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Integrating National Research
Agendas on Solar Heat for Industrial Processes

Project Deliverable 5.6: Key design strategies for hybridization concepts

D 5.6 –KEY DESIGN STRATEGIES FOR HYBRIDIZATION CONCEPTS	
WP	**5**
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HISTORY		
Authors: Ahmed J. Tahir, Carles Ribas, Elena Guillén	Date: 18 January 2021 (v1) Date: 10 March 2021 (v2)	Comments: v1 had to be modified due to confidentiality issues

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Contents

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1. Content of deliverable

This deliverable describes the key design strategies of some of the hybrid examples already presented in DL 5.4 and together with new examples of proposed hybrid concepts (i.e.: Waste heat, HP, CSP, PV, storage, etc.) for heat industrial demand.

The final **objective** is to identify and evaluate, based on technical, exegetical and economical KPIs, some **optimized combinations of renewable technologies** to cover the **industrial process heat demand** developed in other projects.

The DL contains 3 different industrial examples on which the **methodology approach is described**. A small overview of the industry is given and then specific **design strategies/criterium for the selection of the hybrid system components are provided**. These are mainly related to the source and quality of the energy supply required and the specific thermal and electrical load (which is also provided for each example). In section 3 the proposed optimized hybrid systems are discussed. Finally, in section 3.2, the proposed KPIs for the overall system and optimization are explained and discussed.

2 of the companies have been audited by AEE INTEC, while one company has been analyzed by an external project partner within the Austrian project “CORES” coordinated by AEE INTEC. All three audits, respectively the company data is confidential and therefore not part of this deliverable.

2. Industrial systems analyzed

2.1. System 1 – fruit industry

This case study deals with the operation and preparation of fruits, including cooling, deep-freezing, mixing and pasteurization. There is also a hot water demand for cleaning.

2.1.1. Design strategies/criterium for the selection of the hybrid system components

The thermal energy demand is covered by a gas-supplied steam boiler. The plot of monthly consumption shows that **energy consumption is relatively constant throughout the year**, despite the additional heat demand of the heating system in winter. Electricity is supplied from the grid.

2.2. System 2 – milk processing

This case study deals with the processing of milk for the production of milk, cream and cheese. Most of the energy relevant processes for this sector are typically batch processes. The delivery of milk is followed by the pasteurization process and storage. Either it is processed to milk and cream (cooling and heating) or to cheese including fermentation, whey processing, cooling. Additional cleaning processes take place.

2.2.1. Design strategies/criterium for the selection of the hybrid system components

The thermal energy demand is covered by a gas-supplied boiler. The monthly consumption shows that **energy (gas) consumption, losses and heat recovery are relatively constant throughout the year.** There is also an important **electrical demand** having a constant **basic load component** and a **variable component** which is also **quite stable** throughout the year.

2.3. System 3 – building materials

This use case is a European producer of raw materials, building materials and tiles. The production steps are mainly drying and heating.

2.3.1. Design strategies/criterium for the selection of the hybrid system components

A remarkable fact about this case study is that the temperature levels are considerably higher than in the other examples.

3. Proposed Hybrid Systems

The following schemes and concepts have been developed and further detailed within the Austrian research project "CORES", funded by the Austrian Climate and Energy Fund and carried out as part of the Energy Research Programme 2018.

General hybrid systems for heat supply are proposed for the industrial processes and analyzed in the following section. The simulation and evaluation of the suitability of these schemes for the real industrial cases here showed, is out of the scope of this DL. The objective of this DL is **to present the strategies followed to propose these hybrid systems. These strategies are based on the following key points:**

- **Temperature** of the industrial production processes. All the production processes are sub-divided into **three different temperature levels** and the **thermal energy demand** at these temperature levels are provided by the hybrid energy systems.
- **Load profiles** of the industrial processes to ensure the flexibility, stability, reliability of the supplied energy from the hybrid systems.
- **Availability and volatility of the renewable resources** e.g., solar energy and waste heat potential.
- **Market availability**, **maturity** and **techno-economic** performances of the energy supplying utilities.

Based on these design strategies, series of hybrid system concepts for energy supply are proposed. **These concepts are not limited to any one of the aforementioned case studies** but will be further simulated and evaluated for all industrial cases **based on the KPIs (defined in section 2.5)**.

This DL does not contain the simulation and evaluation of the industrial cases but it shows **the hybrid concepts proposed** and the **KPIs** upon which the evaluation can be performed.

3.1.1. Hybrid systems proposed

The hybrid systems consist of **solar thermal**, **photovoltaics** and **heat pumps** as energy supply technologies to industrial processes at three different temperature levels. Storages and auxiliary energy supply units are also considered in this system. **To match the supply energy from the solar thermal system with the temperature levels** of the production processes, the heat pumps can either be arranged as parallel or in series configurations. The boundary conditions of the hybrid systems proposed are:

- To supply heat only
- Maximum temperature level is ~150ºC
- PV is only used to supply power to the HP, not the industry

3.1.1.1. Hybrid Systems 1 and 2

Hybrid System 1 consisting of solar thermal, photovoltaic and heat pumps in series configuration and system 2 in parallel configuration

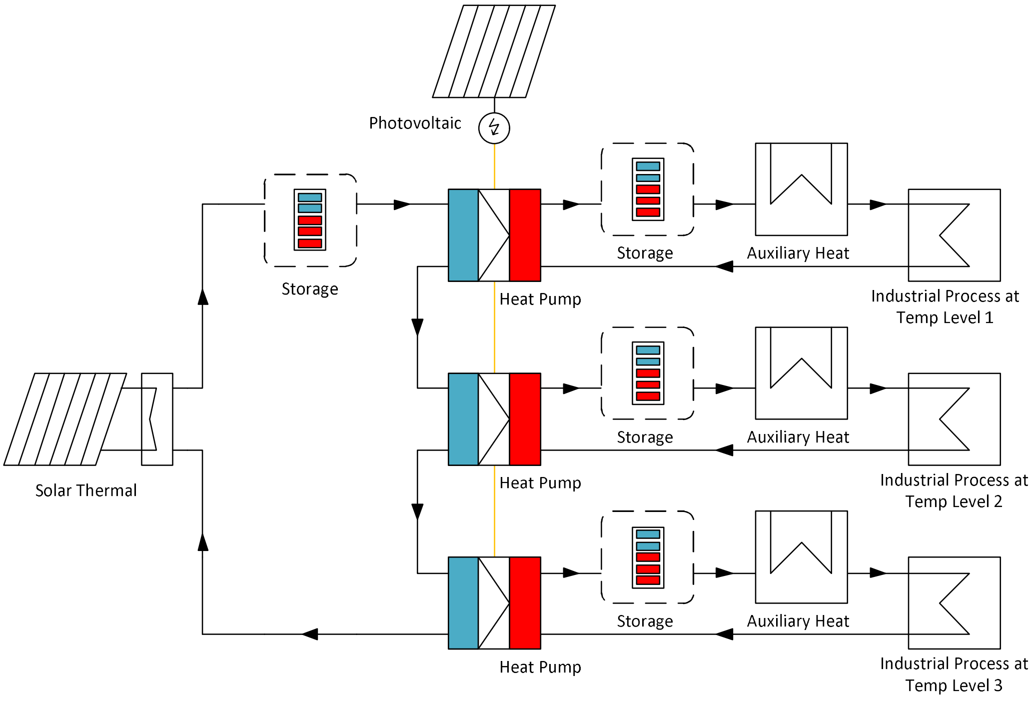

Figure 1: Hybrid System 1 consisting of solar thermal, photovoltaic and heat pump as energy supply utilities. Heat pumps in this hybrid system are in series configuration (developed and designed by D.Seliger - TU Wien, Institute for Energy Systems and Thermodynamics (IET), S.Dusek - Austrian Institute of Technology GmbH, Sustainable Thermal Energy Systems, A.Tahir & C.Ribas Tugores – AEE INTEC, within the project CORES)

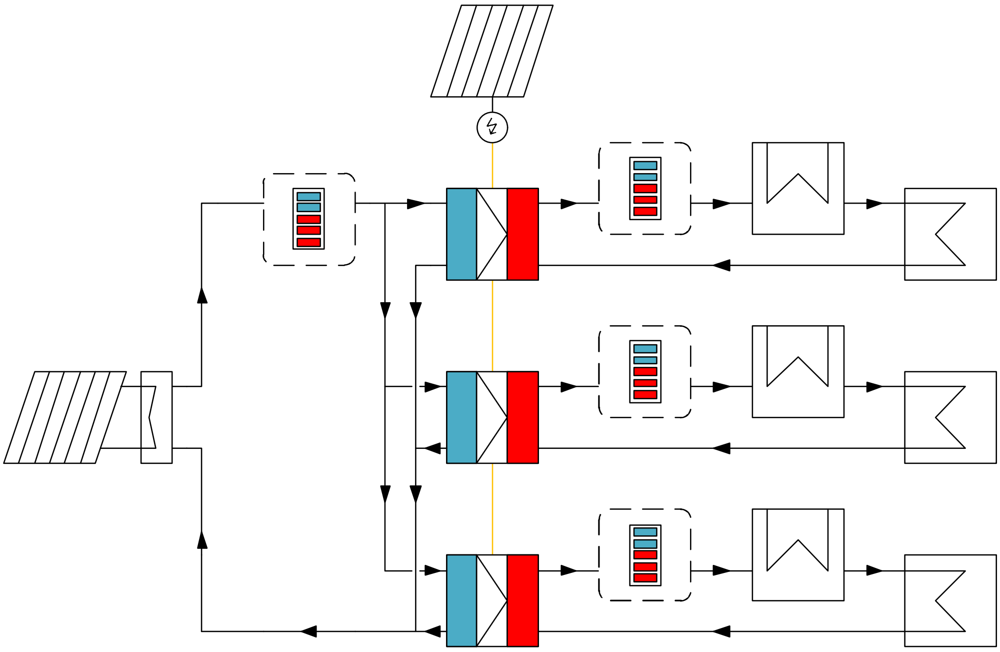

Figure 2: Hybrid System 2 in parallel configuration (developed and designed by D.Seliger - TU Wien, Institute for Energy Systems and Thermodynamics (IET), S.Dusek - Austrian Institute of Technology GmbH, Sustainable Thermal Energy Systems, A.Tahir & C.Ribas Tugores – AEE INTEC, within the project CORES

3.1.1.2. Hybrid System 3

Hybrid System 3 consisting of **photovoltaic-thermal (PVT)**, **photovoltaic** (PV) and **heat pumps** (series or parallel configuration)

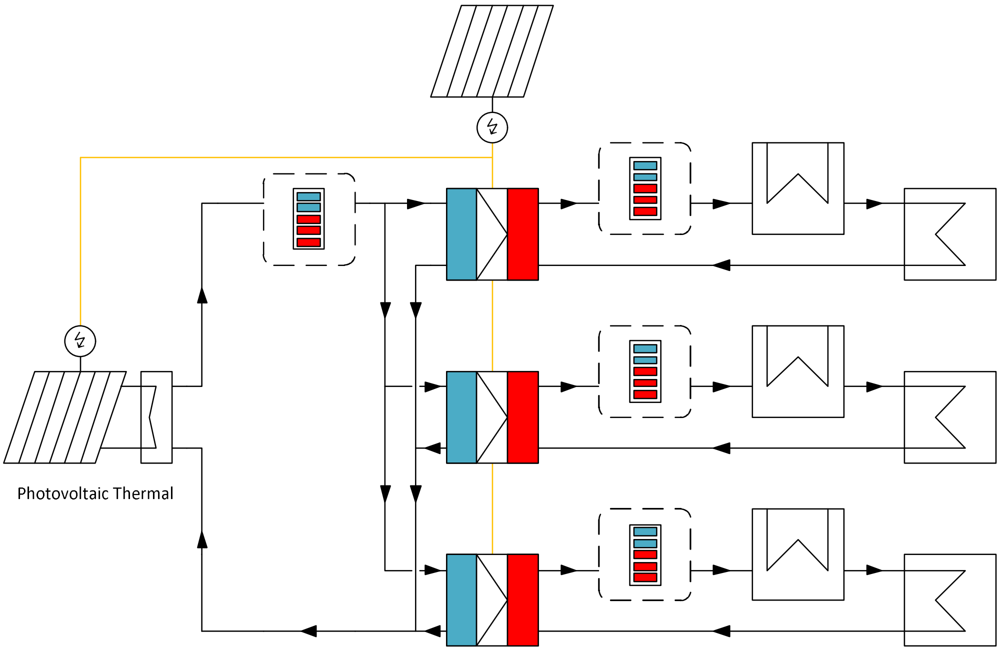

Figure 3: Hybrid System 3 consisting of excess heat recovery, photovoltaic and heat pumps as energy supply utilities. Heat pumps in this hybrid system can either be in series or parallel configuration (developed and designed by D.Seliger - TU Wien, Institute for Energy Systems and Thermodynamics (IET), S.Dusek - Austrian Institute of Technology GmbH, Sustainable Thermal Energy Systems, A.Tahir & C.Ribas Tugores – AEE INTEC, within the project CORES

3.1.1.3. Hybrid Systems 4 and 5

Hybrid Systems 4 and 5 consisting of **excess heat recovery**, **photovoltaic** and **heat pumps** (in series or parallel configuration). **System 5** contains a variation: depending on the temperature level of the industrial processes and the excess heat, the arrangement of the solar thermal and heat recovery utilities can be reversed.

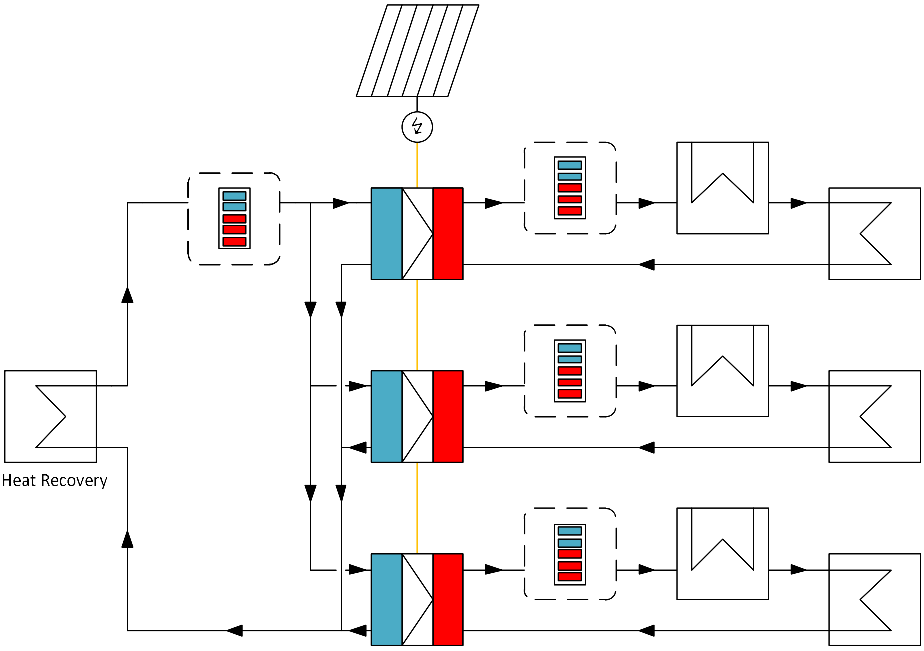

Figure 4: Hybrid System 4 consisting of excess heat recovery, photovoltaic and heat pumps as energy supply utilities. Heat pumps in this hybrid system can either be in series or parallel configuration (developed and designed by D.Seliger - TU Wien, Institute for Energy Systems and Thermodynamics (IET), S.Dusek - Austrian Institute of Technology GmbH, Sustainable Thermal Energy Systems, A.Tahir & C.Ribas Tugores – AEE INTEC, within the project CORES

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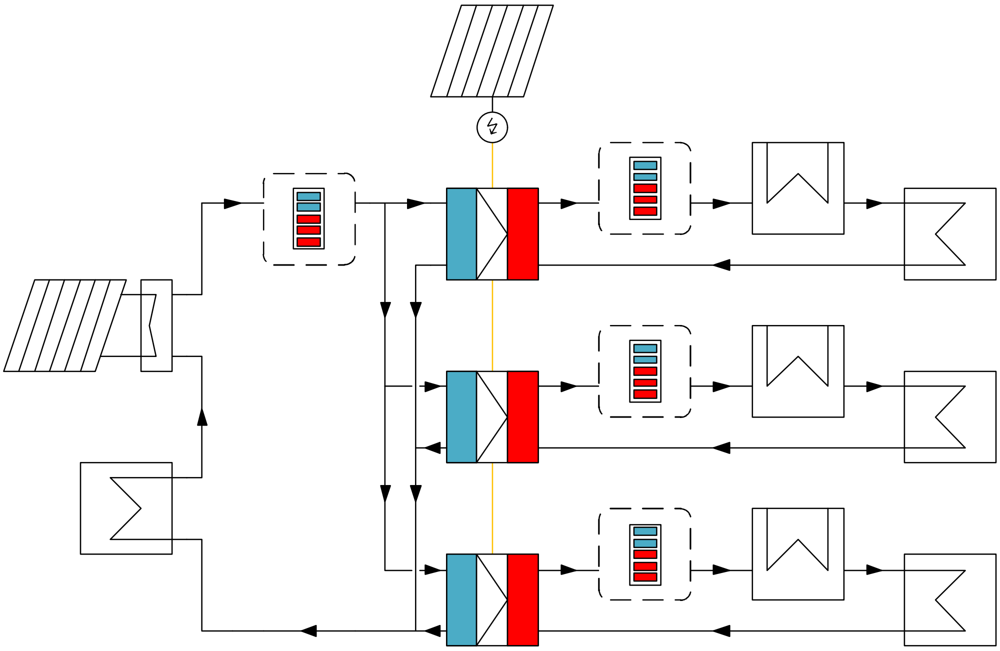

Figure 5: Hybrid System 5 consisting of solar thermal, excess heat recovery, photovoltaic and heat pumps as energy supply utilities. Heat pumps in this hybrid system can either be in series or parallel configuration. Variation: Depending on the temperature level of the industrial processes and the excess heat, the arrangement of the solar thermal and heat recovery utilities can be reversed (developed and designed by D.Seliger - TU Wien, Institute for Energy Systems and Thermodynamics (IET), S.Dusek - Austrian Institute of Technology GmbH, Sustainable Thermal Energy Systems, A.Tahir & C.Ribas Tugores – AEE INTEC, within the project CORES

3.1.1.4. Hybrid System 6

Hybrid System 6 consisting of **photovoltaic-thermal, excess heat recovery, photovoltaic and heat pumps** (in series or parallel configuration). Also, **depending on the temperature level** of the industrial processes and the excess heat, the arrangement of the photovoltaic-thermal and heat recovery utilities can be reversed.

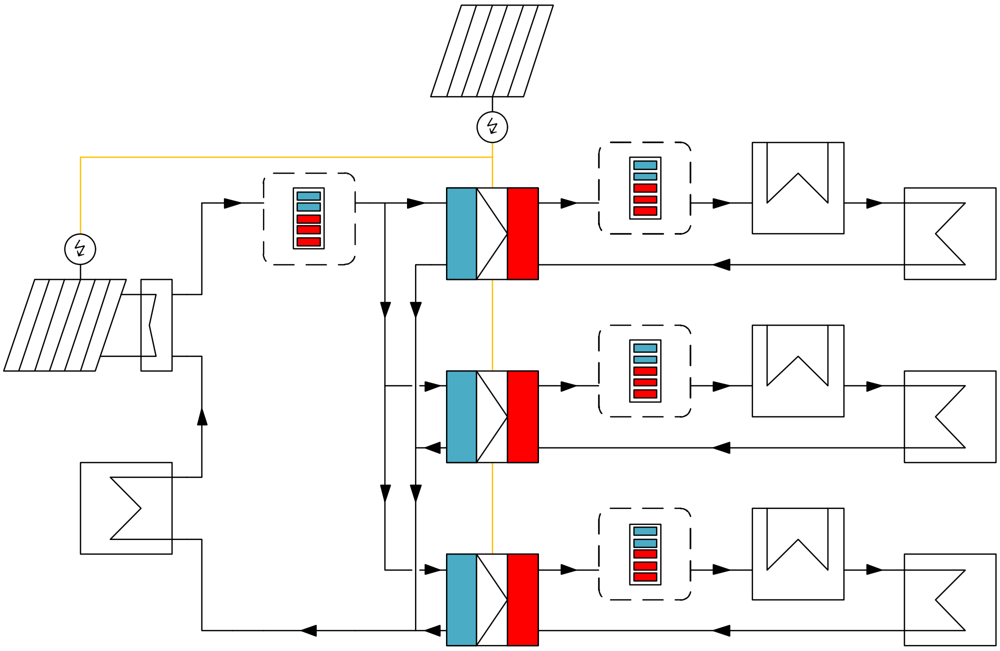

Figure 6: Hybrid System 6 consisting of photovoltaic-thermal, excess heat recovery, photovoltaic and heat pumps as energy supply utilities. Heat pumps in this hybrid system can either be in series or parallel configuration. Variation: Depending on the temperature level of the industrial processes and the excess heat, the arrangement of the photovoltaic-thermal and heat recovery utilities can be reversed (developed and designed by D.Seliger - TU Wien, Institute for Energy Systems and Thermodynamics (IET), S.Dusek - Austrian Institute of Technology GmbH, Sustainable Thermal Energy Systems, A.Tahir & C.Ribas Tugores – AEE INTEC, within the project CORES

3.2. KPIs

To evaluate the technical and economic performance of the above-mentioned hybridization systems, the following KPIs are proposed. These are divided in technological KPIs (KPIs that can be applied to specific components or subsystems) and system KPIs (KPIs that are to be applied for the whole installation. Notice that some of the system KPIs could be also calculated for subsystems).

Technological KPIs

3.2.1. Specific solar yield

The specific solar yield, defined as energy delivered by the solar system in kWh per collector area in m^2, can be used to assess the operation of a PV, solar thermal or hybrid solar plant. To calculate this KPI it is important to first clearly the subsystem being considered. The common approach in the case of a solar thermal systems is to consider the main solar field (solar collectors, piping and main heat exchanger). The thermal heat storage (if any) can also be considered, this is not always done, especially in the case the heat thermal energy storage is shared with other units (e.g., boilers).

3.2.1. Solar fraction

Defined as the share of the yearly energy demand covered by solar energy.

3.2.2. Coefficient of performance - COP

The COP of a heat pump, defined as the useful energy (heating and/or cooling energy) divided by the effort (electric consumption).

3.2.3. Storage cycles

The storage cycles are especially meaningful for thermal energy storages. It is defined as the amount of energy discharged divided by the energy capacity of the storage.

3.2.4. Storage efficiency

It is defined as the ratio between discharged and charged energy. It is mainly affected by the energy losses during the charging, storing and discharging phases of a storage.

3.2.1. Full operating hours

Especially interesting for dispatchable energy production units (e.g., boilers, heat pumps), which degree of use can be evaluated by looking at the number of full operating hours. This is defined as the amount of energy produced divided by the nominal capacity of the unit considered.

System KPIs

3.2.2. Surface needed

The amount of area needed for the technical solution is indeed a relevant KPI, especially for solar technologies. It is common to distinguish between the type of areas used. E.g., between façade, roof or ground areas.

3.2.3. Levelized Cost of Heat

The techno-economic approach is usually based on the estimation of the Levelized Cost of Energy (LCOE). This is a widely used figure for estimating the average cost of electric power generation over the lifetime of power plants. This indicator is quite well documented and brings transparent results, which can be explained by a clear statement of the assumptions. Furthermore, the LCOE can be applied to several types of technologies and it can be handled in complexity by including different levels of details. When the heat generation is considered, the Levelized Cost of Heat (LCOH) is calculated. The formula shown below is applied to each selected technology:

$$LCOH = \frac{\sum_{t=1}^{n}[(CAPEX_t + \ OPEX_t + \ Fuel_t) * (1+r)^{-t}]}{\sum_{t=1}^{n} Q_{th} * \ (1+r)^{-t}}$$

The investment ($CAPEX$), operation and maintenance ($OPEX$) and fuel costs are estimated on an annual basis through the economic lifetime n of the technologies. These costs are averaged on the corresponding heat generation Q_{th}. The discount rate r is assumed as a constant parameter. When different technologies are combined within the same system, the overall $LCOH$ should be calculated as the weighted sum based on the contribution of each option.

3.2.4. Payback period

In case of an existing system is refurbished, the payback period will indicate how much time is needed to recover the initial investment (we are assuming that the new system will have lower operating and maintenances costs than the existing system). It can be calculated by dividing the initial investment in Euro by the yearly savings in Euro/a.

3.2.5. Long-term economic evaluation

A long-term economic evaluation consists in the consideration of the yearly costs over a long period of time and the calculation of the accumulated costs. It is important to consider all relevant costs (initial investment, annuity of the necessary loan, operating and maintenance costs, fuel costs). Cash inflows can also be considered (if any). In regard of the cash inflows only those coming from energy/fuel cells are to be considered (e.g., feed in into the grid). A good approach is to calculate the net present value (NPV),

$$NPV = \sum_{t=1}^{n} \frac{C_{in,t} - C_{out,t}}{(1+i)^t} - I_0$$

Where $C_{in,t}$ and $C_{out,t}$ are the yearly cash inflows and outflows respectively, i is in the discount rate, I_0 is the initial investment, t the period (year) and n the timeframe considered (e.g., 20 years).

3.2.6. CO_2 Emissions

As environmental indicator, the CO_2 emissions associated with the fuels are estimated by using pre-calculated emission factors on the primary energy consumption.

3.2.7. Primary and final energy consumption

The primary energy consumption (PE) is directly associated with the cost of operation of heat and power, and with the CO_2 emissions, depending on the type of fuel that it is used. Peak PE consumption is responsible for higher costs and CO_2 emissions due to the type of technologies operated to cover the peaks. The final energy consumption, as a performance indicator, helps to analyze the impact on the consumer side.

3.2.8. Share of renewables

It represents the share of energy produced by renewable energy sources out of the total energy produced. Notice that Internal use of waste heat is in general not to be considered since it is already been produced from one of the main energy production units (or grid). How waste heat from an external source or energy from a grid have to be considered is case dependent.

3.2.9. Flexibility and stability of the supplied energy

The flexibility and stability factor of a hybrid system is here defined as the share of the installed heat capacity of dispatchable sources and the peak energy demand. Renewables are mostly non-dispatchable sources and are thus often combined with energy storage solutions. The flexibility and stability factor can be calculated twice, without taking into account the storage capacity and accounting a portion of it.

3.2.10. Autarky degree

Indicates the degree of self-sufficiency. We calculate it based on the energy produced by the different energy production units, dividing the self-production by the total energy produced/imported. Notice that the autarky degree can be calculated in a rigorous way, where energy from external sources in any form (i.e., including fuel import) are considered extern and a soft approach where energy locally produced (even if influenced by external fuel supply) is considered part of the self-produced amount.

4. Conclusion

It is almost mandatory that in order to achieve a high degree of decarbonization and increase the presence of REs in the supply system of industries, **hybrid concepts are needed**. This DL has shown the methodology and basic strategies that AEE INTEC and the project partner follow within the project CORES to propose hybrid concepts to supply the industries with process heat.

Overall, the guidelines of this methodology can be summarized in the following points:

- **Combining advantages of single technologies** and reduce disadvantages
- Come up with hybridization **strategies** based on **global system goals: including design and operation and include optimization.**
- Address those system goals through the **evaluation of technological specific KPIs**

Regarding the technical strategies for planning hybrid systems, they have to be based on the following point and evaluated through the corresponding KPIs (provided in this DL)

- **Matching the temperature** and **thermal energy demand** of the industrial processes.
- **Ensuring** flexibility, stability, reliability when supplying **the load profiles** of the industrial processes.
- **Assess and foresee solutions for the availability and volatility of the renewable resources**
- **Evaluate the market availability**, **maturity** and **techno-economic** performances of the energy supplying utilities.

In pursuing this decarbonization and optimization of very complex systems like hybrid systems **digitalisation is a powerful and necessary tool** and more effort and research in this field this end is needed.

5. Degree of progress

The deliverable has been finished on-time without any major delays. However, the first version of the DL submitted in Jan 2021 had to be modified due to some confidentiality concerns from the industrial data shared in it. This last version (v2) was then submitted in March 2021.

6. Dissemination

No dissemination activities within the INSHIP consortium are foreseen since most of the data within this task and DL belong to real companies.