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

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EDITION

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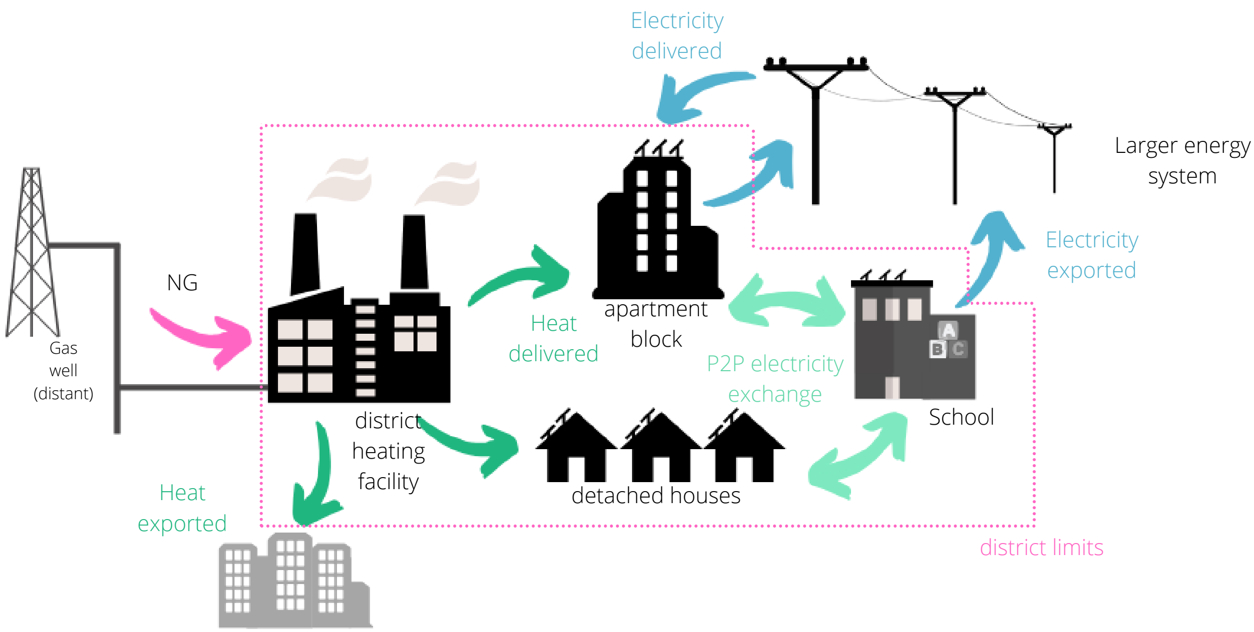
THE OBJECTIVE

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

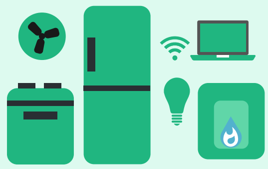
A Positive Energy District (also known as PED) is an urban area with clear boundaries, consisting on buildings of different typologies that actively manage the energy flow among them, as well as the larger energy system to reach an annual positive energy balance (in total or non-renewable primary energy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

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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).

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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
☒	☐	☐	☐

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 (m² or people)		kWh/unit		kWh
Building 1:	Lighting		X		=	
						+
	Ventilation		X		=	

+

		Units (m² or people)		kWh/unit		kWh
Building 2:	Lighting		X		=	
						+
	Ventilation		X		=	

+

⋮

		Units (m² 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 =				=	

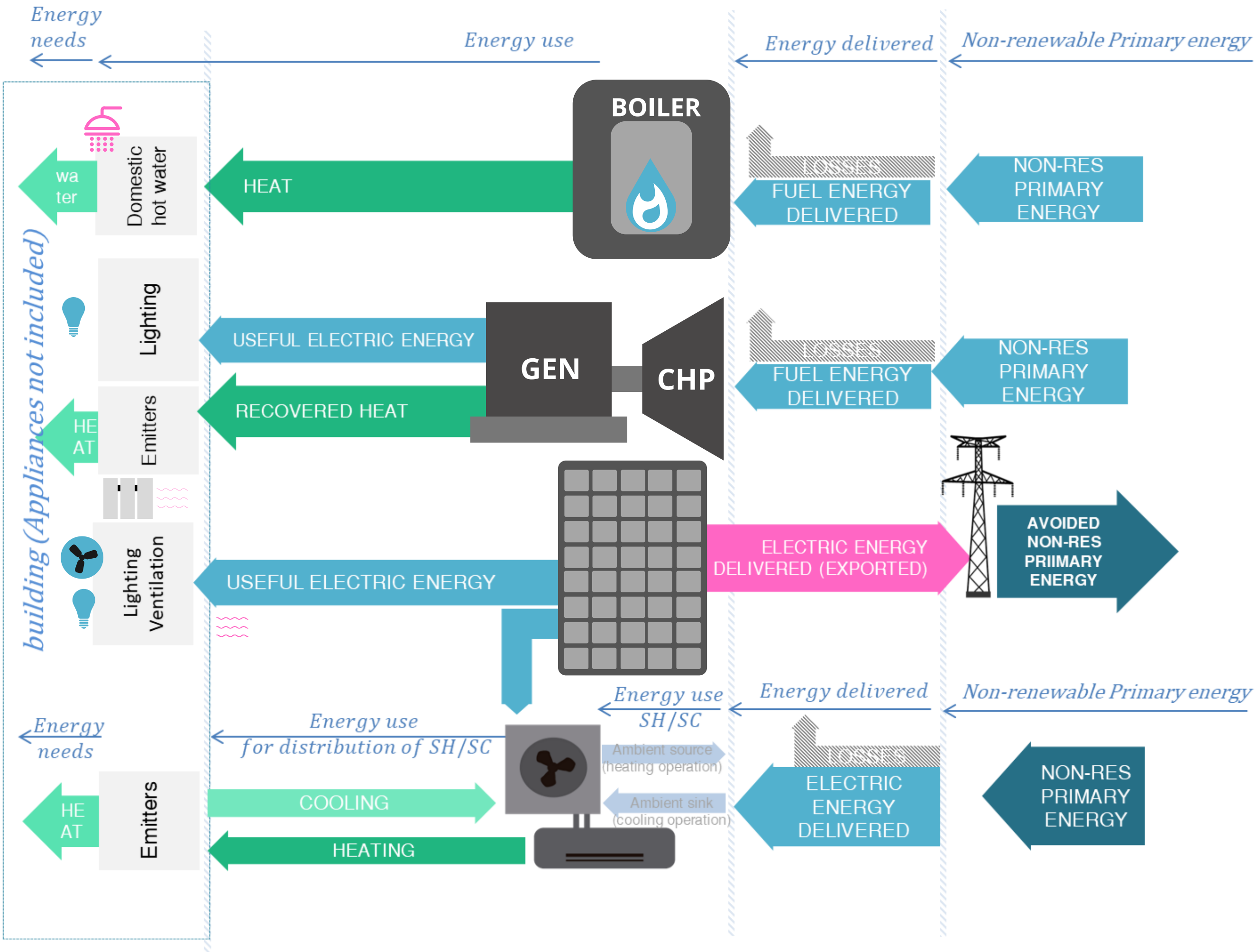
Delivered energy from Renewable Energies (Biomass, biogas...etc.)

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)

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		=	+

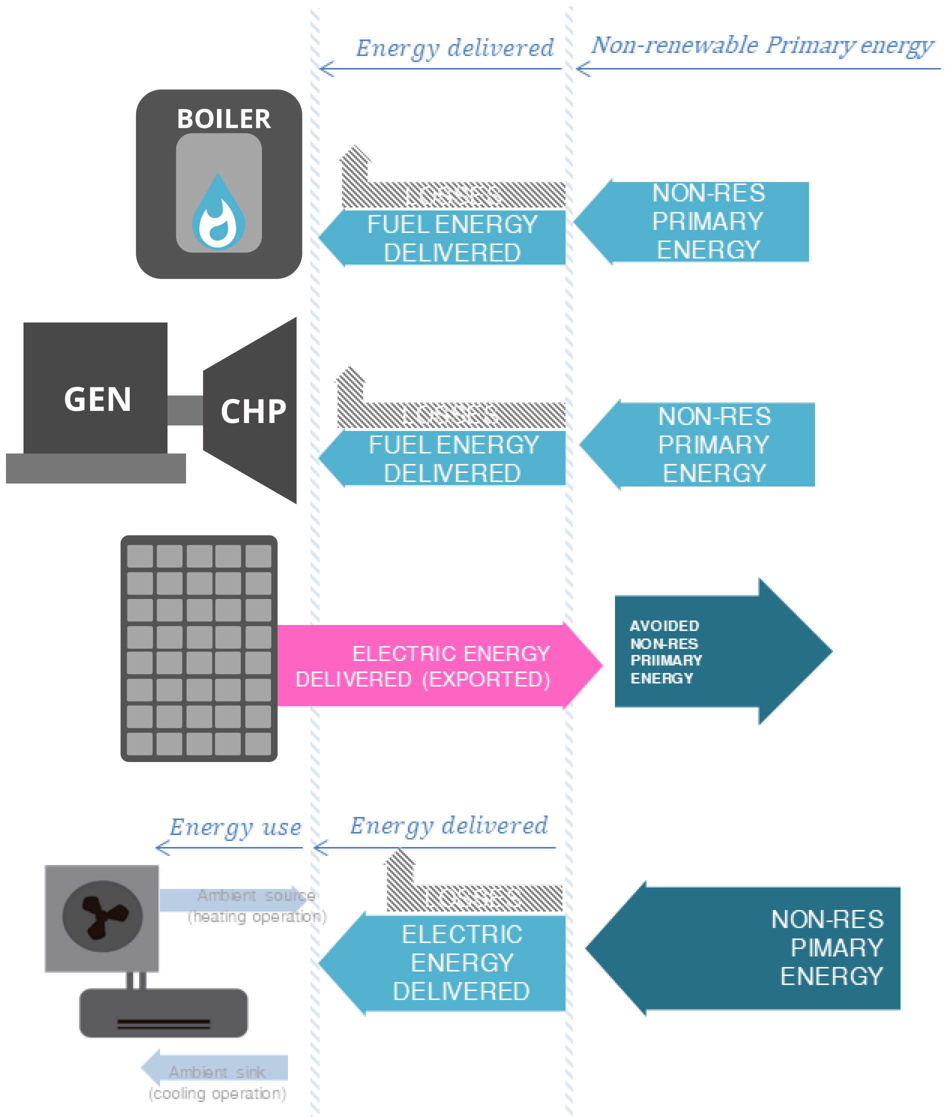
Primary Energy Exported(-):

		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

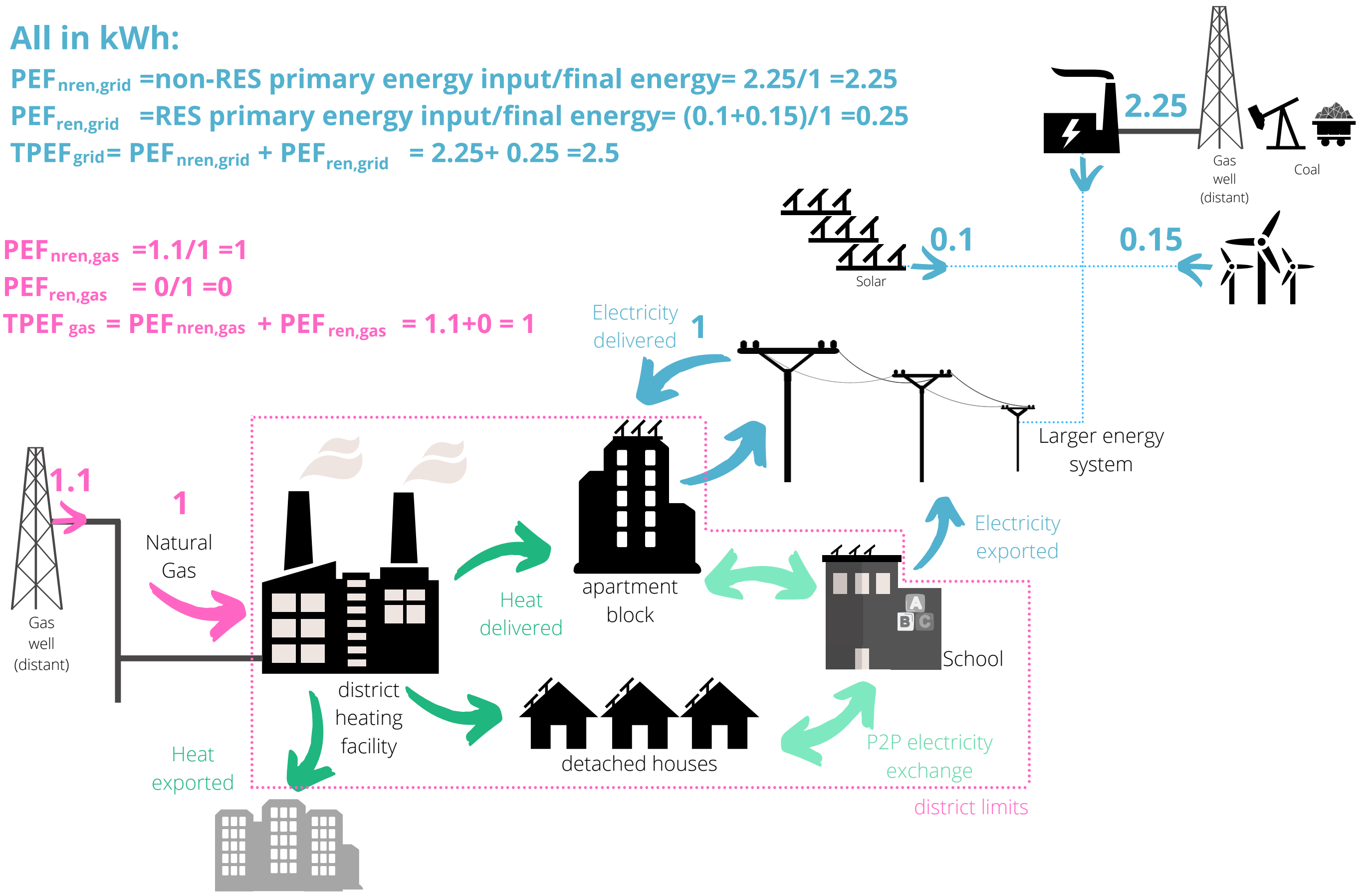
$PEF_{ren,grid}$ =RES primary energy input/final energy= (0.1+0.15)/1 =0.25

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

$PEF_{nren,gas}$ =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.

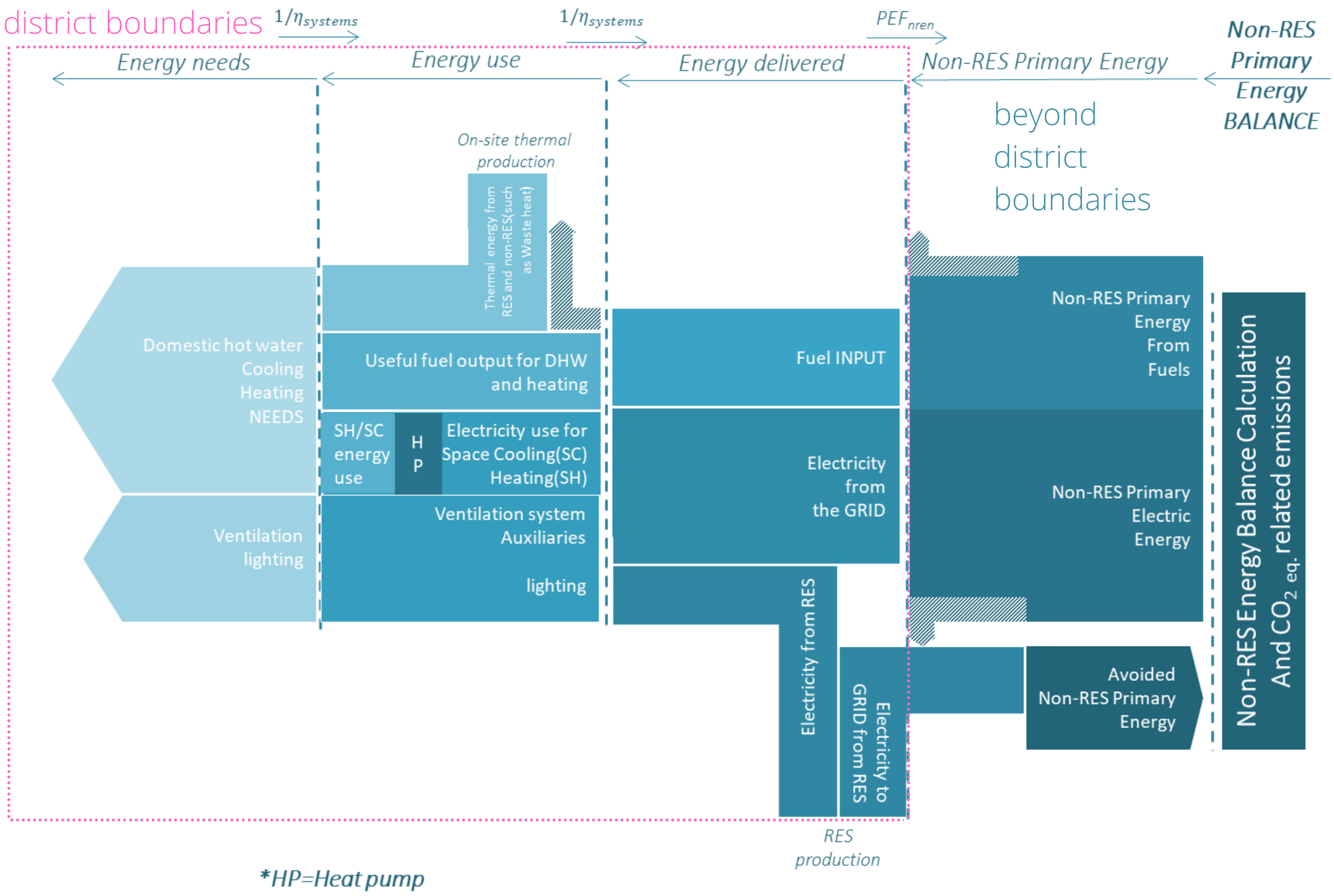
Attention, as Primary energy factors (total, non-RES, RES) are country specific, it is advisable to use the ones specific to your country, since the calculation methods and the efficiency of the entire supply change might differ from country to country.

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.



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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