5 Energy delivered

Energy delivered Groningen North

In Groningen North, part of the thermal energy is provided gas boiler at dwelling level while there is a surplus of electric energy that can be exported.

The delivered energy is calculated (separating streams: thermal and electricity) :

	Remaining energy		Efficiency		**Delivered energy**
Gas boiler	0.006	/	0.95	=	0.006
Last check: Any remaining energy to be covered??					
electr_grid national	**-0.07**			=	**-0.07**

Figure 35: Energy delivered in MAKING-CITY tables for Groningen North in GWh/year

Energy delivered Groningen South

In Groningen South, part of the electric energy is provided by the power grid while there is a surplus of thermal energy that can be exported to the District heating network.

The delivered energy is calculated [separating streams: thermal and electricity] :

Last check: Any remaining energy to be covered??	Remaining energy	Efficiency		Delivered energy
electr_grid national	0.08		=	0.08
DH_national av.	-0.249			-0.25

Figure 36: Energy delivered in MAKING-CITY tables for Groningen South in GWh/year

6.1.6 Primary Energy Balance

Primary energy balance Groningen North

PED is achieved. Primary Energy Balance = -0.099 GWh

NON-RENEWABLE PRIMARY ENERGY BALANCE:

Nren Primary Energy Imported(+) :	Delivered		PEFnren		Nren Primary Energy	
national gas network	0.006	x	1.03	=	0.006	
Nren Primary Energy Exported(-) :	Delivered		PEFnren		Nren Primary Energy	
electr_grid national	-0.072	x	1.46	=	-0.10	
					+	
			PRIMARY ENERGY BALANCE (NON-RENEWABLE)	=	-0.099	GWh/year
					PED Achieved!	

Figure 37: non-RES Balance in MAKING-CITY tables for Groningen North in GWh/year

Primary energy balance Groningen South

PED is achieved. Primary Energy Balance = -0.1380 GWh

NON-RENEWABLE PRIMARY ENERGY BALANCE:

Nren Primary Energy Imported(+) :	Delivered energy		PEFnren		Nren Primary Energy
electr_grid national	0.081	x	1.46	=	0.12
Nren Primary Energy Exported(-) :	Delivered energy		PEFnren		Nren Primary Energy
DH_national av.	-0.249	x	1.03	=	-0.26
			PRIMARY ENERGY BALANCE (NON-RENEWABLE)	=	-0.138
					PED Achieved!

Figure 38: non-RES Balance in MAKING-CITY tables for Groningen South in GWh/year

6.1.7 Energy Flow Diagrams

Sankey diagram energy flow Groningen North (in MWh/yr)

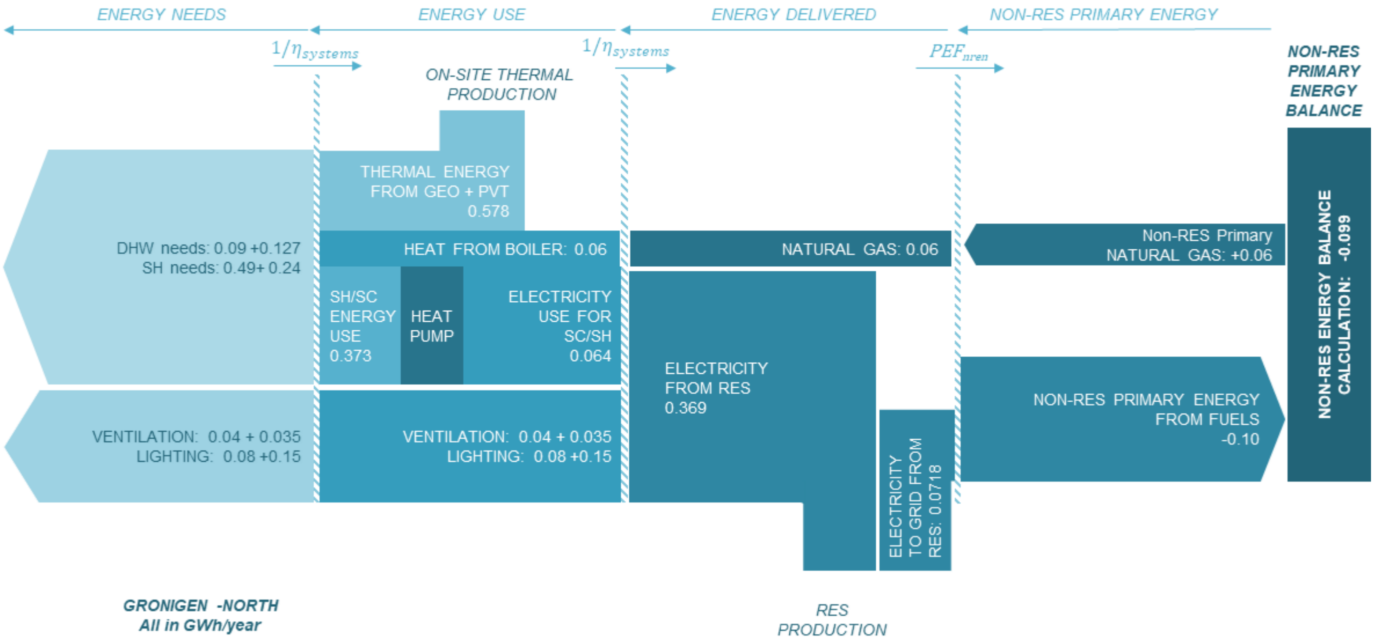


Figure 39: Energy flows (Sankey Diagram) in MAKING-CITY tables for Groningen North in GWh/year

Sankey diagram energy flow Groningen South (in MWh/yr)

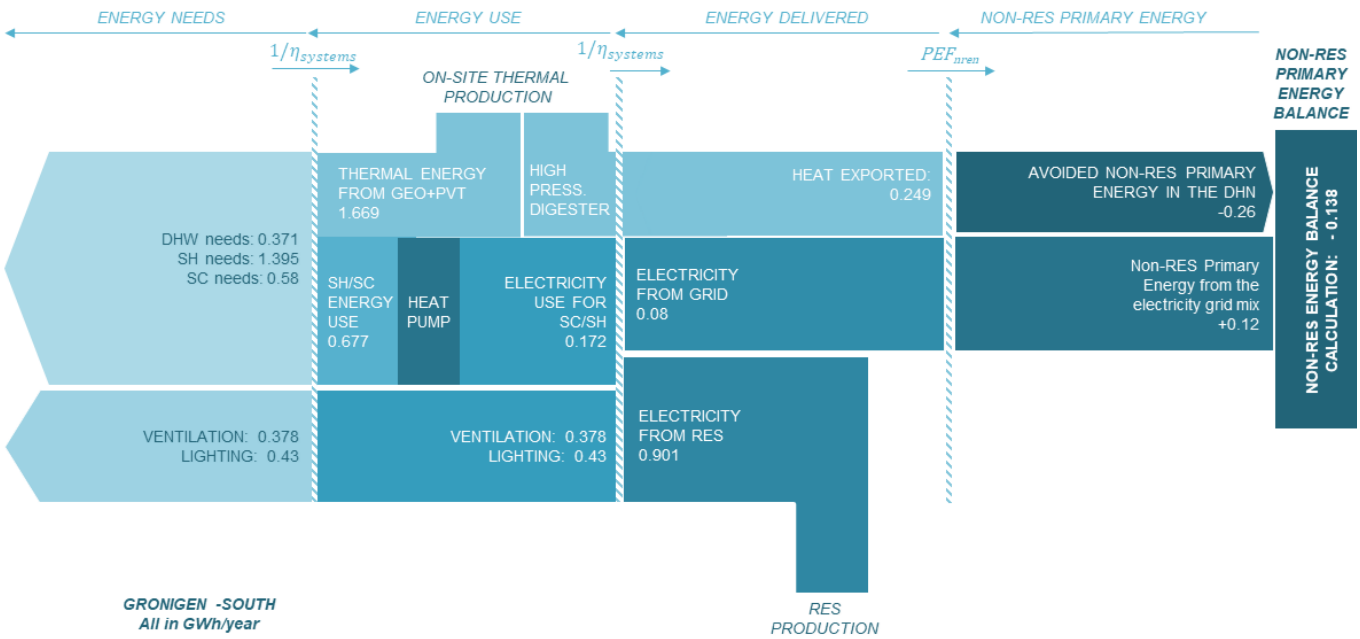


Figure 40: Energy flows (Sankey Diagram) in MAKING-CITY tables for Groningen South in GWh/year

6.2 Lighthouse City - Oulu

In the next sections the results of the reference calculations for the PED area of Kaukovainio district is explained.The energy balance described in this document corresponds to the original planning.
Kaukovainio district consists of 5 buildings: 2 rental houses (SIV), 2 private houses (YIT) and a commercial centre (Arina). All except one of the buildings are new and built according to the latest energy specifications. Most buildings are planned to have energy recovery systems and own production. Because of the good public transportation system, the area will not have as many private parking facilities as before. Thus, a car sharing facility using Ecars is planned to solve the need of personal mobility. Part of the electricity for charging these cars is produced locally in a solar power plant.

6.2.1 PED boundaries definition

Oulu will address the development of a PED by means of the very high efficiency heat pumps and PV panels. Waste heat will be used in a district heating network (DHN) and the temperature will be raised up until the desired temperature at each building. The five buildings (4 residential and one shopping mall) will be interconnected by means of the DHN.

Figure 41: Location of buildings in Kaukovainio district (PED boundaries)

6.2.2 Energy needs inside PED boundaries

Sivakka, the rental housing company, has comprehensive data about energy consumption in their buildings. Thus, DHW, ventilation and SH needs for buildings is estimated from this data. The shopping mall energy needs is estimated considering the properties of the building (U-values). Lighting needs is estimated considering the hours per day the bulls will be used.

ENERGY NEEDS

THERMAL ENERGY NEEDS

		Units (m2 or people)		kWh/unit		GWh (divide by 10^6)
buildings	DHW needs	13200	x	10	=	0.13
						+
	SH needs	13200	x	65	=	0.86
						+
Shopping mall	DHW needs	2000	x	2	=	0.004
						+
	SH needs	2000	x	50	=	0.10
						=
				Total Thermal Energy Needs	=	1.09

ELECTRIC ENERGY NEEDS

		Units (m2 or people)		kWh/unit		GWh (divide by 10^6)
buildings	Lighting	13200	x	9	=	0.12
						+
	Ventilation	13200	x	1	=	0.01
						+
Shopping mall	Lighting	2000	x	20	=	0.04
						+
	Ventilation	2000	x	1	=	0.002
						=
				Total Electric Energy Needs	=	0.17

Figure 42: Energy needs MAKING-CITY tables for Kaukovainio district (Oulu) in GWh/year

6.2.3 Energy Use

For these initial calculations no losses between energy needs and energy use has been considered. The thermal energy needs of the buildings are covered by heat pumps that use the waste heat injected into the DHN for drive the evaporators and achieve a higher efficiency. Thus, the thermal energy use is zero. The electricity consumed by the heat pumps is allocated in "electric energy use".

ENERGY USE

THERMAL ENERGY USE

	GWh	Energy needs		Efficiency of the emitter+distribution losses		GWh (divide by 10^6)
buildings	DHW use	0	/	1	=	0
						+
	SH use	0	/	1	=	0
						+
Shopping mall	DHW use	0	/	1	=	0
						+
	SH use	0	/	1	=	0
						+
						=
				Total Thermal Energy use	=	0.00

ELECTRIC ENERGY USE

	GWh	Energy needs		Efficiency of the emitter		GWh (divide by 10^6)
buildings	SH electric use	0.13	/	1	=	0.13
						+
	DHW electric use	0.03	/	1	=	0.03
						+
	Ligthing needs	0.12	/	1	=	0.12
						+
	Ventilation needs	0.01	/	1	=	0.01
						+
Shopping mall	Ligthing needs	0.04	/	1	=	0.04
						+
	Ventilation needs	0.002	/	1	=	0.00
						+
	Other(process)	0.12	/	1	=	0.13
						=
				Total Electric energy use	=	0.47

Figure 43: Energy uses MAKING-CITY tables for Kaukovainio district (Oulu) in GWh/year

6.2.4 RES production inside the PED

Waste heat will be injected in the DHN from excess heat from cooling machines and refrigeration in the mall, heat from DH return water and exhaust air from ventilation in building 1. As this heat would otherwise be wasted is considered a renewable source. The waste heat is injected into the DHN and distributed to the buildings to drive the heat pumps.

Furthermore, PV panels are installed on the roofs of B1, B2 and B5, and on the southern façade of B1. The PV production is estimated based on approximate irradiation values in Finland. PVgis gives a result of the same magnitude. Additionally, a windmill is considered to produce extra electricity on-site (In Oulu city limits).

The useful energy (output) from renewable energy sources is calculated:

GWh	PV	Geothermal	in Oulu wind/hydro
Total=	0.090	1.530	0.077

Total energy from RES(electric)		=	0.17
Total energy from RES(thermal)		=	1.53
Remaining (thermal)	**= Total**	=	-0.72
Remaining (Electric)	**= Total**	=	0.30

Figure 44: RES production in MAKING-CITY tables for Kaukovainio district (Oulu) in GWh/year

6.2.5 Energy delivered

A remaining (electric) energy is needed to cover partially the electric energy uses (for heat pumps, ventilation and lighting). Thus, electricity from the power grid is used to cover it.

A total amount of 0.72 GWh of waste heat is exported to the DHN to other areas of the city.

The delivered energy is calculated (separating streams: thermal and electricity) :

Any remaining energy to be covered??	Remaining energy	Efficiency		Delivered energy
electr_grid national	0.30		=	0.30
DH_national av.	-0.717			-0.72

Figure 45: Energy delivered in MAKING-CITY tables for Kaukovainio district (Oulu) in GWh/year

6.2.6 Primary Energy Balance

Taken into account the primary energy consumed in Oulu's district heating networks (DHN), the local non-renewable primary energy factor for the district heating is calculated. Oulu's DHN uses a mix of wood, peat and oil for both heat and electricity production (through CHPs). Thus, the PEF_{nren} is 0.7.

The non-renewable primary energy imported to the district is 0.35 GWh/year, which is the result from using electricity from the power grid (whose energy mix is . The equivalent non-renewable primary energy avoided due to the exported energy is 0.5 GWh/year. The difference is the non-renewable primary energy balance for the PED (-0.16 GWh/year). The minus sign is due to the direction of the flow (exports>imports and opposing the natural direction of consumption flows).

NON-RENEWABLE PRIMARY ENERGY BALANCE:

Nren Primary	Delivered		PEFnren		Nren Primary Energy	
electr_grid national	0.298	x	1.16	=	0.35	
Nren Primary	Delivered		PEFnren		Nren Primary Energy	
DH_national av.	-0.717	x	0.7	=	-0.50	
	PRIMARY ENERGY BALANCE (NON-RENEWABLE)			=	-0.16	GWh/year
					PED Achieved!	

Figure 46: non-RES Balance in MAKING-CITY tables for Kaukovainio district (Oulu) in GWh/year

6.2.7 Energy Flow Diagram

At the end, the energy flow diagram is drawn.

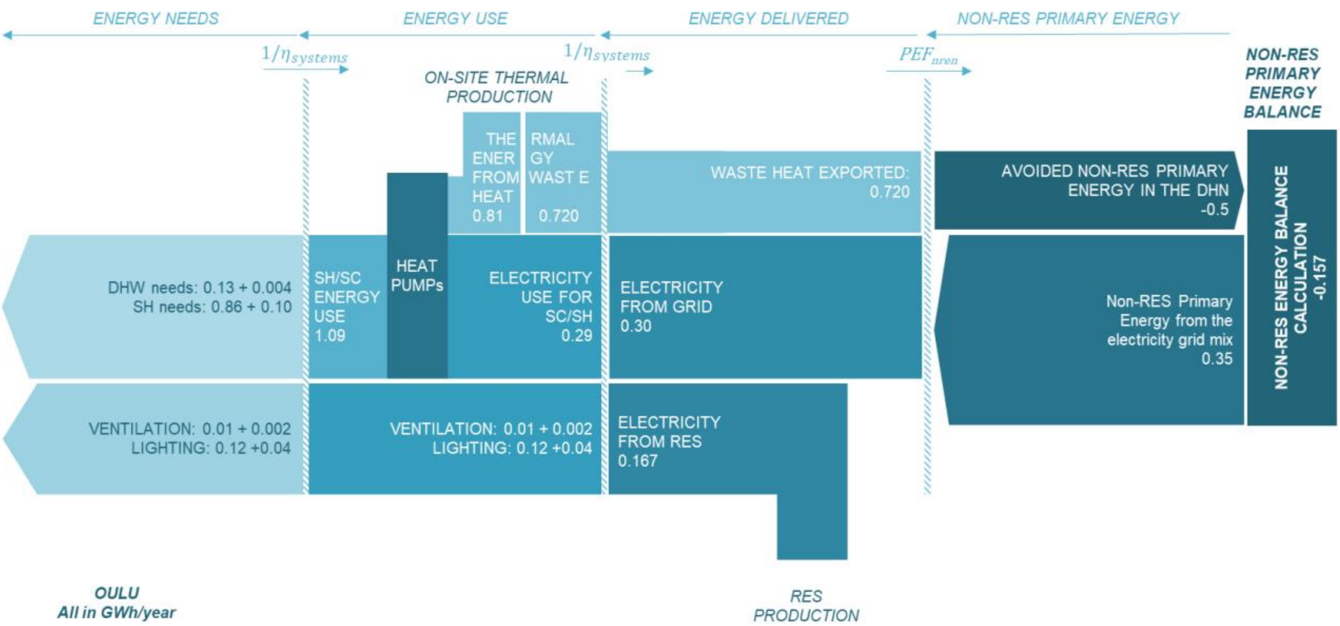


Figure 47: Energy flows (Sankey Diagram) in MAKING-CITY tables for Kaukovainio district (Oulu) in GWh/year

7 Identification of guidelines

1. **Define your PED boundary:** The boundary is defined by the spatial and administrative relationship between the final energy consumption and the energy generation units (inside the buildings or beyond the boundaries, e.g. the grid). A dedicated generation for the building demand indicates a geographical boundary while a distributed energy from a generation unit under the control and management of the consumer through a larger grid is considered as a functional boundary. If the energy demand is covered by generation unit that is shared also with other consumption points that is not controlled or managed by the consumer, then this is considered as a virtual boundary.

2. **Calculate your energy needs:** Heating, cooling, domestic hot water and electric energy needs must be identified. The need could be determined by several approaches including monitoring, calculations based on bills, simulation, standards or statistical data.

3. **Calculate your energy use:** The amount of energy used to cover the demand is determined as thermal and electric energy use, i.e. the needed energy input to satisfy the needs. It can be also identified as the useful energy output of the thermal and electrical generation systems

4. **Calculate your on-site energy generation:** First identify the energy systems used to cover the determined energy uses. Several different systems could be used in combination with other systems for a single demand. Second, calculate the useful output of these systems (i.e. the energy generation). Later, identify if there is any remaining energy to be covered by non-renewable energy systems such as boilers. All systems including grids or networks carrying energy into the boundary from outside the boundary will be also taken into account

5. **Estimate the energy delivered**. Each systems' output and input are linked with a source of energy inside or outside the boundary for each energy carrier. A greater energy consumption over a renewable energy generation within the boundary indicates an import (in) from outside of boundary. A greater renewable energy generation within the boundary over energy import from outside the boundary indicates an export (out) to outside of boundary.

6. **Calculate primary energy**. Weight your energy imports (delivered to the PED) and exports (delivered outside the PED) per energy carrier using primary energy factors, to calculate the primary energy exported and the primary energy imported. Primary energy factors could be taken from national or international standards.

7. **Calculate the energy balance.** The primary energy balance is calculated as the difference between the primary energy imported to the PED boundaries minus the primary energy exported outside the PED's boundaries.

8. Once all the steps are finalized, an energy flow diagram can be drawn (known as **Sankey diagram)** based on energy flows identified in the previous steps (energy need, energy use, energy delivered and primary energy columns).

8 Integrated tool for PED framework calculation

One tool used for the generation of the simulation models within the MAKING-CITY project will be ENERKAD®, a plugin for QGIS developed by Tecnalia which evaluates urban energy scenarios at building, district and city scale. It calculates the energy demand and consumption per hour for each building in a district, departing from cadastral data, basic cartography and climatic information of the study area, foregoing the use of representative buildings and using individual building information as input data.

The ENERKAD® internal database can be adapted for each location, modifying the climatic information and adapting the parameters needed in each case to specific values for the study area.

The outline of the methodology used is given on Figure 48.

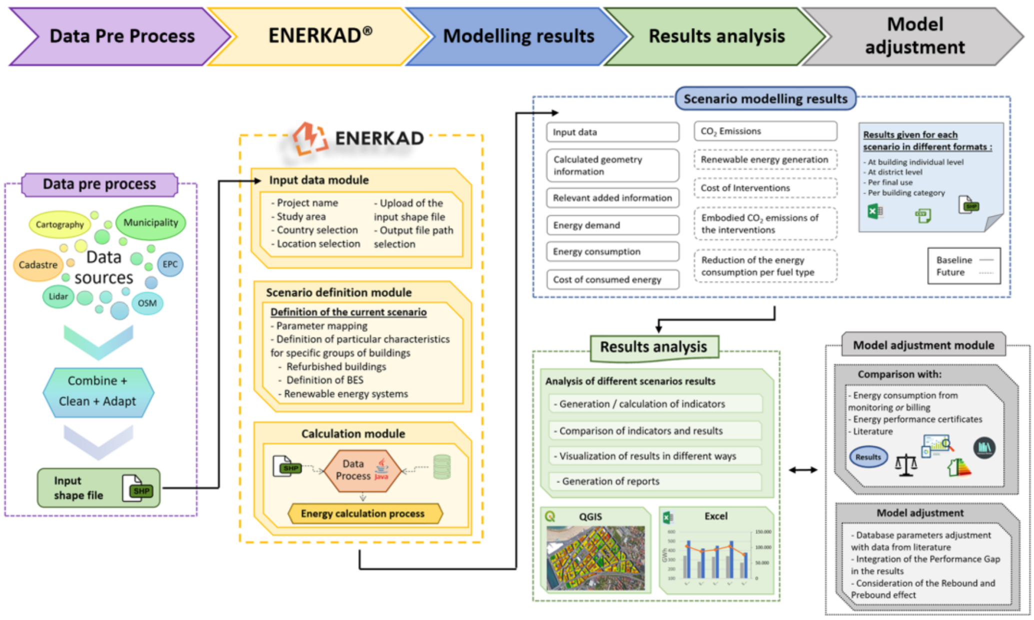


Figure 48: Outline of ENERKAD® methodology

8.1 Data acquisition

The information related to the buildings can be differentiated into 2 groups: geometrical information and semantic information.

For the basic analysis of the energy demand, only 5 basic parameters are needed, which are normally available in the cadastre of the city or the municipality. The minimum input information necessary to carry out the modelling is the following:

- Building ID
- Footprint area
- Building Height (Height or number of floors)
- Construction year
- Building use

The height of buildings is sometimes not available or is not very precise, but it can be calculated by means of LIDAR files to obtain a precise value in each building. Although the method has been used and validated in previous studies (Andríc et al., 2016; Santos et al., 2014), the LIDAR files are not publicly available in all countries and the information related to the height provided in the cadastre has to be used.

If more semantic information is available, a more detailed analysis could be carried out. In the following table, all the possible additional inputs are shown. These parameters are not usually included in the cadastre file and have to be provided by the municipality from sources such as municipal databases or energy performance certificates. This information should be provided for each building, although some parameters can be defined generically by use and age of the building, such as the Building Energy Systems.

The second part of the data collection focuses on actual consumption information, which can also come from various sources, such as energy performance certificates, bills or information provided by supplier companies. This part of the process is especially important since it crucial to quantify current energy consumption correctly and not to overestimate the reduction potential of the measures applied in future scenarios.

8.2 Data pre-process

The objective of the "Pre-process" is to obtain detailed geometry at building level and the greatest number of attributes associated to that geometry. The detailed urban model obtained from the data pre-process will serve as an input for Enerkad®.

Parameter	Mandatory / Optional	Parameter	Mandatory / Optional
Building ID	Mandatory	Roof area	Optional
Footprint area	Mandatory	Energy system	Optional
Building Height	Mandatory / Optional	Boiler type	Optional
Number of floors	Optional*	Number of boilers[1]	Optional
Construction year	Mandatory	Number of dwellings[1]	Optional
Building use	Mandatory	Effective roof %[1]	Optional
Protection degree[16]	Optional	Solar irradiance m^2 [1]	Optional
Gross floor area	Optional		

With this basic information, ENERKAD® is able to perform an energy **DEMAND** assessment for the area selected, that can range from small neighbourhoods to cities of more than 100,000 buildings.

The energy consumption and the associated CO_2 emissions, costs and primary energy balance can also be calculated if the necessary information related to the energy systems is provided. If this information is not available for each building, it can be defined during the scenario definition process in a more general way.

8.3 Baseline scenario definition

For the generation of the baseline scenario, the country and the location are defined, which establishes the climatic parameters that will be taken into account when making the energy calculations. The information related to the building energy systems and fuels used in each building can also be defined manually if not available in the input shape file. This categorisation is performed per building use and year summing a total of 70 categories.

In order to obtain a realistic model, the particularities of the study area are defined in the best possible way to represent the current circumstances. Once the baseline scenario is correctly defined and with this basic information, the energy demand assessment can be carried out.

8.4 Calculations

To generate heating and cooling demand profiles, Enerkad® bases its calculations on the heating degree hour method taking into account different characteristics of each building, like the building use and the construction year, which will define other parameters used in the calculations through inference rules.

[16] Only used for the future scenario calculations, not for the baseline

Departing from the basic information and potentially other locally measured data, statistics or simulations of the building stock, the energy needs for heating, cooling, DHW, lighting and appliances are obtained. If the information related to the building energy systems is provided, the energy consumption for the different final uses, the emissions and the primary energy demand and therefore, the non-renewable and total primary energy balances will also be calculated.

Other parameters needed for the calculations, such as the volume, the window area or the adjoining wall surface, are internally calculated by Enerkad®

8.5 Results analysis and adjustment

The results provided by the model will vary depending on the input information available. In the case of having provided only the mandatory parameters, the energy results obtained from the simulation will be the demand for heating, cooling, DHW, lighting and equipment.

The different formats of the output results allow the visualization of the results graphically, using any GIS tool (shape file), or numerically (using csv files), obtaining an overview of the results, individualized at building level, so that it is possible to see detailed information at the building level or group the information based on the parameter that the user needs.

By using the shape file, it is possible to visualize, together with the results obtained from the energy simulation, building parameters (such as use and age) or any other parameter included in the input shape file, such as the energy performance certificates.

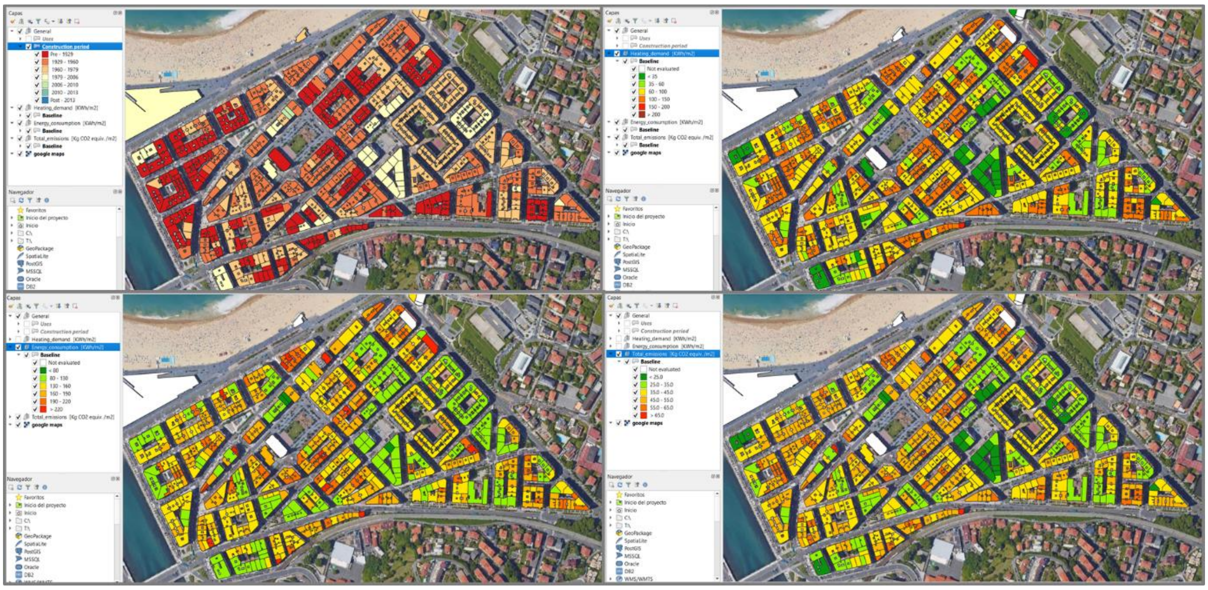


Figure 49: Visualization of the results in QGIS

8.6 Modelling the selected interventions

Enerkad® allows the modelling of different interventions at district or city level.

- It will serve to calculate the impact of the different PED solutions in different districts, in order to be guide the selection of PED from the energy perspective. Example of solutions that can be modelled and calculated include: Implementation of passive strategies (refurbishment of building envelope elements)
- Replacement of building energy systems by more efficient technologies.
- Implementation of solar photovoltaic and thermal systems.

The use of a GIS-based model such as ENERKAD®, allows to model a district with great detail, and different solutions can be analysed for specific buildings, calculating the corresponding hourly energy balances with the established methodology. Work is under development to be able to simulate in an hourly basis the different networks and technologies within a district, and being able to evaluate the potential benefits of energy flexibility and demand management solutions.

9 Future of PED Calculation Methodologies / What to consider next?

9.1 Consideration of Energy Flexibility in PEDs

The presented calculations in this deliverable have not considered how a district, as an energy system, could interact with the energy grids to which it is connected. The balance which has been used for the definition is an annual balance, where the import and export of energy through the boundaries of the district are directly compensated. This is a necessary simplification for early stage planning, preliminary feasibility studies and evaluation of potential of achieving PEDs in different cities.

For the detailed design and techno-economic evaluation of PEDs, the interaction of the district (and its buildings and energy systems) with the energy grids is of great importance. The value of energy flexibility is expected to increase as we move towards a more sustainable and renewable energy systems, with a higher share of renewables in the electricity mix and with increasing interactions between electricity grids, thermal demands, and mobility.

Figure 50 shows an example of hourly electricity balance of a residential building with a large PV installation as an example. During central hours of the day, the PV production is significantly larger than the actual electricity use in the building. In this case, a battery is supplied to be able to store some of the energy and use it in the following hours when demand is high, and no solar PV output exists. The batteries therefore are an element that provides certain flexibility to the interactions with the electricity grid.

In the case shown of PV system and batteries in a building, the economic evaluation for their benefits is relatively simple, from a comparison of electricity costs from the grid and costs of the electricity produced and self-consumed through the battery, that otherwise would have been supplied to the grid. Although different regulations regarding the connection to the grid are applicable in different countries, generally the remuneration for the exported electricity is considerably lower than the electricity cost from buying from the grid, and in simple terms, this difference should justify economically the cost of the battery for this example, after an hourly analysis has been carried for a full year.

PEDs can be however much more complex energy systems with different energy uses and supply technologies, integrating thermal and electrical demand and supply options through heat pumps, heating or cooling networks, different options for heat or cold storage , electric storage or even hydrogen production and use. The potential for energy flexibility in PEDs can be particularly high when a combination of these technologies interact through district networks. In all these cases, the value energy flexibility in PEDs needs to be acknowledged, beyond an annual energy balance. Tools to allow detailed hourly assessment of PED through their evaluation process, from concept development, through design and operation need to be used. As a result, it can be expected that for those PED where there is a good matching between electricity demand and supply, in an hourly basis, a better overall system efficiency and better economic performance can be achieved.

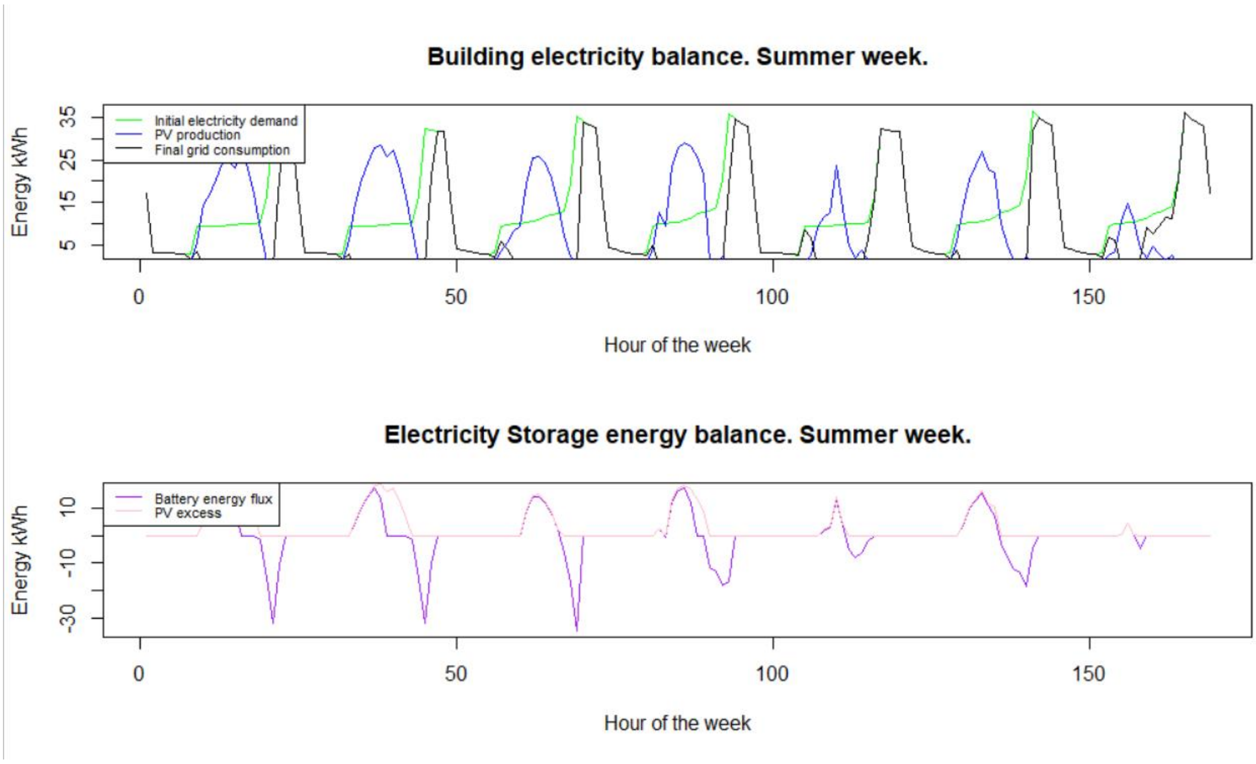


Figure 50: Building electricity and storage energy balance

Different tools exist for a detailed analysis and simulation of districts in an hourly or sub-hourly steps, some of which have been reviewed in the IEA EBC Annex 60 *'New generation computational tools for building and community energy systems based on the Modelica and Functional Mockup Interface standards'* . These tools can serve the purpose of facilitate design and control option for complex district systems and calculate a detailed energy balance. Different weighting factors for exported and imported energy in hourly or sub-hourly basis could then be applied for technical, environmental, or economic balance, therefore allowing the potential benefits of the different strategies and technologies that provide energy flexibility to the PED.

Section 9 describes ENERKAD® tool, which is being used for modelling the districts in MAKING-CITY in an hourly basis, which could be used as a basis for simplified analysis of energy flexibility in districts and its economic and environmental value.

9.2 Extending boundaries - From PEDs to PENs/PERs/Positive Energy Cities

As the rural surplus of people has declined in most Member States – except for Poland and Romania – the immigrant share of urban inflows has grown, especially in cities such as Paris, London, Madrid, Barcelona, Athens, Vienna and Berlin (European Union, 2011). Madrid is a city with a huge demand and where all the electricity production is located outside its region. Positive Energy Cities or Positive Energy Regions with space available and resources on-site could be a key factor for descarbonizing megacities.

Extending the boundaries -from PEDs to PENs to Positive Energy cities- bring out a diversity of new parameters (loads from different sectors, generation systems…) and assumptions on the table for calculations. Similar to the PED definition, which loads are considered in the balance of a city should be stated. In ENERKAD® tool heating, cooling, DHW, lighting and appliances energy needs are obtained. These energy needs can be transformed into energy uses if information about the different energy systems is available. From it, a model in LEAP can be performed considering the production of each system and its energy carrier. LEAP modelling at city or region level can help to evaluate their positiveness.

Conclusions

This document successfully lays down a step by step guideline on how to calculate an annual energy balance of a defined Positive Energy District. Although many assumptions are required to be made based on the district, region or country context (such as Primary Energy Factors), European Directive Guideline 2012/C 115/01 is followed within MAKING-CITY project to perform the energy balance calculation.

A major element in calculation is the definition of boundaries. District boundaries are important for the evaluation of the performances of the district and the calculation of the annual primary energy balance. When deciding the district boundaries, the specific typology of the district must be taken into account. MAKING-CITY identifies three boundary typologies; virtual, geographical and functional, mostly determined based on relation of energy supply elements to demand side elements. However, the overall goal should be to maximize local renewable energy consumption within the district, a sustainable urbanization and helps the city/region by means of the surplus RES production. Smart and active management should be prioritized.

Developped methodology and guideline will be the basis for eenergy balance calculations for both lighthouse cities Groningen and Oulu, which will serve as verification of the identified methodologies and guidelines.

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Annexes

Annex I: Simplified version of the Guidelines to calculate the annual energy balance of a Positive Energy District

A simplified version of the guidelines developed in this deliverable has been created and is shown in this Annex. In order to make easier the comprehension by the Follower cities and therefore by any other city that would like to implement the methodology developed in MAKING-CITY project for the annual energy balance calculation in a PED, this simplified guideline can be use as first contact with the calculation procedure. Meanwhile, for going deeper into the procedure, the complete text of the deliverable D4.2 can be used.

GUIDELINES TO CALCULATE THE ANNUAL PRIMARY ENERGY BALANCE OF A POSITIVE ENERGY DISTRICT

MAKING-CITY is a HORIZON2020 Project supported by the European Commission under contract No. 824418.

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Making City

2020

EDITION

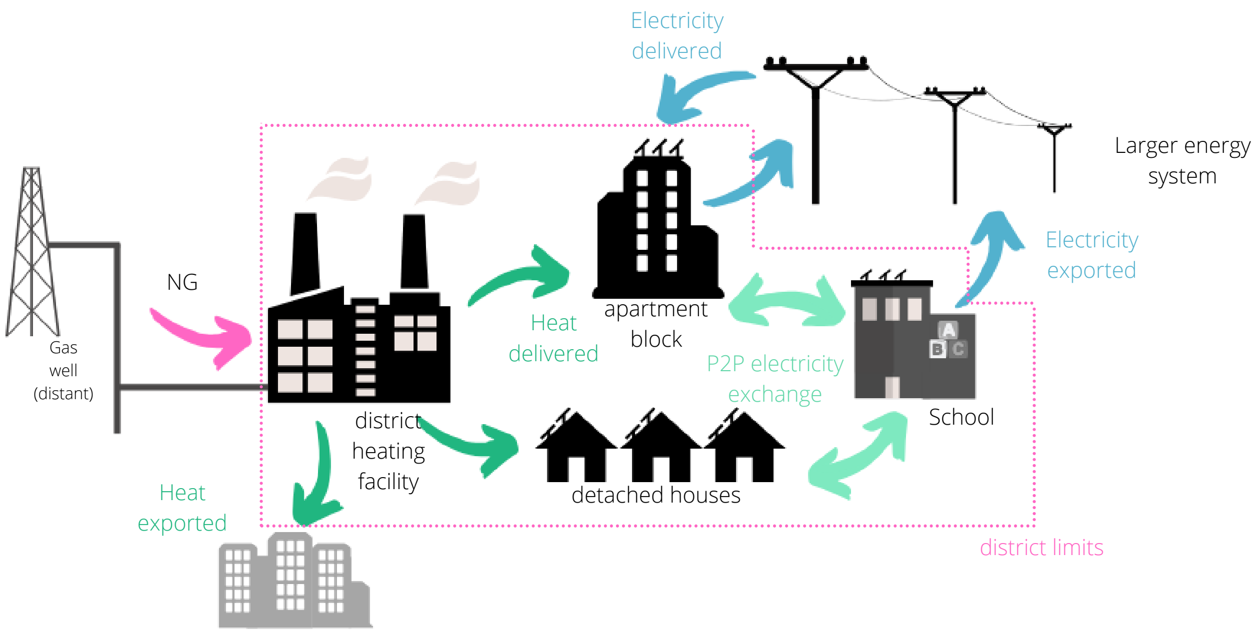
MAKING-CITY G.A. n°824418

THE OBJECTIVE

The present document aims to set a methodology for calculating the annual primary energy balance within a district that produces more energy than it consumes. It could be a practical tool for cities during the design and evaluation processes of a
Positive Energy District.
Calculation methodology for annual balance may be generated following a few steps. Firstly, energy sources and resources within the limits of the district need to be identified. Once both analyses are done, an iterative process and examination of energy balances will result in different alternatives for the district. In order to assess how positive a certain district is, the balance is made in total or non-renewable primary energy terms, as it compares different types of energy carriers and considers the benefits within and beyond the limits of the district.
The guidelines for the calculation follow the process performed during the initial state of the MAKING-CITY project. This is a 5 year-long project and, thus this document will continue to evolve from what has been observed and learnt. The methodology is based on the energy performance assessment of buildings defined in ISO 52000-1(2017).

OUR APPROACH

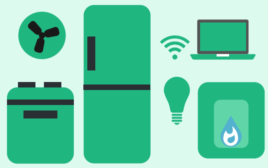
A Positive Energy District (also known as PED) is an urban area with clear boundaries, consisting on buildings of different typologies that actively manage the energy flow among them, as well as the larger energy system to reach an annual positive energy balance (in total or non-renewable primary energy terms).



USEFUL DEFINITIONS

Primary energy is the energy embodied in energy resources, that has not been subject to any conversion or transformation process, such as coal, crude oil, sunlight, wind, running rivers, vegetation or uranium.

Final energy (also known as energy delivered) is known as the energy consumed by the end users, such as electricity or natural gas consumed in a household.



In order to provide this final energy to the users, the primary energy has been subject to several transformations, from the well to the processing plant and transport processes, until the moment it arrives to the user-point. In each of these phases, energy is lost in the process. To account for these losses, **primary energy factors are used**, which transform final (or delivered) energy to the primary energy uses at the very beginning of the energy chain.

To have a Positive Energy District, it is necessary to achieve an annual positive primary energy balance, i.e. more energy is produced than it is consumed within the district boundaries. But, how do we calculate this annual balance? What are the district boundaries? What is considered "imported energy" and "exported energy"? You will find all the answers in this guide! The guide follows iterative steps, so you can go back and forth, but also, skip some steps (e.g. If final energy or energy delivered has been already identified, you can start the process at step 5).

METHODOLOGY

To calculate your primary energy balance (in terms of non-renewable primary energy) you can follow this eight-step methodology:

1 DEFINE YOUR PED BOUNDARY

The boundary is defined by the spatial and administrative relationship between the final energy consumption and the energy generation units (inside the buildings or beyond the boundaries, e.g. the grid). Depending on the relationship, your PED can have virtual, geographical or functional boundaries.

2 CALCULATE YOUR ENERGY NEEDS

Heating, cooling, domestic hot water and electric energy needs must be identified. The need could be determined by several approaches including monitoring, calculations based on bills, simulation, standards or statistical data.

3 CALCULATE YOUR ENERGY USE

The amount of energy used to cover the demand is established as thermal and electric energy use, i.e. the energy input needed to satisfy the needs. It can also be identified as the useful energy output of the thermal and electrical generation systems.

4 CALCULATE YOUR ON-SITE GENERATION

Once the energy systems used to cover the determined energy uses are identified, .alculate the useful output of these systems (i.e. the energy generation). Then, identify if there is any remaining energy needs to be covered by non-renewable energy systems or external grids.

5 ESTIME THE ENERGY DELIVERED

Both the output and input of each system are linked with a source of energy inside or outside the boundary for each energy carrier. A greater energy consumption over a renewable energy generation within the boundary indicates an import (in) from outside the boundary. A greater renewable energy generation within the boundary over energy import from outside the boundary indicates an export (out) to outside the boundary.

6 CALCULATE THE PRIMARY ENERGY

Weight your energy imports (delivered to the PED) and exports (delivered outside the PED) per energy carrier using primary energy factors, in order to calculate the primary energy exported and the primary energy imported. Primary energy factors could be taken from national or international standards.

7 CALCULATE THE ENERGY BALANCE

The primary energy balance is calculated as the difference between the primary energy imported to the PED boundaries minus the primary energy exported outside the PED's boundaries.

8 SANKEY DIAGRAM

Once all the steps are finalized, an energy flow diagram can be drawn (known as Sankey diagram), based on the energy flows identified in the previous steps (energy needs, energy uses, energy delivered and primary energy columns).

DEFINE YOUR BOUNDARIES

A system boundary can be defined as "a borderline that includes several systems, installations, facilities and/or buildings that are interconnected with each other, either with some energy infrastructures, grids or virtual/contractual connection". Thus, the boundary is defined by the spatial, contractual and administrative relationship between the final energy consumption and the energy generation units (inside the buildings or beyond the boundaries, e.g. the grid).

Furthermore, PEDs can be delimited by spatial-physical limits including delineated buildings, sites and infrastructures. Therefore, the PED will be characterized by geographical boundaries. If buildings are not close to each other, but are interconnected thanks to a gas, electric or heating network, the PED will have functional boundaries If the energy demand is covered by a generation unit, which is shared with other consumption points (e.g. a windmill) and located outside the geographical boundaries of the PED, then this is considered a virtual boundary. When the district cannot afford to own an energy infrastructure, but purchases their RES energy by means of a Power Purchase Agreement (PPA) or by buying green energy certificates, it can be considered a virtual boundary as well. However, it is currently debated whether to consider it a PED or not.

At the table below, it is possible to select (by crossing the box) the different elements and boundaries to be considered for your balance:

Elements in the Energy Balance (Loads)

DHW needs	SH needs	SC needs	Lighting	Appliances	Ventilation
Humidification	**Car charging**	**Processes**	**District Infrastructure**		

EPB standards usually omit domestic appliances, and mobility (traffic lights, road lights, EV cars etc.)

Energy consumed within an **industry process, or a commercial activity** (e.g. kitchen in a restaurant)

PED limits of your district:

Geographical	Virtual	Functional

Objective of your PED:

Positive	Self-sufficient	Circular	Net GHG emissions
X			

To be considered as a PED you need to achieve a **Positive Energy Balance**

ENERGY NEEDS

Thermal energy needs are the heat to be delivered to:

- Cover the energy demands of the building, in order to maintain an intended space at a given temperature (space heating=SH, and/or space cooling=SC)
- Raise the cold network temperature to the desired temperature for domestic hot water (DHW) consumption

	Units (m^2 or people)		kWh/unit		kWh
Building 1: DHW needs		X		=	
					+
SH needs		X		=	
					+
SC needs		X		=	
					+

	Units (m^2 or people)		kWh/unit		kWh
Building 2: DHW needs		X		=	
					+
SH needs		X		=	
					+
SC needs		X		=	

⋮ +

	Units (m^2 or people)		kWh/unit		kWh
Building n: DHW needs		X		=	
					+
SH needs		X		=	
					+
SC needs		X		=	
					=

Total Thermal Energy Needs =

By "electric energy needs", we understand the energy delivered to cover the energy demand for lighting and ventilation of a building.

- Usually "electric energy needs" and "electric energy use" by the building for lighting and ventilation purposes are the same (losses can be omitted).
- Electrical energy to drive the heating system (such as **heat pumps or electrical heaters**) **and auxiliary elements** (pumps, etc.) **should be included as energy use. On the contrary, the heating or cooling output from the heat pump to cover the space heating and space cooling needs are included in the thermal needs** (Table above)

		Units (m^2 or people)		kWh/unit		kWh
Building 1:	Lighting		X		=	
						+
	Ventilation		X		=	

+

		Units (m^2 or people)		kWh/unit		kWh
Building 2:	Lighting		X		=	
						+
	Ventilation		X		=	

+

⋮

		Units (m^2 or people)		kWh/unit		kWh
Building n:	Lighting		X		=	
						+
	Ventilation		X		=	

=

Total Electric Energy Needs =

ENERGY USE

Thermal energy use is the energy input into the heating, cooling or hot water distribution systems (radiators, heat exchangers, etc.) **to satisfy the energy needs for heating, cooling or hot water respectively.**
It can also be identified as the useful energy output from the thermal generation systems (e.g. solar thermal collectors, boilers, thermal output from CHP, etc.).

	Energy needs (kWh)		Efficiency of the emitter		kWh
Building 1: DHW use		/		=	
					+
SH use		/		=	
					+
SC use		/		=	
					+

	Energy needs (kWh)		Efficiency of the emitter		kWh
Building 2: DHW use		/		=	
					+
SH use		/		=	
					+
SC use		/		=	

⋮ +

	Energy needs (kWh)		Efficiency of the emitter		kWh
Building n: DHW use		/		=	
					+
SH use		/		=	
					+
SC use		/		=	
					=

Total Thermal Energy Use =

To cover the energy needs, distribution systems, emitters (such as fan coils, radiators, etc.), storage tanks, and heat exchangers are used. To take into account all the losses, from the generation system to the energy needs (DHW, SH, SC) of a building, some typical efficiencies can be considered. The efficiency transforms "energy needs" into "energy use". Typically, heat exchangers have a conversion efficiency from the primary stream (source) to the secondary stream (sink) of 70%, but it might be higher or lower, depending on many factors, such as the area of heat transmission. Distribution losses can vary a lot, from 5% for systems with high insulation, to 20% if thinner insulation is installed. For more detailed information, refer to the EN15316-3:2017.

Electric energy use is the electricity directly consumed by buildings (from grid or local RES as PV, wind...) **to supply the needs** (heating, cooling, ventilation, lighting and domestic hot water). Only electric energy uses in the EPB standards are considered, therefore the electricity used within the district boundaries for **domestic appliances, and mobility** (traffic lights, road lights, EV cars etc.) **are omitted in this table** (It is up to the city or national standards to take them into account). In commercial and industrial buildings, the correspondent standards should be taken into account.

Electric energy use can also be identified as the useful energy output from the electric generation systems, but there may be a slightly difference between the energy use on the appliances and lighting and the energy produce, as part of the electric energy will be lost in the form of heat. Nevertheless, most of the times this energy loss can be omittedas it is smaller than the overall consumption.

	Energy needs (kWh)		COP/EER/efficiency		kWh
Building 1: SH electric use		/		=	
					+
SC electric use		/		=	
					+
DHW electric use		/		=	
					+
Ligthing+process+Ventilation needs (usually losses neglected)				=	
					+

	Energy needs (kWh)		COP/EER/efficiency		kWh
Building 2: SH electric use		/		=	
					+
SC electric use		/		=	
					+
DHW electric use		/		=	
					+
Ligthing+process+Ventilation needs (usually losses neglected)				=	
					+

⋮

	Energy needs (kWh)		COP/EER/efficiency		kWh
Building n: SH electric use		/		=	
					+
SC electric use		/		=	
					+
DHW electric use		/		=	
					+
Ligthing+process+Ventilation needs (usually losses neglected)				=	
					=
Total Electric Energy use				=	

ENERGY GENERATION

After identifying which solutions will be considered for a certain district, energy systems can be listed, and the connections between each other (schematics) as well as the energy source supplying the PED (biogas, natural gas, solar, wind, electricity from the grid, etc.) can be identified. Heat pumps with a SCOP higher than 2.5 are considered as a renewable source according to ISO52000. Waste heat is also considered a renewable source in most of the literature, as this heat would otherwise be wasted.

Feature	Data requirement, parameters	Energy sources
Heating systems Boiler CHP Heat pump Electric resistance Solar thermal panel	Schematic Technical specification of heat generators	Fossil fuels or biogas, biomass, biofuels, etc. Electricity Solar
Cooling systems (Reversible) Heat pump (HP) Other cooling system: adsorption HP, absorption HP, compression HP, etc. Storage (ice tanks, etc.)	Schematic Technical specification of heat generators, storage and emitters	Compressor driven: Electricity Thermal driven: solar or boilers run by fossil fuels, biomass, biogas, biofuels, etc.
Photovoltaic (PV) installation	Total installed power and area Location and inclination of panels	Solar
Electric grid	Topology, cable type and load profile	Several sources: primary energy factors gives you information of the percentage of non-renewable and renewable sources that are used
Wind turbine	Rated power. Technology Wind speed data	Wind

The energy carrier fed into the generation systems can come from on-site renewable energy sources (within the boundaries) or also from the outside (incoming energy). To calculate the energy production, seasonal efficiencies of generation, distribution, emission and control systems in the district need to be taken into account. The seasonal efficiencies can be found in the technical specifications of the systems. When these are not available, overall national performances, monitored data, or statistical data can be used to estimate the energy output and input of the different systems – both depend on the efficiency and capacity of the system. ISO standards, as well as the existing national standards of the country can also be used to estimate it.

EN 15316:2018	**Methods for calculation of system energy requirements and system efficiencies** Part 1: General Part 2: Heating and cooling Part 3 : space distribution in H&C and DHW system Part 4-1: Combustion systems (boilers, biomass) Part 4-2: Heat pumps Part 4-3: Heat generation systems, thermal solar and photovoltaic systems Part 4-4: Cogeneration Part 4-5: District heating and cooling Part 4-6: Electric generation coming from RES Part 4-7: Biomass Part 4-8: air heating and overhead radiant heating systems, including stoves (local) Part 4-9: Direct electrical heater Part 4-10: Wind Part 5: storage	In force

The useful energy (output) from renewable energy sources is calculated:

	PV	PVT (el/th)	Solar thermal	Geothermal	Biomass(el/th)	Waste Heat
Building 1						
Building 2						
....						
Building n						

*useful outputs to be use to cover total thermal and electric energy uses

Total Energy from RES (electric) =

Total Energy from RES (thermal) =

With the useful outputs calculated, the remaining energy to be covered (or the surplus energy to be exported) is calculated:

Remaining (Thermal) = Total Thermal Use - Total RES Thermal =
(Surplus if negative, remaining to be covered by external sources if positive)

Remaining (Electric) = Total Electric Use - Total RES Electric =
(Surplus if negative, remaining to be covered by external sources if positive)

ENERGY DELIVERED

With the useful outputs calculated, the remaining energy to be covered has been identified. This remaining energy (when is positive) needs to be covered by the electricity grid and the remaining energy systems in the buildings (boilers, CHP, etc.) that use non-renewable energy sources (e.g. consume natural gas) or biomass. The latter is usually considered a renewable source coming from outside the boundaries (thus, it is delivered to the PED). That incoming energy (to be used by biomass boilers or CHP boilers) needs to be accounted for as well.

The energy delivered is known as the energy supplied to the PED (thermal and electricity) that is produced outside the district boundaries. Usually, it comes from thermal, gas or electric grids and feeds the energy systems available within the district (on-site).

Delivered energy from fossil fuels:

	Remaining Energy (kWh)		efficiency		Delivered Energy kWh
Natural gas =		/		=	
Oil =		/		=	
Other fuels =		/		=	

Delivered energy from external grids (still any remaining energy not covered?):

District heating =				=	
Grid =				=	

Delivered energy from Renewable Energies (Biomass, biogas...etc.)

Biomass boiler =	Thermal	/		=	
Biogas turbine =		/		=	
Biomass CHP =	Thermal	/		=	
	Electric	/			

Typical efficiencies: A typical condensing boiler has a thermal efficiency of 90% to 95%, in comparison with non-condensing boilers, which typically have around 70% to 88%. Furthermore, a cogeneration unit (CHP) typically has an electric efficiency of 30% and a thermal efficiency of 60%. For more detail on how to calculate these efficiencies, refer to EN15316-3:2017 or take some nominal values from a technology manufacturer.

Biomas Energy Delivered in a CHP is only accounted once (but it gives two outputs: heat and electricity)

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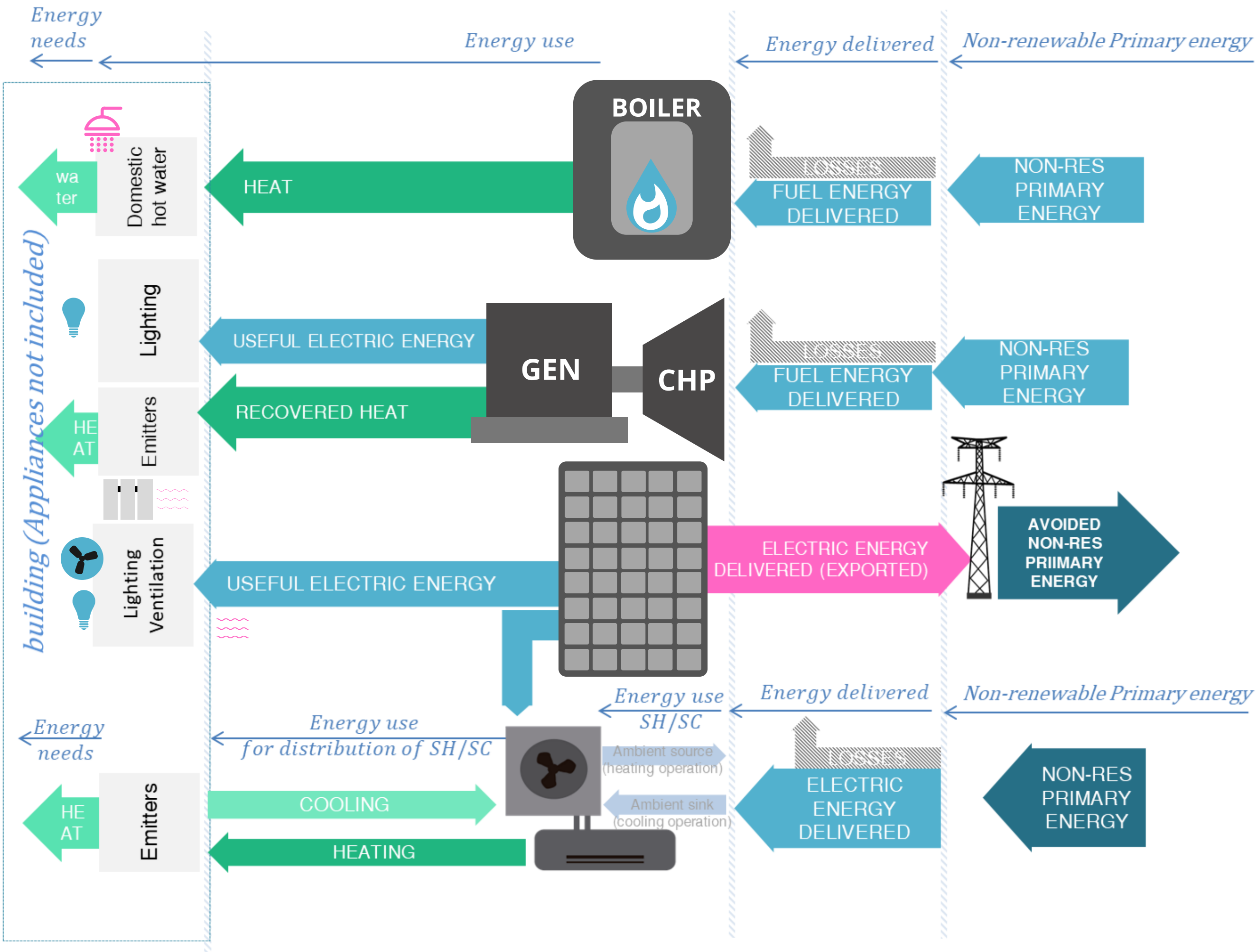
From the above-mentioned calculations, the different energy streams can be displayed in a Sankey Diagram. The energy delivered to the district and from the district to outside the boundaries, is transformed in following steps into non-renewable primary energy terms, using non-renewable primary energy factors.



PRIMARY ENERGY

Primary energy is the energy that has not undergone any conversion in the transformation process, calculated by energy carrier using non-renewable primary energy factors (PEFnren). The primary energy balance is calculated as the difference between the non-renewable primary energy delivered to the district (added by all energy carriers) and the non-renewable primary energy exported outside the PED's boundaries.

Usually, the non-renewable primary energy factor for the electricity exported energy is something similar to the grid's non-renewable primary energy factor, since by exporting it, this amount of energy is avoided. The same thing happens with the heat exported to a district heating.

The "Delivered Energy" per energy carrier is transformed into primary energy as follows:

Primary Energy Imported(+):

	Delivered Energy (kWh)		PEFnren		kWh
Natural gas =		**x**		**=**	**+**
Grid =		**x**		**=**	**+**
Biomass =		**x**		**=**	**+**
Other fuels =		**x**		**=**	**+**
District heating =		**x**		**=**	**+**

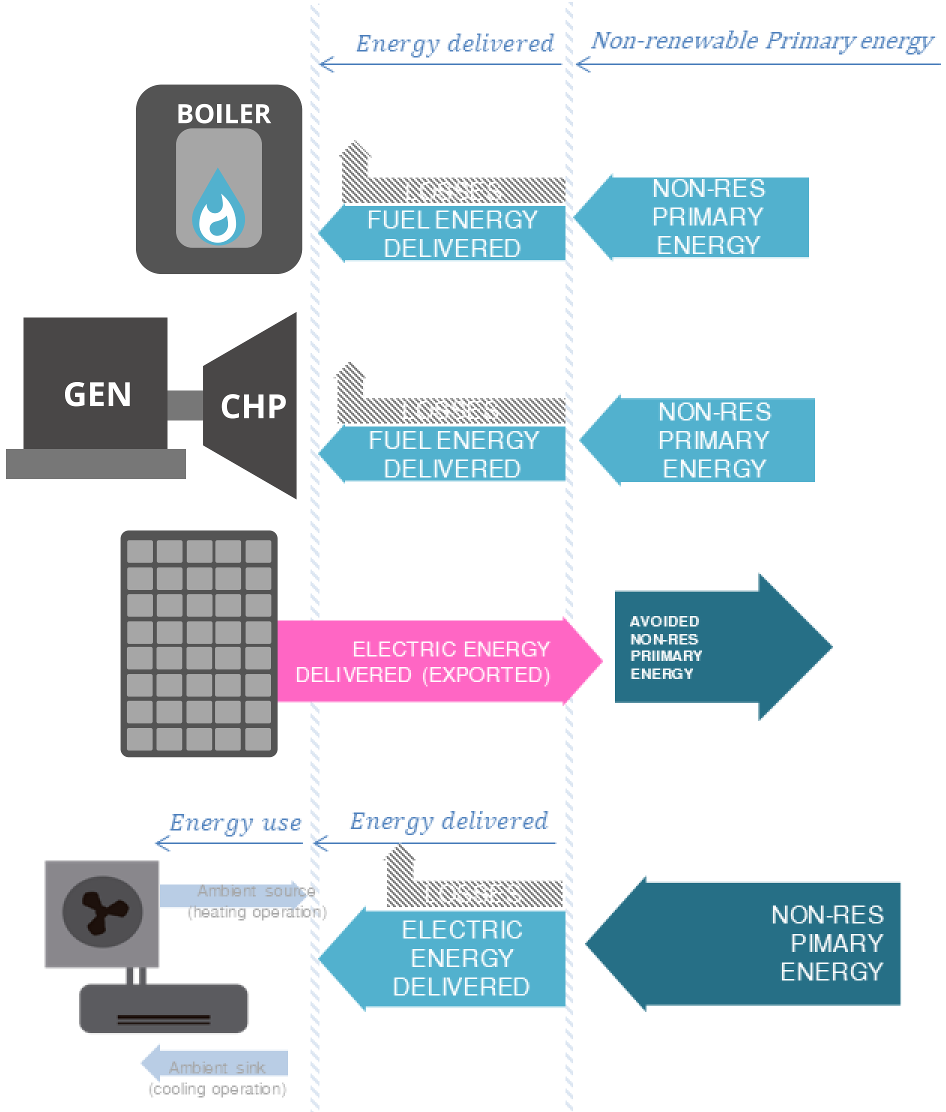
Primary Energy Exported(-):

	Delivered Energy (kWh)		PEFnren		kWh
Surplus El. Energy =		**x**		**=**	**-**
Surplus Th.Energy =		**x**		**=**	**-**
Surplus fuel Energy =		**x**		**=**	**-**

Non-Renewable Primary Energy Balance =

If the Balance gives you a negative number you have achieved a Positive Energy District!

Finally, in a Sankey diagram, the non-renewable primary energy delivered to the district and from the district to outside the boundaries, can be represented as follows:



To calculate the non-renewable or total primary energy, primary energy factors are needed. But, what are the primary energy factors?

Primary energy factors are the ratio of a given type of primary energy (renewable, non-renewable, total) to the actual energy amount. On the one hand, if only non-renewable primary energy is taken into account in the analysis, non-renewable primary energy factors are used. On the other hand, if renewable and non-renewable primary energy is considered, then, total primary energy factors are used.

Thus, the total PEF (TPEF) can be calculated as the sum of the non-renewable primary energy factor (PEFnren) and renewable primary energy factor (PEFren):

TPEF = PEFnren + PEFren

Non-renewable primary energy factor(PEFnren) proves how much primary energy from non-renewable sources is used to generate a unit of final energy through the use of consumption indicators.

Renewable primary energy factor(PEFren) proves how much primary energy from renewable sources is used to generate a unit of final energy through the use of consumption indicators.

All in kWh:

$PEF_{nren,grid}$ =non-RES primary energy input/final energy= 2.25/1 =2.25

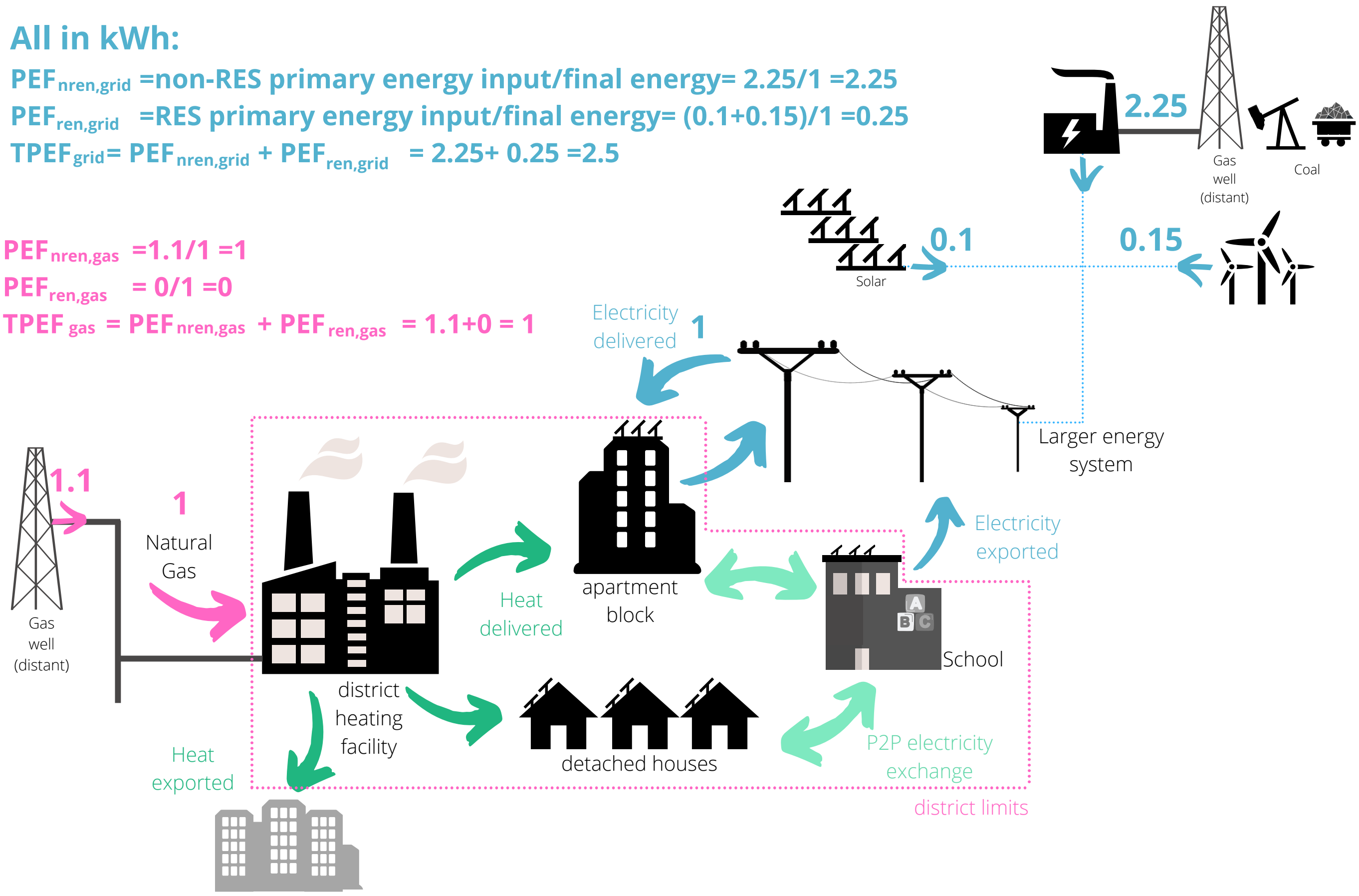
$PEF_{ren,grid}$ =RES primary energy input/final energy= (0.1+0.15)/1 =0.25

$TPEF_{grid} = PEF_{nren,grid} + PEF_{ren,grid}$ = 2.25+ 0.25 =2.5

$PEF_{nren,gas}$ =1.1/1 =1

$PEF_{ren,gas}$ = 0/1 =0

$TPEF_{gas} = PEF_{nren,gas} + PEF_{ren,gas}$ = 1.1+0 = 1



Usually, in order to transform the thermal energy delivered (e.g. gas consumption) or the electricity delivered to a district into primary energy terms (total, non-RES or RES), the primary energy factor of the thermal and electric grids are used. For example:

$TPEF_{grid}$ for electricity indicates how much primary energy (renewable and non-renewable) is used to generate a unit of electricity. This electricity usually comes from the grid, and in that case, it is a country specific indicator and it depends on the country's energy mix.

$TPEF_{gas}$ for an energy carrier (e.g. fuels such as natural gas) indicates how much primary energy (renewable and non-renewable) is used to generate a unit of useable thermal energy. It commonly applies to fuels, but it depends on the equipment installed and on the energy carrier (gas, biogas, etc.)

Primary energy factors for renewable sources are a bit more intrincate.

For example, in the case of biomass, it has a TPEF around 1.05-1.1, where, generally, PEFren=1 and PEFnren=0.05 to 0.1, to account for the non-renewable energy use for processing and transporting the biomass. But, what if the biomass extraction rate were higher than the regrowth rate? Then, it could be considered that this biomass is a non-renewable source. This is what happens with "peat", which is considered a non-renewable source due to its low regrowth rate[1]. Peat is actually considered as dead organic matter, since it accumulates on the land with a low carbon secuestration yield (20 to 50 kg/ha per year)[2].

Therefore, it is advisable that, in the case of peat or biomass with an extraction rate higher than the regrowth rate, its primary energy factor is allocated to the PEFnren and not to the PEFren (generally: $PEF_{nren,peat}$ =1.05 and $PEF_{ren,peat}$ =0).

For renewable sources such as PV or Wind, some countries consider the non-renewable energy used in the entire supply chain, therefore $PEF_{ren,PV/wind}$=1 and $PEF_{nren,PV/wind}$=0.05

Waste heat can be seen as a renewable source (with a $PEF_{ren,waste}$ of 1) that is used to reduce the heat input, as this heat would otherwise be wasted. But what if this heat comes from an intensive energy industry that emits a lot of greenhouse emissions? Is this waste heat still considered clean although the industry is not part of the district? Part of the literature considers that “if everything has been done to optimize the energy usage within the industry, then it can be assumed that the waste heat has zero carbon dioxide emissions”, but this issue is still under discussion.

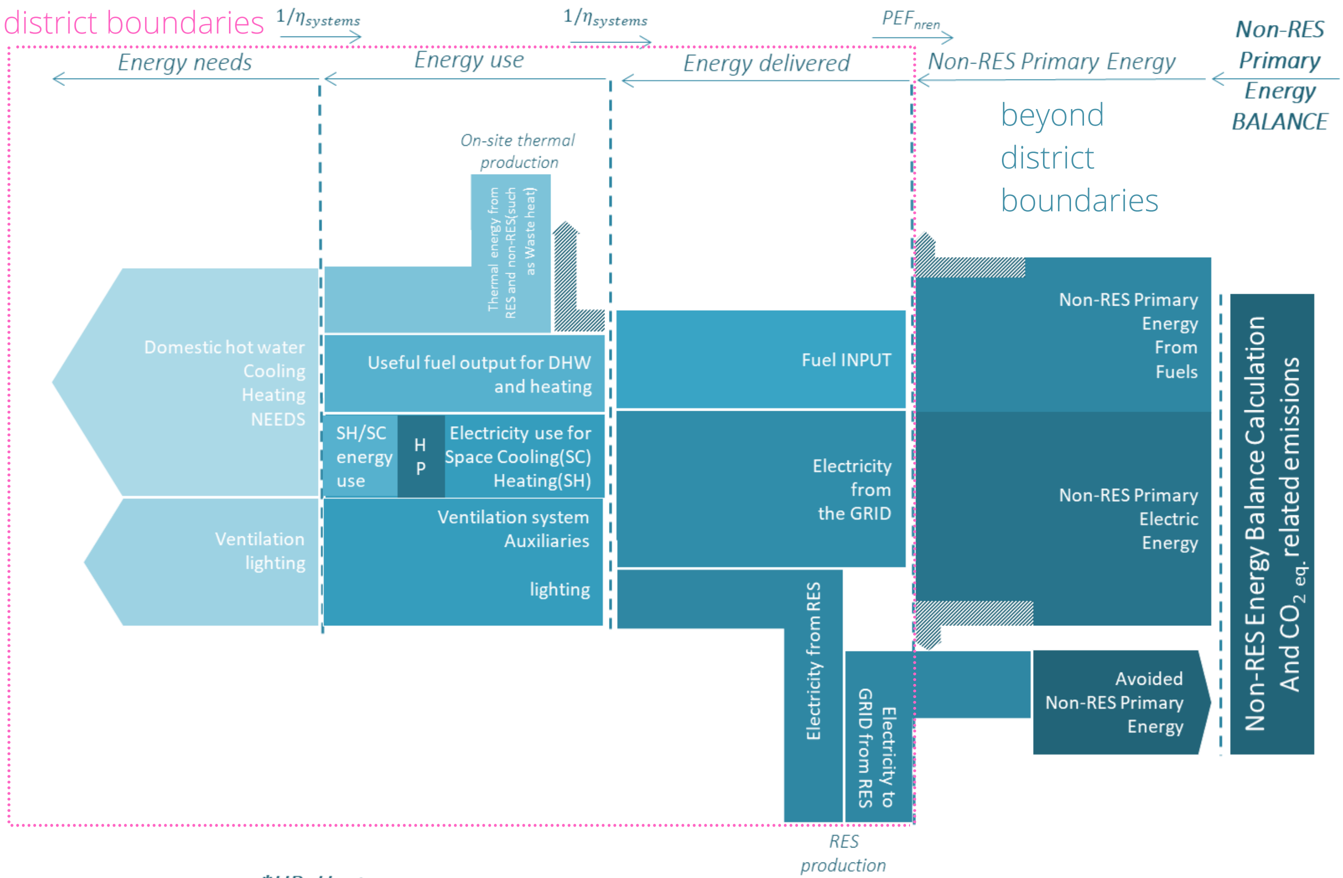
Attention, as Primary energy factors (total, non-RES, RES) are country specific, it is advisable to use the ones specific to your country, since the calculation methods and the efficiency of the entire supply change might differ from country to country.

Nevertheless, if some factors cannot be found, the ISO52000 standard provides a table with default total, non-renewable and renewable Primary Energy Factors.

		PEF_{nren}	PEF_{ren}	TPEF
Solar (PV,PVT,FPC...)		0	1	1
Environment (Geo-, aero-, hydrothermal)		0	1	1
Biofuels	solid	0,2	1	1,2
	liquid	0,5	1	1,5
	gaseous	0,4	1	1,4
Waste Heat		0	1	1
Electricity grid (imported and exported)		2,3	0,2	2,5
Fossil fuels	solid	1,1	0	1,1
	liquid	1,1	0	1,1
	gaseous	1,1	0	1,1
District heating/cooling		1,3	0	1,3

SANKEY DIAGRAM

This graphic representation shows the energy flows for the different stages of the balance. The energy needs that the district demands, the energy used for covering this demand, the final energy delivered into de district, and this energy represented in terms of primary energy, are the four stages that cover electric and thermal energy. The fifth section of this diagram shows the result of the primary energy balance and represents the surplus of energy that the PED could have.



*HP=Heat pump

Striped arrows represent the losses. As it can be seen at the Sankey diagram, RES production reduces the necessity to import energy from outside the boundaries (reducing the energy delivered) and it shows that the balance is made at the final stage (right side of the diagram) subtracting the imported primary energy by the exported primary energy.

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