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Identification of Key Performance Indicators related to the implementation of a hybrid energy supply system based on renewable energy sources

Identification of Key Performance Indicators related to the implementation of a hybrid energy supply system based on renewable energy sources

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Abstract. Complex energy systems need to evaluate their performance through the achievement of its own objectives but also by comparison with best practices. This can be realized by identifying the key performance indicators (KPI) that clearly monitor the progress towards project goals. The work focuses mainly on the identification and categorisation of KPIs through a quantitative approach for the case of implementation of a hybrid energy supply system into the existing district heating network of University Politehnica of Bucharest. The main results of the study show that two levels of KPI can be defined: technology specific and overall DHC system. If on the technology level, the approach is to use the specifics standards already existing for the main technologies, for the system level, little information is available and consequentially, a method for calculating separately the cooling and heating impact in terms of energy, environment, and economy is proposed.

1. Introduction

Present paper establishes key performance indicators (KPIs) for complex energy supply systems related projects. The research is based on a case study of a demonstration project at the University Politehnica of Bucharest (UPB). The project will investigate the integration of renewable energy systems into the existing district heating (DH) system of the university. The proposed demo constitutes one of the first hybrid geothermal-PV technological solution at the local level through which energy is produced and injected into the existing networks (thermal and electrical).

KPIs are a key element for assessing a project evolution and success being very important for planning and controlling, creating transparency and supporting decision makers of the management [1]. An appropriate definition is the one describing KPIs as being "a set of measures focusing on those aspects of organizational performance that are the most critical for the current and future success of the organization." [2]. Thus, energy projects KPI's are used to measure the most important aspects of the project implementation success. One immediate problem is then to decide upon the most important aspects [3]. This is particularly true for complex systems, which involves different technological innovation in a single ensemble, as it is case for project pilots, and more generally for different renewable energy technologies integration in district energy systems. The project requires the KPIs which can enlighten the energy, economic and social performance of the particular technologies to be developed, improved and/or integrated within the project, as well as to reflect the most significant aspects of a district heating and cooling system overall behaviour.

The KPIs to be used in a project context, are linked to the project success or failure [4]. They have to be measurable and controllable providing quantitative and qualitative information, which is calculated in transparent and traceable manner [5, 6]. Following a holistic perspective, the choice of appropriate collection of KPIs should allow to evaluate the proposed and demonstrated set of solutions at different stages within the project, from the concept design to the results of the monitoring demo phase.

The best method of identifying and defining the KPIs presented below is to use the existing recognized references as starting point and to relate to established standards. Evidently, for some of the KPIs there is a need to elaborate new, more precise definitions in order to be able to accomplish the project objectives. This is the case for the systems which provide several energy forms (electricity, heating and cooling). During the literature review we have identified a lack of methodologies to calculate differentiated KPIs for power generation and supply, heating and cooling services. Because we considered this division useful for a complete comparison of different District Heating and Cooling system architectures, we opt to develop KPIs capable of representing electricity and both heating and cooling performance in an independent manner.

2. Research Methodology

The analysed project is focused on integrating renewable energy sources (RES) for supplying district heating and cooling networks. As a result of the project approach, it is necessary to evaluate the project at two levels: i) system, to consider the integration of technologies; ii) technology, to evaluate the specifications and development of each compared to the current existing ones. Moreover, the focus of the project is on the supply of heating and cooling to the network.

The EuroHeat&Power association developed guidelines for evaluation of DHC through the Ecoheat4cities project [7]. This considers as system boundaries on one side the primary energy input to the production, including all kinds of thermal energy production plants, including cogeneration and waste energy recovery, and on the other side the energy transfer devices included in the building/client substation.

The implementation of the Euroheat&power boundaries to the analysed demo site set of technologies is presented in figure 1. As defined by the project objectives, the focus of the project is into the energy harvesting, storage, and conversion.
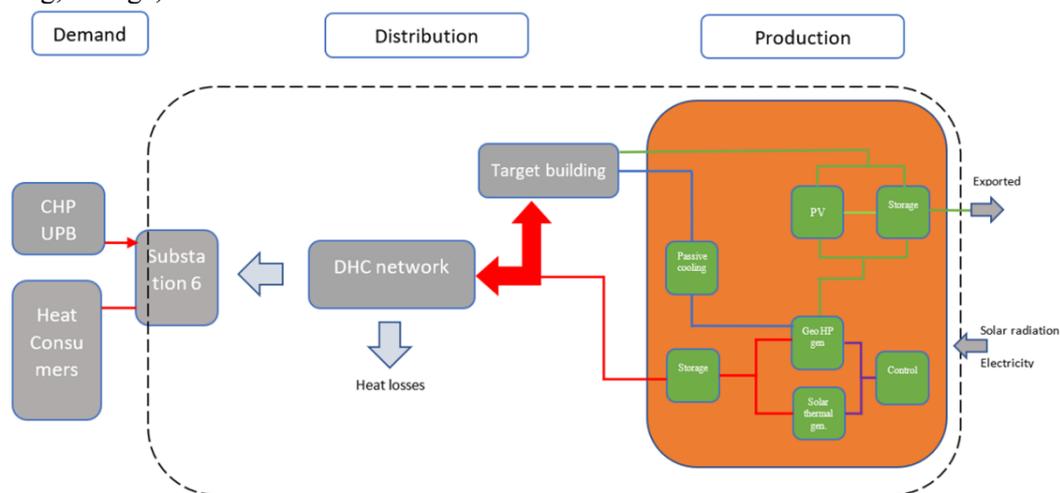

Figure 1. System analysis boundaries**.**

Within the national targets "Europe 2020" assumed by Romania on Energy and Climate Change, increasing energy efficiency is one of the three national priorities, along with reducing greenhouse gas emissions and increasing the share of energy produced from renewable sources in gross final consumption energy [8]. In this direction, the aim of the demonstration site is defined by the desire to carry out at the UPB a pilot project for the implementation of a hybrid solution based on renewable

sources to inject heat into the existing system. Hence, most of the technologies are included into the production block, comparable to the usual heat only (HOP) of combined heat and power plants (CHP). However, the project moves beyond the usual DHC approach, also including technologies for energy conversion at user side: photovoltaic panels (PV), hybrid photovoltaic and thermal panels (PVT), electrical energy storage (EES), thermal energy storage (TES) and , heat pumps (HP).

As clearly identified by the project objectives and stakeholders' interest, the evaluation requires defining KPIs at two levels: system (technological configuration) and technology. The system level is focused on monitoring the progress towards the project overarching objectives. In this terms, it considers the evaluation boundaries defined in figure 1 as a black box. That means it measures the performance of the integration of technologies considering the inputs and outputs from its borders. At the technology level, the goal is to provide parameters to evaluate the potential and capabilities of each proposed element, as well as its intended target goals. Therefore, the technologies are evaluated independently to the system, yet the measured parameters define its performance while operating within it.

3. Relevant KPIs for the analysed project

In order to achieve the proposed objectives, the approach of defining the performance indicators took into account the following criteria simultaneously:

- Time of determination: during the audit (initial assessment); as part of the feasibility study (for proposed schemes, based on them, the optimal scheme is selected); after implementation and will be monitored during the period of operation.
- Level of the evaluated contour (boundaries): KPIs (Tech) – for each technology (HP, PV, PVT, TES tank, EES battery); KPIs (Config) – for the technological configuration (system); KPIs (Building) – for building DEMO and KPIs (DH) – for the district heating system of UPB.
- Type of project impact: A. Energy, B. Economic and Financial, C. Environmental and D. Social. This criteria are minimal for all the analyzed KPIs and will determine the main type of the indicator.

3.1. KPIs (Tech) – for each technology (HP, PV, PVT, TES tank, EES battery).

They will be calculated as part of the feasibility study and after implementation and will be monitored during the period of operation. The classification is made for each main equipment of the demo configuration.

A. Related to the *Energy* impact, we can define the next KPIs:

For the geothermal heat pumps (HP), the first KPI that can be taken into consideration is the coefficient of performance (*COP*), representing the ratio of the heating capacity (*Q*) divided by the overall electricity consumption (*P*) under steady state conditions.

$$COP = \frac{Q_{HP}}{P_{HP}} \ [-] \tag{1}$$

The second important KPI is the seasonal performance factor (SPF), defined for different system boundaries and represents a ratio of the useful energy output to the overall useful energy input to the system within those boundaries.

$$SPF_{HP} = \frac{\int Q_{HP} \cdot dt}{\int P_{HP} \cdot dt} \ [-] \tag{2}$$

For the photovoltaic system (PV) we determined two main indicators: the operational time at nominal power (*T_SP*) and the specific roof surface (*A_SP*):

$$T_{SP} = \frac{E_{TP}}{P_{PV}} \ [\frac{h}{year}] \tag{3}$$

$$A_{sp} = \frac{A}{P_{PV}} \; [\frac{m^2}{kW}] \tag{4}$$

Where (E_{TP}) is the yearly energy production [kWh], (P_{PV})is the installed power of the photovoltaic system [kW] and A represents the area [m²] of the space where the system is placed.

Efficiency of the electrical storage is the main KPI of the electrical storage batteries and corresponds to the full cycle of charging (E_{IN})-discharging (E_{OUT}) the battery:

$$\eta_{EES} = \frac{E_{OUT}}{E_{IN}} \cdot 100 \; [\%] \tag{5}$$

Regarding the photovoltaic and thermal hybrid system (PVT), we established three main indicators: the thermal, electrical and overall efficiencies.

η_{th}- Thermal conversion efficiency can be defined as the useful heat (Q_u) related to the product between irradiance and the collector area:

$$\eta_{th} = \frac{Q_u}{G_{STC} \cdot A_c} \cdot 100 \; [\%] \tag{6}$$

η_{el}- Electrical conversion efficiency is the nominal power (P) at Standard test conditions (STC) divided by the product between irradiance and the collector area. (G) is the Irradiance measured in W/m², and Ac is the collector area measured in m². The nominal power depends on the Voltage (V) and the Current (I) both at STC:

$$\eta_{el} = \frac{P_{STC}}{G_{STC} \cdot A_C} \cdot 100 \; [\%] \tag{7}$$

$$P_{STC} = V_{STC} \cdot I_{STC} \; [kW] \tag{8}$$

η_{tot}- Overall PV/T efficiency defined as the sum between thermal and electrical efficiency:

$$\eta_{tot} = \eta_{th} + \eta_{el} \; [\%] \tag{9}$$

For the thermal energy storage (TES Tank) we highlighted four different KPIs:

DoD - The Depth of Discharge describes how deeply a TES tank can be discharged to provide usable energy (with respect to the reference conditions which it is designed for) without negatively affecting its proprieties:

$$DoD = \frac{C_T - C_{TUsMax}}{C_T} \; [\%] \tag{10}$$

Where (C_T) is the total capacity and C_{TUsMax} represents the maximum useful capacity, both expressed in kWh.

η_{tank} – Energy efficiency defined as the ratio between the heat released to the heat sink during discharging and the energy absorbed by the system during charging:

$$\eta_{tank} = \frac{C_T - C_{TUsMax}}{C_R} \cdot 100 \; [\%] \tag{11}$$

Where (C_R) represents recharging energy capacity, expressed in kWh.

η_c – Charging efficiency is the efficiency of the charging phase of the TES:

$$\eta_c = \frac{C_T \cdot DoD}{C_R} \cdot 100 \; [\%] \tag{12}$$

η_d –Discharging efficiency is the efficiency of the discharging period of the TES:

$$\eta_d = \frac{C_T - C_{tUsMax}}{C_T \cdot DoD} \cdot 100 \ [\%] \tag{13}$$

B. Related to the *Economic and Financial* impact, we can define the next KPIs*:*

CAPEX – Investment costs for implementing the technology configuration. The investments (*Inv*) needed to implement each technology –(*k*)- (HP, PV, PVT, TES tank, EES battery):

$$CAPEX_k = \Sigma \ Inv_k \ [\text{€}] \tag{14}$$

OPEX - Annual operational and maintenance costs being the sum of the annual maintenance and operation costs (*MO*cost) for each technology -*k*- (HP, PV, PVT, TES tank, EES battery):

$$OPEX_k = \Sigma \ MO_{cost,k} \ [\frac{\text{€}}{\text{year}}] \tag{15}$$

$C_{Sp,k}$ − Specific cost (*SP*) of energy production for each technology (HP, PV, PVT) is the cost of useful energy (C_{Ek}) produced by each technology related to the energy produced (E_k):

$$C_{Sp,k} = \frac{C_{Ek}}{E_k} \ [\frac{\text{€}}{kWh}] \tag{16}$$

$C_{Sp,EES}$ −Cost of Storage as a Service (*SaaS*) for electrical energy storage (*EES*) represents the cost of storing in a cycle of 1 kWh of energy:

$$C_{Sp,EES} = \frac{\left[\frac{C_{SS}}{N_{CYCLES}} + C_{EE}(1 - \eta_{EES})\right]}{E_{nom}} \ [\frac{\text{€}}{kWh}] \tag{17}$$

Where (C_{SS}) is the price for the whole storage system [€], (C_{EE}) represents the cost [€] of 1 kWh of electric energy, (η_{EES}) is the efficiency of EES, (N_{CYCLES}) is the number of charging-discharging cycles and E_{nom} is the nominal energy storage capacity [kWh].

Specific investment (*i*) for PVT/ PV technology is the capital cost of PVT/ PV technology (C_k) per square meter:

$$i = \frac{C_k}{A_{Ck}} \ [\frac{\text{€}}{m^2}] \tag{18}$$

Specific investment (*i*) for HP/TES/EES technology is the capital cost of HP/TES/EES technology per installed capacity (P_k):

$$i = \frac{C_k}{P_k} \ [\frac{\text{€}}{kW}] \tag{19}$$

$\eta_{E,PVT}$- Economical efficiency of PVT technology. The total cost of useful energy produced related to the total energy potential of the technology. In equation 19, E represents the energy in kWh (*th*-thermal or *el*-electric), (*C*) is the cost [€] of 1 kWh of energy, (*G*) is the irradiance measured in [W/m²], at Standard Test Conditions (*STC*), and (A_C), is the collector area, in [m²]

$$\eta_{E,PVT} = \frac{E_{th}C_{th} + E_{el}C_{el}}{G_{STC} \cdot A_C} \cdot 100 \ [\%] \tag{20}$$

$\eta_{E,PV}$- Economical efficiency of PV technology. The total cost of useful energy produced related to the total energy potential of the technology. All the intervening parameters were defined above:

$$\eta_{E,PV} = \frac{E_{el}C_{el}}{G_{STC} \cdot A_C} \cdot 100 \ [\%] \tag{21}$$

3.2. KPIs (Config) – for the technological configuration (system).
They will be calculated as part of the feasibility study and after implementation and will be monitored during the period of operation.

A. Related to the *Energy* impact, we can define the next KPIs:
$OPER_t$-Overall primary energy ratio for total thermal energy production in the system technologies configuration. It can be defined as the product of the overall efficiency of the thermal energy production from renewable sources (η_{RRt}) and the efficiency of the tank (η_{TES}).

$$OPER_t = \eta_{RRt} \cdot \eta_{TES}[\%] \tag{22}$$

where the overall efficiency of the thermal energy production from renewable sources, is:

$$\eta_{RRt} = Rt_{HP} \cdot \eta_{HP} + Rt_{PVT} \cdot \eta_{PVT} \tag{23}$$

The energy ratio of the total thermal demand, for Heat Pumps (HP) and for Photovoltaic and Thermal Panels (PVT), are defined in equations (24) and (25), as the ratio between the thermal energy (*Et_HP*) generated by HP, respectively by PVT (*Et_PVT*) and the total thermal energy (*E_t*), all types of energy being measured in kWh:

$$Rt_{HP} = \frac{Et_{HP}}{E_t}[\%] \tag{24}$$

$$Rt_{PVT} = \frac{Et_{PVT}}{E_t}[\%] \tag{25}$$

$OPER_e$-Overall primary energy ratio for total electrical energy production in the system technologies configuration that can be defined as the product of the overall efficiency of the production of electrical energy from renewable sources (η_{RRe}) and the efficiency of the storage batteries (η_{EES}).

$$OPER_e = \eta_{RRe} \cdot \eta_{EES}[\%] \tag{26}$$

Where the overall efficiency of the production of electrical energy from renewable sources is presented below:

$$\eta_{RRe} = Re_{PV} \cdot \eta_{PV} + Re_{PVT} \cdot \eta_{PVT}[\%] \tag{27}$$

With the following formula we can calculate the electrical energy ratio from renewable resources (*Re_PV/PVT*), defined as the ration between electrical energy generated (*Ee_PV/PVT*) by the renewable sources (PV/PVT) and the total electrical energy necessary for the target building (*E_e*):

$$Re_{PV} = \frac{Ee_{PV}}{E_e} \cdot 100 \, [\%] \tag{28}$$

$$Re_{PVT} = \frac{Ee_{PVT}}{E_e} \cdot 100 \, [\%] \tag{29}$$

R_{SS} −Self sufficiency ratio, represents, on a time period, the ratio between local produced energy (*E_k*) and local consumed energy (*E_HP*), in the technological configuration.

$$R_{SS} = \frac{E_k}{E_{HP}} \cdot 100 \, [\%] \tag{30}$$

Where *k* can be PV or PVT respectively.

B. Related to the *Economic and Financial* impact, we can define the next KPIs*:*
CAPEX − Investment costs for implementing the technology configuration, defined as the sum of the investments (*Inv*) needed to implement the technology configuration.

$$CAPEX = \Sigma \, Inv \; [\text{€}] \tag{31}$$

OPEX - Annual operational and maintenance costs is the sum of the annual maintenance and operation costs (*MO$_{cost}$*) for the technology configuration.

$$OPEX = \Sigma \, MO_{cost} \; [\frac{\text{€}}{\text{year}}] \tag{32}$$

GRT- Gross Payback Period, is the total investment related to the difference between total income (*IN*) and total expenditure (*Ex*).

$$GPP = \frac{Inv}{IN - Ex} \; [years] \tag{33}$$

Note: (*IN-Ex*) represents the expenditure savings generated annually after implementation of the new technological configuration.

NPV – Net Present Value, represents the algebraic sum of annual net present value over the lifetime (*n*- number of years), where (*a*) is the discount rate.

$$NPV = \sum_{k=1}^{n} \frac{(IN - Ex)_k - Inv_k}{(1 + a)^k} \tag{34}$$

C. Related to the *Environmental* impact, we can define the next KPI:

$ECO_{2_{tc}} -$ The annual amount of CO₂ emissions related to the technological configuration energy production (*E*) for both heat and electricity:

$$ECO_{2_{tc}} = \frac{ECO_{2_{total}}}{E} \; [\frac{\text{kgCO}_2}{\text{MWh}}] \tag{35}$$

3.3. KPIs (Building) – for building DEMO.

They will be calculated during the audit (initial assessment), as part of the feasibility study and after implementation and will be monitored during the period of operation [9].

A. Related to the *Energy* impact, we can define the next 9 KPIs:

$E_{Sp,H} -$Specific energy requirement for heating is defined as the thermal energy requirement for heating (*E$_H$*), related to the heated area (*A$_{heated}$*) and year:

$$E_{Sp,H} = \frac{E_H}{A_{heated} \cdot 8760} \; [\frac{KWh}{m^2 year}] \tag{36}$$

$E_{Sp,C} -$Specific energy requirement for cooling defined as the energy requirement for cooling (*E$_C$*), related to the cooled area (*A$_{cooled}$*) and year:

$$E_{Sp,C} = \frac{E_C}{A_{cooled} \cdot 8760} \; [\frac{KWh}{m^2 year}] \tag{37}$$

$E_{Sp,T} -$Specific thermal energy demand defined as the heating and cooling energy requirement, related to the heated and cooled areas (*A*), and year:

$$E_{Sp,T} = \frac{E_H + E_C}{A \cdot 8760} \; [\frac{KWh}{m^2 year}] \tag{38}$$

$E_{Sp,E} -$Specific electrical energy demand representing the total amount of electrical energy demand (*E$_e$*) per year:

$$E_{Sp,E} = \frac{E_e}{8760} \ [kWh/year] \tag{39}$$

The above Energy KPIs– are calculated only within the framework of the energy audit (for building), for the assessment of the initial situation. They could be modified afterwards, only if the building's needs are reduced by possible measures to increase energy efficiency prior to implementation of the proposed new energy supply solution.

$PEC_{Sp,H}$ −Specific primary energy consumption for heating described by the amount of fuel consumed to cover the heating requirements (PEC_H) expressed in energy units [kWh], related to the heated area (*A_heated*):

$$PEC_{Sp,H} = \frac{PEC_H}{A_{heated}} \ [kWh/m^2/year] \tag{40}$$

$PEC_{Sp,C}$ − Specific primary energy consumption for cooling defined as the amount of fuel consumed to cover the cooling requirements (PEC_C) expressed in energy units [kWh], related to the cooled area (*A_cooled*):

$$PEC_{Sp,C} = \frac{PEC_C}{A_{cooled}} \ [kWh/m^2 year] \tag{41}$$

$PEC_{Sp,T}$ − Specific primary energy consumption for thermal energy supply, identified as the amount of fuel consumed to cover the heating and cooling requirements (PEC_T) expressed in energy units [kWh], related to the heated and cooled areas, and year:

$$PEC_{Sp,T} = \frac{PEC_T}{A_{heated} + A_{cooled}} \ [kWh/m^2 year] \tag{42}$$

$PEC_{Sp,E}$ − Specific primary energy consumption for electricity supply. The amount of fuel consumed annually (PEC_E) to cover the related electricity needs (E_E):

$$PEC_{Sp,E} = \frac{PEC_E}{E_E} \ [kWh/year] \tag{43}$$

DRR_b −The degree of contribution of the renewable resources to the district heating. The amount of energy produced from renewable sources (E_{RS}), compared to the total amount of energy produced in order to ensure the energy needs of the building (E_{total}):

$$DRR_b = \frac{E_{RS}}{E_{total}} \cdot 100[\%] \tag{44}$$

B. Related to the *Economic and Financial* impact, we can define one important KPI*:*

$C_{Sp,T}$ − The specific cost of the energy consumed to cover the thermal energy demand, representing the ratio between the costs of all forms of the energy consumed (C_{energy}) and the thermal demand of the building (E_T):

$$C_{Sp,T} = \frac{C_{energy}}{E_T} \ [€/kWh] \tag{45}$$

C. Related to the *Environmental* impact, we can define the next KPI:

$ECO_{2,b}$ − Specific CO_2 emission. The amount of emissions to produce annual thermal and electrical energy ($Emission_{year}$), related to the surface of the building, (*A_b*):

$$ECO_{2,b} = \frac{Emission_{year}}{A_b} \left[\frac{kgCO_2}{m^2 year}\right]$$ (46)

D. Related to the *Social* impact, we can define the next KPI:

$D_{s,o}$ − Degree of satisfaction of the occupants of the building. Number of satisfied occupants of the building (N_s), related to the total number of permanent occupants (N):

$$D_{s,o} = \frac{N_s}{N} [\%]$$ (47)

3.4. KPIs (DH) – for the district heating system of UPB.

They will be calculated during the audit (initial assessment), as part of the feasibility study and after implementation and will be monitored during the period of operation. The classification was focused only on the energy type of indicators and highlighted 2 KPIs.

A. Related to the Energy impact, we can define the next 2 KPIs:

η_{DH} − Global efficiency of district heating which represents the product between the efficiency of production (η_{prod}), transport and distribution ($\eta_{network}$), conversion ($\eta_{thermal\_substation}$) and the final consumption of energy ($\eta_{building}$):

$$\eta_{DH} = \eta_{prod} \cdot \eta_{network} \cdot \eta_{thermal\_substation} \cdot \eta_{building}$$ (48)

DRR_{DH} −The degree of contribution of the renewable resources to the district heating. The energy injected into DH from renewable resources ($E_{DH_{RS}}$), related to the total thermal energy supplied in DH (E_{DH}):

$$DRR_{DH} = \frac{E_{DH_{RS}}}{E_{DH}} \cdot 100 [\%]$$ (49)

4. **Interpretation and conclusions**

The system boundaries were modified according to the technological configuration for Bucharest Demo (Figure 1), where the boundaries were specified according to the KPI's definitions which characterize the specific conditions for both present and future situation (after the project implementation).

Energy performance indicators (eg. *OPER, COP, η, E_{SP}, CEP_{SP}, DDR_b*) defined at different levels of reference framework, from simple to complex: equipment-configuration scheme - centralized power supply system, allow the selection of the most efficient equipment, in terms of energy but also the optimal integration for the achievement of the proposed objectives by implementing the new energy supply system of the building, and its integration in the existing district heating system. The optimal combination of equipment - components of the scheme, leads to the realization of operating regimes, that will be quantified both in terms of energy, but also in terms of environmental impact (eg. *ECO₂*) and social impact (eg. *D_{S,O}*).

Thus, the energy performance indicators have the determining role in the pre-investment stage, namely in the feasibility study, they are representing the key elements in the configuration of the new solution. The decisional factor regarding the optimal solution of thermal energy supply adopted, considering both the energetic and the environmental elements, is represented by the economic-financial performance indicators (eg. *NPV, GPP*).

Practically, both in the pre-investment stages of the project, but also later in its exploitation, an essential role belongs to the KPIs (from the mentioned categories), starting from the evaluation phase of the existing situation (by preparing the energy audit), selecting the optimal solution (feasibility), execution of assembly works and monitoring of its operation (after commissioning).

The key performance indicators (regardless of the defined typologies) represent practically the barometer of the energetic, ecological, social and economic effects of the project implementation, the final decision being practically conditioned by their definition, determination, and monitoring.

The objective of this paper was to identify the most representative KPIs (of all the categories mentioned in the article) on the basis of which to carry out an efficient monitoring of the project implementation, in all phases: pre-investment, investment and exploitation. The actual calculation of the indicators was not the main objective of this work, considering the fact that in the development of the project so far, only the stages of the pre-investment phase have been covered, namely the energy audit and the feasibility study.

The evaluation of the initial situation was made, based on the energy audit, the phase in which the indicators of energy efficiency and impact on the environment were determined (on different levels of contours defined in the article: building, overall scheme, DH).

In the feasibility study, two solutions for the production of thermal energy imposed by the consumer were comparatively analysed, both using renewable sources (the main objective of the project), namely: Hybrid geothermal-solar system and Trigeneration that uses biomass. Based on calculation of economic indicators (*NPV, PP, IRR*) for the entire project life cycle (20 years), their role being decisive, it was selected as the optimal solution the hybrid geothermal-solar system. For example, the calculated values are presented in table 1.

Table 1. Results of the economic analysis of the two solutions.

Economic KPIs	Hybrid geothermal-solar system	Trigeneration on biomass
NPV (Euro)	140 877	-731 671
PP (years)	4	>life span
IRR (%)	27.07%	Beyond limits

The financing conditions (non-reimbursable co-financing from European funds) and other hypotheses within the compared solutions were similar for both.

For example, the values calculated for two energy and environmental performance indicators determined in the audit stages and in the feasibility study can be presented, and will be monitored at the commissioning of the project and during its operation. The determined values are presented in table 2.

Table 2. Results of the economic analysis of the two solutions.

KPIs	Reference case	New solution
ECO$_2$ (kg/(m^2 year))	59.92	0
DRR (-)	0	1

As data may be not available full time (research TRL5-7 project, not using only TRL9 components), gaps in data recording may occur. In these situations, averaging, interpolation, comparison and other methods will be used for covering missing data, in order to calculate with best trust, the longer term KPIs calculations.

Other KPIs, derivate from these KPIs and changes of the KPI meaning may be considered during the development and use of the system developed in the project, based on various inputs and on implemented technology.

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