SHIP2FAIR - Best practices guide

Deliverable 7.5
WP7. T7.4

SHIP2FAIR - Solar Heat for Industrial Process towards Food and Agro Industries commitment in Renewables

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ABREVIATIONS

ETC: Evacuated tube collector
FPC: Flat plate collector
GHG: Greenhouse gas
HVFPC: High vacuum flat plate collector
SHIP: Solar Heat for Industrial Processes
LCOH: Levelized cost of Heat
LCOE: Levelized cost of Energy
PBT: Pay Back Time
LFR: Linear Fresnel Reflector
ESCO: Energy Supplier Company
PLC: Programmable Logic Controller
MPC: Model Predictive Controller
KPI: Key Performance Indicator
ICT: Information and communication technologies
GUI: Graphical User Interface
HMI: Human Machine Interface
BoP: Balance of Plant

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PUBLISHABLE SUMMARY

This document is a list of lessons learnt during the SHIP2FAIR project. It is a synthesis of best practices and recommendations. It aims to become a guide for supporting any stakeholder (technology providers, ESCO, plant owners, engineering companies among others) interested in building a project on solar heat integration in the industrial processes addressed in the use cases.

The SHIP (Solar Heat for Industrial Processes) guide develops all the necessary steps to develop a SHIP project and maximize its benefits in the less possible complex way.

This document gives tip for the 2 mains phases of a project:

- The feasibility studies
- The onsite building

In the feasibility studies, we presented the lessons learnt from the 10 uses cases studied using the replication tool. We also presented the economical feasibility of a SHIP project. In this section we presented the average cost of the Solar Thermal energy versus the price of natural gas and electricity. Solar Thermal energy is very competitive. We also explained the different incentives and business model possible. During the project, we enlighten the very important aspect of the control strategy. This aspect should be addressed from the beginning of the project. We explained the different level of control possible for optimizing the integration of solar energy in the existing process.

The lessons learnt from the on-site building give precious recommendations about the preparatory phase. This preparatory phase is very important to avoid misunderstanding between the end user and the techno provider. The detailed engineering is also a very important aspect; it is the key point of a successful project. The connection point, the functioning modes, the temperature setting point and the local environment should be addressed with a particular attention. In this section, we also addressed the lessons learnt from the control strategy applied. Once the technical specifications have been settled, the procurement and installation phase can start. This phase must be as short as possible. For that, we gave some recommendation regarding the component procurement, the factory pre-assembly and the logistic. The more the preparation phase is meticulous, less the impact on-site on the industrial process will be. After the on-site installation, the next phase is the commissioning. For this phase, we gave some very useful tips. This phase is also a way to check that the plant has reached the expected performances.

Finally, when the solar thermal plant has been commissioned, the maintenance phase is the last phase of the project. The maintenance should continue through the lifelong of the plant and a good maintenance is necessary to guaranty the long-term performance and life of the plant.

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1 Introduction

Taking into account both the results extracted from the methodologies developed in WP3 to WP5 and the commissioning and demonstration activities, a list of lessons learnt during the project has been developed and synthetized in a guide with best practices and recommendations.

This document aims to become a guide for supporting any stakeholder (like technology providers, energy companies, plant owners and engineering companies among others) interested in building a project on solar heat integration in the industrial processes addressed in the use cases. It provides all the necessary steps to develop a SHIP project and maximize its benefits in the less possible complex way, supposing as well a key tool for the project results replication among the EU solar heat spheres.

This document relates the 2 mains phases of a project:

- The feasibility study
- The onsite building

The lessons learnt from the feasibility studies give some insights about how to conduct a techno-economic study. It gives also an overview of some studies performed in the frame of SHIP2FAIR project. A specific attention should be paid on the solar integration in the existing process and the control of the solar production is a key factor. A specific chapter is dedicated on this topic.

The lessons learnt from the on-site building give precious recommendations about the detailed engineering, the best control strategy, the on-site building and commissioning, the performance achieved and the maintenance.

2 Lessons Learnt from Feasibility Studies

2.1 Replication Feasibility

2.1.1 Technical Feasibility

In the context of the Ship2Fair project, and specifically in Task 8.4, ten replication studies have been carried out using the Ship2Fair Replication Tool, to evaluate the technical and financial feasibility of the installation of solar thermal solutions in ten industrial sites external to the Ship2Fair consortium.

In addition to providing useful inputs to the beneficiary companies potentially willing to invest in the installation of this kind of plants, the realization of the replication studies has contributed to the creation of knowledge regarding the use of the Ship2Fair Replication Tool and the procedures required to carry out a good feasibility study for the implementation of solar thermal solutions in various industrial sectors.

This paragraph summarizes the main lessons learnt regarding the procedures for realizing a good feasibility study, with a focus on the experience developed in the use of the Ship2Fair Replication Tool. However, the key actions to be taken and the key data to be collected remain the same even in case the feasibility study is carried out in a more conventional way, based on self-constructed calculation sheets, e.g. built on Microsoft Excel®.

Considering that the key parameters and algorithms for the evaluation of the technical and financial feasibility of the solution under analysis do not need to be collected for each feasibility study, since they generally do not change from a site to another and, in case of use of the Ship2Fair Replication

Tool they are embedded in the tool itself (although they can be edited from the final user if needed), it is clear that the main data to be collected are related to the site under analysis.

The data to be collected are related to:

- geographical and spatial information about the site, including:
  - latitude and longitude – required to evaluate the solar radiation data from available databases;
  - rooftop or other surface availability in terms of area, orientation, slope and presence of shadow – needed to identify the size of the plant and to quantify the actually producible energy starting from the theoretically available solar resource;
- characterization of the energy demand of the site in the baseline situation, including:
  - annual/monthly demand of all energy carriers used for the production of thermal energy in the plant (natural gas, diesel, other fuels, electricity), needed to quantify the annual input energy to the plant for heating purposes;
  - list and characteristics (power, efficiency) of thermal energy related equipment (e.g. boilers, heat pumps, etc.), required to evaluate the useful thermal demand associated to the energy input to the site in form of fuels or electricity;
  - list and characteristics of heat demanding processes carried out in the site, with for each process, indication of the annual heat demand (as a percentage of the total annual heat demand of the site), of the thermal energy carrier type (e.g. steam, pressurized water, water, air, etc.) and typical temperature range, of the equipment used for its production and of the typical daily, weekly and annual production schedule; this is required to build the hourly trend of thermal energy demand in different forms and at different temperature levels, needed to identify the most suitable size of the solar thermal plant and of the related thermal energy storage;
- economic parameters related to the price of energy carriers used in the plant, required to evaluate the financial viability of the solar thermal solutions as a replacement of the existing technologies.

Based on the experience developed in the execution of the feasibility studies using the Ship2Fair Replication Tool, most of these data can be easily retrieved by companies having already carried out an energy audit, either following the requirements of Art. 8 of the EU Energy Efficiency Directive or within a voluntary scheme, or by those already having an energy manager or an energy management team within the technical/maintenance department. The most difficult information to be retrieved is the one related to the typical daily, weekly and annual production schedule for each process realized in the site, since these data can only be estimated with a low level of accuracy in case the site is not equipped with a sub-metering system covering also thermal aspects, which is an issue encountered quite often especially in small and medium industrial companies.

2.1.2 Economical feasibility

Solar thermal is already the most cost competitive renewable way of providing heat for several applications.

The market analysis has enlighten many assets of SHIP as of today. The branches mainly covered with solar heat worldwide are mining, agriculture, food & beverage, textile and chemical. Food and beverage industry have an important number of installations in comparison to others, but relatively lower capacity installed. During the last 15 years, in Europe, the power installed associated with SHIP projects for the food and beverage industry shows an ascending trend. The reduction of costs enabled through economies of scale gave a push in the right direction. Solar thermal has today competitive

Levelised Cost of Energy (LCOE) (for South and Central Europe, 0.04-0.11 EUR/kWh based on IRENA report) in comparison to fossil fuels. According to the European project SO-PRO, very low-temperature solar thermal applications had an average LCOE of 0.02-0.05 EUR/kWh in 2010, and medium-temperature systems would have an LCOE of 0.05-0.15 EUR/kWh in 2010. The LCOE for large and small solar thermal is forecasted to range between 0.03-0.04 EUR/kWh in high irradiance areas by 2030, and 0.04-0.05 EUR/kWh in low-to-medium irradiance areas by 2030.

One very important asset is that the SHIP can guaranty a stable price on energy for the 20 next years. At the opposite, the fossil fuel and electricity prices trend to increase significantly in all countries. The figure 1 shows this trend.

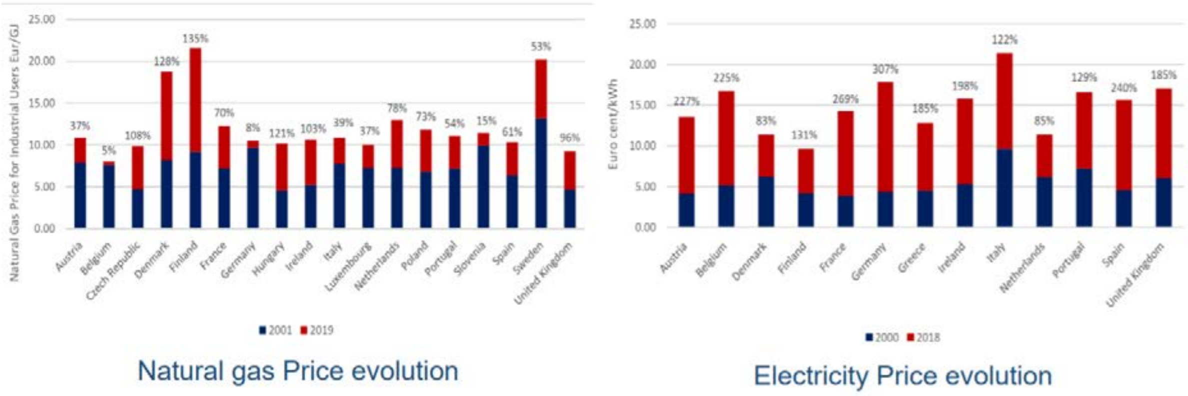


Figure 1: Electricity and Natural gas price evolution

This tendency has been dramatically increased by the Ukraine war. The volatility of the energy price is nowadays a major concern of all industries.

However, there are still many hindrances to SHIP expansion. We can mention the political regulations, the financial support scheme, and the access to project financing and growing economy. The financing scheme is the most critical point. This is exacerbated by the fact that the capital takes between 50-70% of the total costs. CAPEX of SHIP installations is expected to be around 500 EUR/m² For large scale systems and 700 EUR/m² for small scale installations.

To fight all these barriers, a lot of effort should be put on stepping-up communication efforts to raise awareness of the technology among potential customers in industries. Implementing a carbon pricing mechanism that reflects adequately negative externalities of fossil fuels consumption across the European economy and adjust their prices is also a very important aspect to implement by the rulers. Supporting financing models to reduce risks and initial costs to small and medium industrial investors should be found. On that last aspect, in Europe, different funding options have been developed. In the different countries involved in SHIP2FAIR the followed measures were implemented:

EU Countries	INCENTIVES FOR SOLAR HEAT
Austria	CAPEX incentives for SHIP projects, amount depends on the size
France	CAPEX contribution up to 65% of the investment
Germany	Loan and CAPEX incentives if supplying 50% or more of the heat demand
Greece	Many different programs based on CAPEX & taxation deductions
Italy	50-75% tax deduction for expenses related to installation of RES heating technologies & loan up to 70% of the admissible costs

Spain	CAPEX/grant up to a maximum amount between 50% and 80% of the eligible investment cost
Sweden	Renewables are exempt from taxes in relation to technologies used for heating at houses, industry or NO tax.

Figure 2: Main incentives in the UE countries

Finding the best business model is a key factor for success a SHIP project. We identified 3 different business model schemes, the third being a hybrid version of the second.

- Build and handover business model

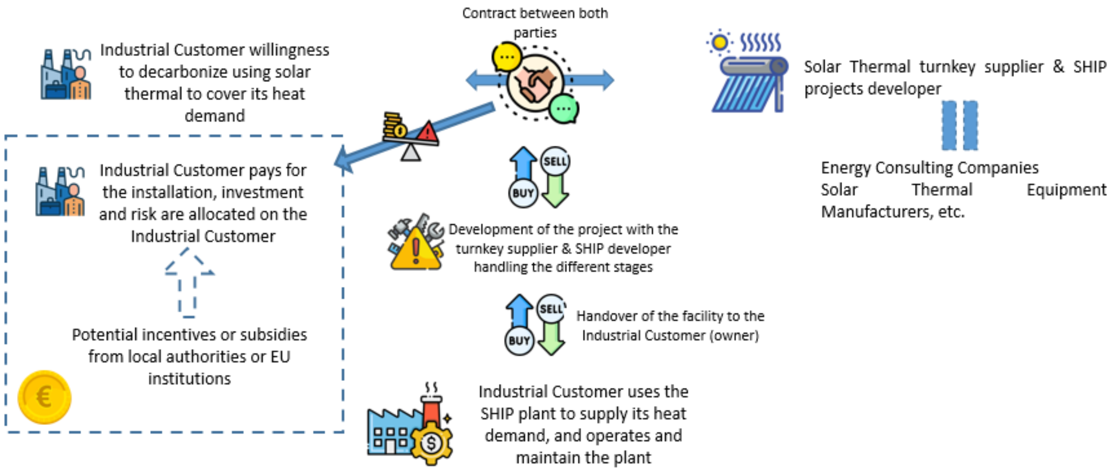


Figure 3: Build and handover business model illustration

- Build and operate business model

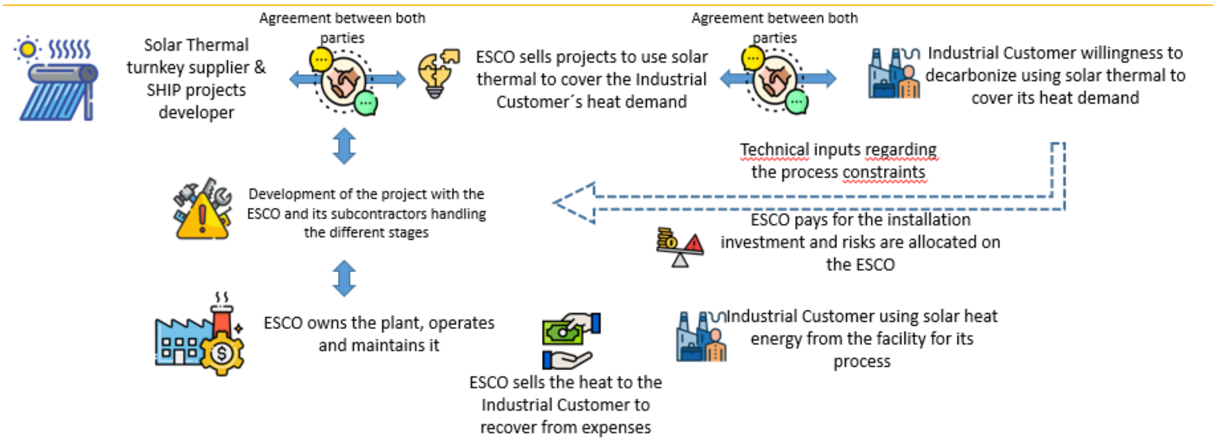


Figure 4: Build and operate business model illustration

- Build and operate hybrid version business model

It is the same principle as in the build and operate BM. Except that the scheme is temporary. The first years, the duration being defined by both partners, the Energy Service Company (ESCO) will oversee the installation operation. He is the one assuming all risks of the project.

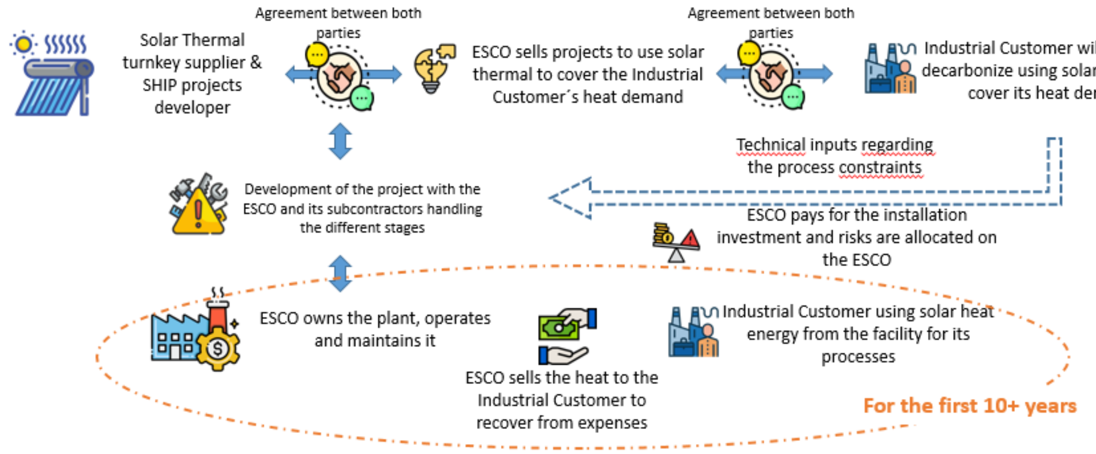


Figure 5: Build and operate business - hybrid version illustration (part 1)

Once the determined period is elapsed, the installation is then sold to the industrial who is now in charge of operating it. The advantage being the installation is fully integrated into the process and the risks mainly endorsed by the ESCO.

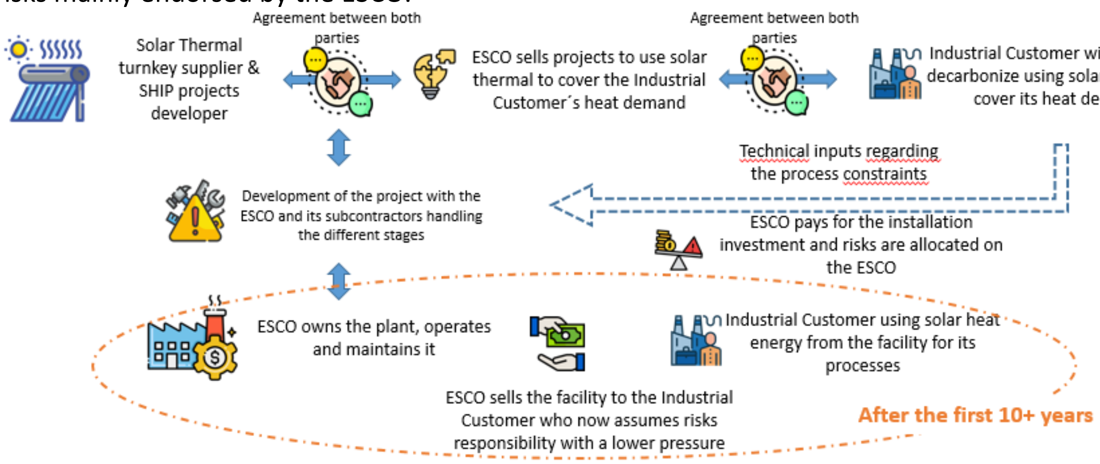


Figure 6: Build and operate business - hybrid version illustration (part 2)

2.1.3 Resume of the Case Studies

A summary of the results obtained in the ten feasibility studies carried out with the Ship2Fair Replication Tool is presented in Table 1. More detailed results are presented in Ship2Fair D8.4.

For each replication site, the industrial sector and the Country are shown but not the company name, to respect the requests of confidentiality posed by the beneficiaries of the studies. Moreover, the Table shows the level of temperature of the heat demand in the site (in form of water when below 100°C, of steam when above 100°C), the best solar thermal technology selected in the study, the collectors area, the corresponding Levelized Cost of Heat (LCOH), the calculated pay-back time (PBT), the solar share and the GHG emissions avoided.

It can be noticed that LFR collectors are in most cases the best suitable technology for sites with thermal demand in form of steam above 130°C, whereas FPC/HVFPC are the best suitable technologies for sites with hot water demand at a temperature below 105°C. The size of the collectors to be installed and the resulting solar share and GHG emissions avoidance are limited by the availability of space on the roof or on the area surrounding the site. To conclude, the financial parameters including LCOH and PBT are mainly influenced by the latitude of the site, which make the thermal energy production of the same plant vary with solar radiation availability, and by the price of thermal energy in the baseline situation, since the two mentioned parameters are those influencing the annual economic savings associated to the solar thermal plant. In this regard, it is also highlighted that the values shown in the Table are referred to energy prices before the 2022 energy crisis: the financial profitability of these solutions can significantly improve with an increase of energy market prices.

Table 1 – Summary of Replication Studies' Results

	Thermal Demand Temperature	Best Technology Selected	Collectors Area	LCOH	PBT	Solar Share	GHG Emissions Avoided
	°C	-	*m^2*	*EUR/MWh*	*Y*	*%*	*tCO_2e/y*
Case Study 1 – Textile, Italy	50-70	FPC	827	76.4	18.7	1.7	87
Case Study 2 – Chemical, Slovenia	130-180	LFR	25,981	44.9	11	6.0	57,868
Case Study 3 – Office/Laboratory, Italy	80-100	LFR	180	49.8	12.1	2.0	433.8
Case Study 4 – Waste Treatment, France	57-90	HVFPC	270	54.9	n.a.	n.a.	n.a.
Case Study 5 – Dairy, Spain	102-105	HVFPC	1,665	16.3	3.2	78.7	352
Case Study 6 – Meat Processing, France	55-96	HVFPC	2,200	44	12	18	520
Case Study 7 – Brewery, Spain	35-100	HVFPC	6,577	34.7	5.6	7.2	1,240
Case Study 8 – Food, Jordan	175	LFR	2,216	43.6	4.4	80.9	453
Case Study 9 – Chemical, Spain	195	LFR	19,684	106	20.2	51.9	1,764
Case Study 10 – Textile, India	170	LFR	17,100	16.8	8	4.3	7,633

LFR: Lineal Fresnel Reflector; **FPC:** Flat plate collector; **HVFPC:** High vacuum flat plate collector

2.2 Control feasibility

2.2.1 The different level of control

In general, it can be distinguished between four different level of control which can be hierarchically structured:

- **Level 0: Safety routines**
  - *Goal:* to ensure a safe operation of the plant at all time as well as a controlled shutdown in the event of a malfunction
  - *Applied control concepts:* simple if-else conditions, state-machines
  - *Reaction time:* very fast (typically below 1 second)

    - *Platform of implementation:* program logic controller (short: PLC) where safety routines should run as separate task with the highest priority.
- **Level 1: Low-level control strategies:**
    - *Goal:* to ensure a good control performance for the respective control variables like mass flow, temperature, pressure by adjusting the respective actuators like pumps, heaters, valves.
    - *Applied control concepts:* typically, proportional–integral–derivative controller (PID controller) - within the project Ship2Fair furthermore feedforward control strategies were developed considering in advance disturbance variables.
    - *Reaction time:* fast, typically in the range of seconds or minutes
    - *Platform of implementation*: since these strategies have to react fast to changes of the control variables or setpoint changes these strategies are typically implemented on PLCs (programmable logic controllers) like the safety routines.
- **Level 2: High-level control strategies:**
    - *Goal:* the goal of the high-level control strategy is to ensure that the overall plant is optimally operated and to decide when to change between different modes of operation (e.g. from *idle mode*, over to *preheating* to *nominal operation*). The low-level control strategies (level 1) then have to take care of efficiently carrying out the modes decided by the high-level control strategy.
    - *Applied control concepts:* typically, a set of static rules or state-machines, which determine the general mode of operation of the plant. Within the project Ship2Fair a more advanced control concept, a model predictive controller (MPC) was developed considering a model of the plant, future conditions about the generation/demand of energy and using an optimization algorithm in order to determine the optimal mode for the plant.
    - *Reaction time:* medium-low, typically in the range of several minutes, since switching the mode of the plant to often could be problematic for the plant and will likely lead to an oscillating behaviour.
    - *Platform of implementation:* depending on the complexity of the high-level control strategy it is implemented on the PLC, an industrial PC or even on a powerful server infrastructure.
- **Level 3: Supporting features for the plant operator (e.g. forecasts, data analysis, fault detection)**:
    - *Goal:* the goal of level 3 is to support the plant operator regarding an efficient operation by providing deeper insights into the performance of the plant by, for example, providing forecast of production and demand, continuously calculating important key performance indicators and automatically drawing attention to potentials problems of the plant. The reason why level 3 can also be considered as "control level" lies in the fact that for this level the operator itself closes the control loop. This means that a supporting feature as the fault detection algorithm points out a potential error of the plant and the operator then has to verify whether it is a real mistake, assess its severity and take appropriate action – therefore closing the loop.
    - *Applied control concepts:* In commercial plants, this third level is often not available or only rudimentary implemented. Typically, certain important parameters are displayed, naive forecasts are used (e.g. the course of the previous day), or a warning is issued when fixed limits are exceeded. In the project Ship2Fair, various algorithms were developed in order to more efficiently and comprehensively the plant operator. The algorithms are based on methods from the field of machine learning which allows an implementation with nearly no parameterization effort.

- o *Reaction time:* medium, typically in the range of minutes
  - o *Platform of implementation:* depending on the complexity of the high-level control strategy it is implemented on the PLC, an industrial PC or even on a powerful server infrastructure.

The goal of the Control Tool developed in the project Ship2Fair is to support the operator regarding the control levels 1 to 3 in order to improve the integration of solar heat into industrial processes. In order to be applied to a multiplicity of systems the tool is built as a "framework" offering to "plug together" certain modules which can be applied separately or together depending on the level of automation available at a plant (see section 2.2.2). These modules are shown in the following figure. The control level modules are together with the addressing modules.

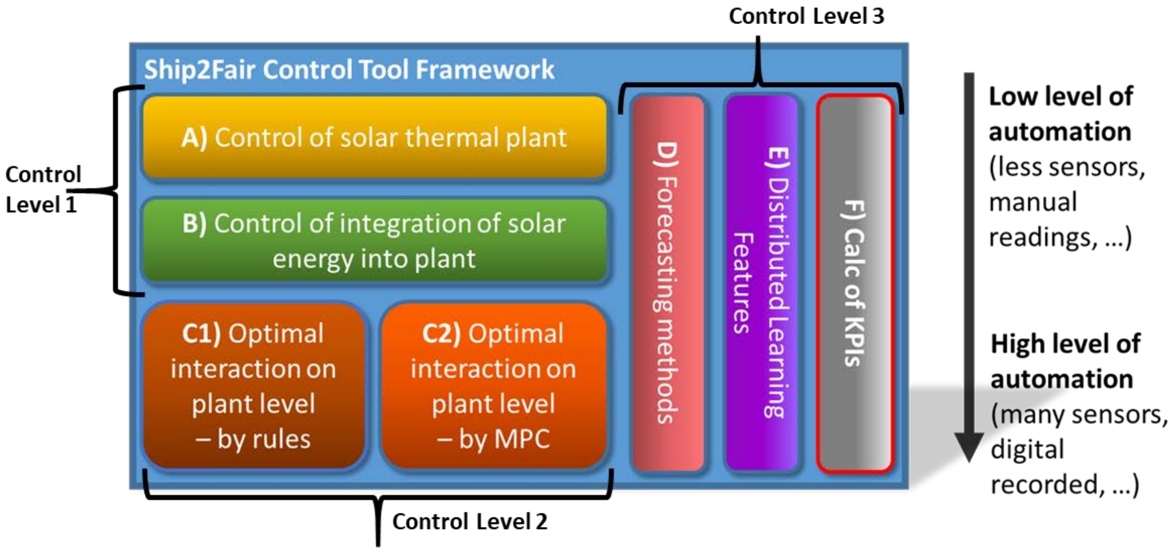


Figure 7: Schematic overview of the Ship2Fair Control Tool Framework and its modules as basis for the individual Control Tools and showing which modules addressing which control levels.

These modules are shown in the figure below and have the following tasks, described in brief:

- **Module – A:** Improving the operation of the solar plant through control strategies to maximize the solar yield.
- **Module – B:** Optimizing the (hydraulic) integration of solar thermal plants while minimizing disturbances to the process plant to a minimum.
- **Module – C:** Controlling the whole system (solar and process plant) in an optimal way either by rules or by a powerful model predictive controller (MPC) which is capable of considering several available heat consumers and producers while considering the different prices for energy (e.g. electricity, gas, …). A publication regarding how the temperature dependency of storages can be considered within such system was published in May 2022 with the title *"A multi-layer model of stratified thermal storage for MILP-based energy management systems"* in the Journal of Applied Energy [2].
- **Module – D:** Forecasting the produced solar heat of various collector technologies increasing the predictability of solar systems. An open access publication regarding Module D was published in July 2021 with the title *"An adaptive short-term forecasting method for the energy yield of flat-plate solar collector systems"* in the Journal Applied Energy [3].
- **Module – E:** Using distributed learning features for providing better insights regarding the operation of the systems, and support the operator to detect faults within the system. Regarding this module a new open access publication with the title "*Fault Detective:*

Automatic Fault-Detection for Solar Thermal Systems based on Artificial Intelligence" was published in the international Journal of Solar Energy Advances [1]. In this publication aspects of Module E were evaluated for three different solar thermal systems with a focus on a long-term performance by using data from more than a year.

- **Module – F**: Calculation of the KPIs of a plant in order to describe the status of the system by certain key values, which should help the operator to quickly evaluate the performance of the plant.

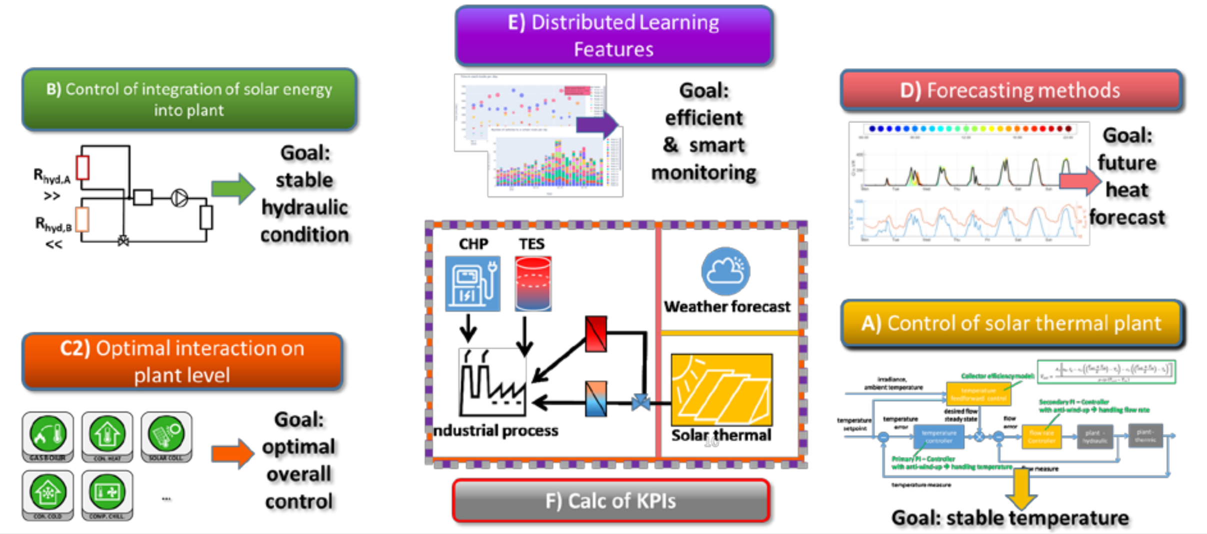
The **goal** of the Control Tool is therefore to optimize and improve the integration of solar heat into industrial processes during operation, regarding:

- from low-level control aspects (e.g. control of temperature) ➔ modules A&B
- through a high- level optimization of the whole system ➔ module C
- to advanced data-mining techniques (e.g. fault detection, forecasts, …) ➔ modules D to F

The **design** of the tool aims to be as flexible as possible in order to be applied to a multiplicity of systems, depending on

- user needs (e.g. control of only solar thermal system),
- plant design (e.g. available heat producers, storages) and
- level of automation (e.g. many sensors, digital recorded)

The different modules from which a specific Control Tool can then be implemented depending on the possibilities available on site (e.g. level of digitalization) and the needs of the plant. The goal of the different modules as well as their system boundary on which they act is shown schematically for an exemplary demo system consisting of a process system and a solar system. The application of the various modules at the different demo plants are described in more detail in the following sections.



$$\eta = f(x, y, z, \dots)$$

Figure 8: Schematic representation of the goals of the modules as well as their boundaries on which the different modules act on for a representative demo plant consisting of the industrial process and the solar thermal plant, including the additional module F) Calculation of KPIs.

2.2.2 Level of automation required

Before the level of automation required is discussed for the different modules of the control tool, three general principles which have to be followed for the implementation of the tool, should be discussed first:

1. Digital measurement and frequency: in case a quantity or amount should be controlled by any control strategy it has to be measured and digitally recorded or it must be at least possible to estimate this quantity from other measurements. Depending on the complexity of the control strategy (e.g. P&ID controller vs. model predictive controller) and its scope (e.g. controlling a certain temperature vs. optimizing the whole plant) typically additional measurements are necessary of the most important influencing variables to the measurement which should be controlled. In general, it is always advantageous to measure more in order to actively consider for example the disturbance variables (e.g. ambient or outside temperature) in the control, especially for modern high-level control strategies this is important. Furthermore, depending on which level of control should be applied the measurement has to be available in the respective frequency (e.g. for low-level control strategies in seconds or minutes). In case it is not sure at the beginning for which control level the data is used it should also be recorded in the highest frequency (smallest timesteps) possible and later one adjusted for the respective control level. Starting with the highest frequency the ICT infrastructure can be tested if it is still capable of collecting the data without problems, the data can then always be interpolated to a lower frequency (larger timesteps) and the data at high frequency could serve the additional purpose of modelling the system.

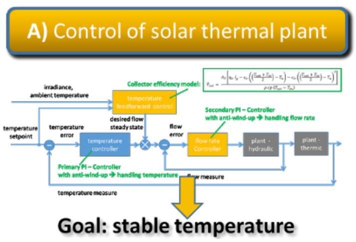
2. Data Quality: furthermore, in case measurement equipment is installed and the data is digitally recorded in the necessary frequency, a respective data quality has to be ensured. This means that the data should have the following characteristics:

- equidistant time steps
- No missing values or NaN (not a number) entries
- No double entries (e.g. with the same timestamp)
- No outliers (if it is not a specific characteristic of the plant, e.g. during fast transient dynamics)
- Correct, unique and reasonable naming of the measurements (the name should follow a certain naming convention and there should be a measurement list which allows to map the sensor to the piping and instrumentation diagram.
- Consistent usage of SI units.

In order to achieve this quality, it could be necessary to apply some (pre-)processing steps (e.g. remove NaN entries) before the data is provided to the plant operator or used for control strategies.

3. Availability of data: The data collected on-site must be globally available. This means if data is recorded on different heterogenous devices (e.g. different PLCs) it should be ensured that the data can be accessed at one central location. This doesn't necessary mean that the data has to be stored centrally but that the necessary interfaces are established so that it is possible to receive the data programmatically (e.g. not by exchanging portable storage devices like usb sticks) from each device (e.g. different PLCs) so that it can be used by the different control levels.

Regarding the different modules of the Ship2Fair control tool the following the concrete data is required:



MODULE A – Control of solar thermal plant: The goal of module A is to achieve a stable outlet temperature even for fluctuating ambient conditions (e.g. solar radiation, clouds). The control strategy has a cascaded structured and is separated in two parts a thermal controller and a hydraulic controller. The control strategy of both parts can be of different level of complexity (e.g. considering only the static conditions vs. considering also the dynamic ones), however the following quantities ones are the minimum necessary to be digitally available for the thermal controller:

- The outlet temperature of the solar collector in [K]
- The inlet temperature of the solar collector in [K]
- The global solar radiation on the collector plane, typically measured in [W/m²]
- The ambient temperature in [K]

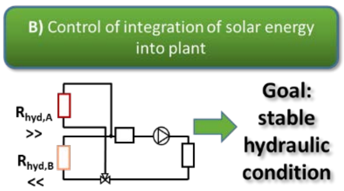
Furthermore, the following parameters have to be given or determined:

- Heat capacity of the heat carrier inside the collector [J/kg K], can be continuously calculated or set constant for the expected medium temperature of the system
- Density of the heat carrier inside the collector [kg/m³], can be continuously calculated or set constant for the expected medium temperature of the system
- Net collector area in [m²], can be found in the design data of the plant
- Collector efficiency parameters the (optical efficiency - eta0, 1st order heat loss coefficient - a1 and 2nd order heat loss coefficient - a2), which can be typically found in the datasheet of the collector manufacturer.

For the hydraulic controller they are:

- The flow going through the collector in [m³/s]
- The relative rotational speed of the pump in [%]
- The pressure over the pump in [Pa] (optional)

For both parts the measurements must be made available for the PLC which is in charge of controlling the pump that drives the mass flow through the collector. The frequency should be about 1 sec, so that the controller can react fast to changes of the solar radiation.



MODULE B – Control of integration of solar energy into plant: The goal of module B is to achieve stable hydraulic conditions and an efficient heat transfer over the heat exchanger. As for Module A there exists different parts, the efficient transfer of heat over heat exchangers as well as model-based control of pump, the following quantities are the minimum necessary to be digitally available for the efficient transfer of heat over heat exchangers:

- The outlet temperature of the primary (the heat source) circuit in [K]
- The inlet temperature of the primary circuit in [K]
- The volume flow of the primary circuit in [m³/s]
- The outlet temperature of the secondary (the heat sink) circuit in [K]
- The inlet temperature of the secondary circuit in [K]
- The volume flow of the secondary circuit in [m³/s]

Furthermore, the following parameters have to be given or determined by experiments:

- Heat capacity of the heat carrier of primary and secondary circuit in [J/kg K], can be continuously calculated or set constant for the expected medium temperature of the system
- Density of the heat carrier of the primary and secondary circuit in [kg/m³], can be continuously calculated or set constant for the expected medium temperature of the system

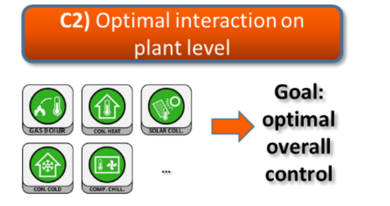
For the model-based control of pump the following data has to be digitally available:

- The volume flow of the pump in the primary circuit in [m³/s]
- The pressure over the pump in [Pa]

Furthermore, the following parameters have to be given or determined by experiments:

- Viscosity of the heat carrier inside the collector [J/kg K], can be continuously calculated or set constant for the expected medium temperature of the system
- Density of the heat carrier inside the collector [kg/m³], can be continuously calculated or set constant for the expected medium temperature of the system

For both parts the measurements must be made available for the PLC(s) which is/are in charge of controlling the flow inside both circuits, the frequency of the measurement should be in the best case about 1 sec, so that the controller can react fast to changes of the hydraulic network.



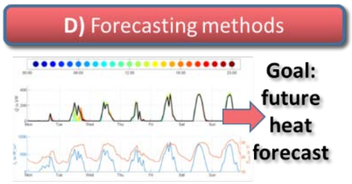
MODULE C – Optimal overall control: Module C is about the optimal interaction of the components on plant level by considering also information from the future (e.g. weather forecasts). This can be done either by rules or by a model predictive controller (MPC) which is capable of considering several available heat consumers and producers together with different prices for energy (e.g. electricity, gas, …). Within the project Ship2Fair it is planned that the module will be only implemented as Decision Support System. This means that that the plant operator has to make sure that the suggestions by the rule-based approach or the MPC is applied to the plant. This is - since the plant operator has the competences to evaluate if the suggested mode of operation is reasonable and not providing by any means harm to the process or the product itself - a risk the developing partners can't take. As mentioned also Module C consists of two parts, a rule-based approach or an MPC. Since both of the approaches have to be applied for a concrete system, the necessary quantities to be digitally available are in general for both approaches:

- The dominant energy flows in [kW] together with the respective volume flows in [m³/s] together with the temperature values in [K] which lead to the energy flows
- forecasts of the most important weather variables like ambient temperature in [K], global solar radiation [W/m²] typically retrieved from a weather service provider (e.g. https://www.meteoblue.com/de/wetter/woche/graz_%C3%96sterreich_2778067)
- the power level of the heat producers to be considered in [%] as well as the respective temperature set points in [K] in case it should be adjusted by the module

In case a rule-based approach is used, it can be typically implemented on the PLC and the measurement data measurements must be made available for the PLC(s). In case an MPC approach is used, typically a more powerful server-based infrastructure is necessary and depending on the complexity of the system to be considered also a commercially available solver like Gurobi[1] is necessary which comes with extra costs. In both cases the frequency of the measurement depends on the inertia of the

1 https://www.gurobi.com/downloads/?campaignid=2027425870&adgroupid=77414946211&creative=355014679607&keyword=gurobi&matchtype=e&gclid=EAIaIQobChMI47mUhdiQ_wIVDq13Ch2vCAhpEAAYASAAEgI6gPD_BwE

systems (e.g. if "slow" heat producers like biomass boilers) are involved but in general it can be in the range of minutes (e.g. 10 – 15 min.)



MODULE D – Forecasting methods: This module provides forecasts regarding the weather and the calculated future solar heat production to the plant operators. Based on that information the operators can decide if it makes sense to adjust the production schedule in order to more efficiently use the available heat produced by solar. For more information how, the method is working, see e.g. [2]. For this approach the necessary quantities to be digitally available are:

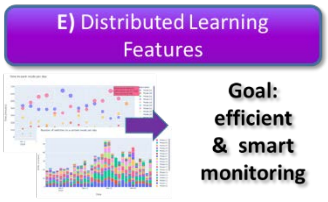
- The outlet temperature of the solar collector in [K]
- The inlet temperature of the solar collector in [K]
- The global solar radiation on the collector plane, typically measured in [W/m²]
- The ambient temperature in [K]
- The solar yield (produced heat of the collector field) in [kW]
- Weather forecasts regarding the future ambient temperature in [K] and the global solar radiation in [W/m²] typically retrieved from a weather service provider (e.g. https://www.meteoblue.com/de/wetter/woche/graz_%C3%96sterreich_2778067)

Since the method is adaptive and self-learning no information of the solar system like area or collector parameters are important. However, some parameters how the method is applied have to be set, but are less critical:

- The forecast horizon in number of hours in [1], a reasonable value is 24 h
- The mean fluid temperature of the collector field in [K], this can be chosen as the arithmetic mean between a typical inlet temperature as well as the desired outlet temperature of the collector.
- The number of training days in [1], a reasonable value is about 2 weeks, which means that always the last two weeks of measurements are used for training.
- the power level of the heat producers to be considered in [%] as well as the respective temperature set points in [K] in case it should be adjusted by the module.

The algorithm was designed platform-independently and can therefore be implemented on a simple PLC as well. However, it needs access to weather forecasts, which, depending on the capabilities of the PLC, can make it still necessary to implement it on server-based infrastructure. Typically, forecasts are available on an hourly basis; therefore, it is enough to recalculate the forecast every hour.

[2] V. Unterberger, K. Lichtenegger, V. Kaisermayer, M. Gölles and M. Horn, "An adaptive short-term forecasting method for the energy yield of flat-plate solar collector systems," *Applied Energy,* 1 July 2021 (https://www.sciencedirect.com/science/article/pii/S0306261921003779)



MODULE E – Distributed learning features: The aim of this module is to use machine learning techniques for implementing innovative functionalities for solar heat efficiency enhancement in industrial processes. These functionalities can help plant operators to react to events early and to keep the system running at optimal performance. The module is divided in two sub-modules, namely mode detection - providing insights regarding the performance of the plant, and fault detection – inform the operator regarding the conditions of the plant and if faults occurring in the system. For the mode detection the following quantities are the minimum necessary to be digitally available:

- All available volume flow measurements in [m^3/s] these are used to determine the principle possible modes within the system
- All available heat flow measurement in [kW] which are used to determine how much energy is transferred during the different modes

For the fault detection the following quantities are the minimum necessary to be digitally available:

- The outlet temperature of the solar collector in [K]

Furthermore, as many measurements from the solar collector field as possible which are then used by the algorithm to predict the solar outlet temperature which is then used to detect possible faults.

For both parts the measurements must be made available for a server-related infrastructure which is capable of calculating the distributed learning features which are programmed in a high-level programming language like python. The frequency of the measurement should be in the range of minutes in order to quickly inform the plant operator about possible faults and provide him with status regarding the modes the plant is running in real time.

$$\eta = f(x, y, z, \ldots)$$

MODULE F – Calculation of KPIs: The goal of the module is to provide a quick way for operators to evaluate the actual and past performance of the plants based on static calculations. The KPIs reasonable to be calculated depend on the needs of the operator as well as on the structure of the plant (e.g. are storages involved?). Therefore, it cannot be answered in a general way which measurements have to be digitally recorded. In most cases, however, the different energy flows in the system are the most important variables together with the quantities leading to values like solar radiation or fuel consumption.

3 Lessons learnt from demosites

3.1 Preparatory phase

The following factors need to be properly addressed to avoid unrealistic system design, cost uncertainties, time delays and/or inefficiencies as SHIP2FAIR activities have revealed:

3.1.1 Data availability

Lack of data from the demo site can create delays and/or suboptimal system design. In such cases carrying out an energy audit may prove essential for the proper dimensioning and engineering of the solar thermal system and the dimensioning of the required thermal storage. An energy audit may also identify areas suitable for the installation of the solar thermal system.

3.1.2 Budget of pre-construction works

The cost of civil works (including rooftop substructure) can hardly be estimated with high accuracy at proposal stage. This needs to be reflected in the proposal budget by e.g. allocating centrally an amount of money that could be used for extra costs related to the demo sites.

3.1.3 Future changes in the energy system and/or processes

An optimal engineering & integration scheme should take into consideration: (i) potential future changes in the production processes and/or energy system of the industrial user, as well as (ii) potential scale up of the system following a successful demonstration campaign.

3.1.4 Raising user awareness

Industrial engineers and plant managers are not familiar with solar thermal technologies and systems. They typically need to learn more about the technology/system to be applied in their cases, their pros & cons and its suitability for their purposes/needs. This way, they may facilitate and accelerate the whole project implementation.

3.1.5 Effective communication

Language barriers may lead to ineffective communication and therefore to misunderstandings and time delays. The involved parties (e.g. industrial users, technology providers, system integrators, local contractors) need to ensure that communication is handled by people fluent in English or any other language common within the team.

3.2 Detailed engineering – process integration

3.2.1 The connection point

The connection point defines the integration scheme; that is, how the solar thermal system will be integrated into the thermal energy system and the production processes of the user. Such a decision is actually reflecting a compromise between convenience, cost and efficiency (given the particularities and needs of its specific case). The following generic integration strategies are considered:

1. Integration into the central steam network implies minimum disruption and modifications in the energy infrastructure and operational mode. It also means that the solar system should operate at higher temperatures and thus at lower efficiency. The cost of the equipment for solar steam generation is typically higher than the cost of hot water production.

   Concentrating systems have lower losses at higher temperatures and are therefore suitable for an integration at supply level in more cases. Certain concentrating collectors such as Linear Fresnel or Parabolic Trough can provide direct steam which simplifies the integration on supply level for steam networks and has energetic and economic advantages compared to indirect steam generation.

2. Integration at process level allows operation of the solar system at hot water mode and temperature set points that are typically much lower than the central steam network. This increases the efficiency of the solar thermal system and thus reduces the levelized cost of heat (LCoH). However, it also requires additional piping to connect to the application point and control at process level.
   Furthermore, integration on process level means that only the partial demand of specific process can be covered. This can lead an increase of solar excess energy, the requirement of a larger energy storage, a size reduction of the solar field and a lower overall solar share.
3. Integration into the return piping – for feedwater pre-heating – allows operation of the solar field at lower temperatures and hot water generation at the expense of a low share of solar heat (around a maximum of 10% on the demand).
   It is of crucial importance to consider the impact of feedwater temperature increase on the steam boiler efficiency. A higher feedwater temperature can increase the exhaust gas outlet temperature and thereby reduce the boiler efficiency. This is of special importance if the boiler is equipped with an economizer. In this case, up to 100% of the heat provided by the solar field could be lost by lowering or disabling the economizer function.

Based on the above it becomes clear that the identification of the right connection points is critical for the feasibility of the solar system and the user acceptance. In this respect, the following steps & rules can be applied:

- Analysis of the current thermal energy system and application points (based on P&ID, process diagrams, heat demand profile, and other relevant information that are made available).
- Identification of potential integration schemes in relation to the three above mentioned integration strategies.
- Impact on boiler efficiency in case of feedwater pre-heating.
- Assessment of the techno-economic feasibility of these integration schemes (taking into consideration the installation point of the solar field).
- Discussion of the 2-3 more attractive options with the client/user and agree on the most suitable one.

3.2.2 The interest of engineering different modes and/or temperature level

Dual mode of operation is possible as a strategy to maximise usable heat production and minimise excess heat (that may be wasted). Such strategy means that the solar system operates at a lower temperature set point during the winter period (or at times where solar irradiance is relatively low), and at a higher temperature during the summer period (sunny conditions). This implies that there are needs for low(er) temperature at the application point. An example is the generation of process heat during summer and meeting space heating needs during the winter period. Such strategy can boost solar heat generation during winter/low irradiance periods and thus reduce the average levelized cost of heat.

The efficiency of solar collectors is better at lower temperature (due to the reduction of the heat losses), it is more relevant to analyse the process in order to find the energy needs at all levels of temperature. If possible, the pre-defined temperature set point of the solar field can be adjusted regarding the energy needs. This temperature set point should be changed/defined manually or by the control system (regarding a predefined law, sensor measurements or self-learned rules). The system can be designed to operate at variable weather prediction). Another option could be to split the solar field in different sub-field with different set points.

3.2.3 The local environment

By definition, SHIP is an integration of a thermal solar plant in an existing process. Therefore, each integration is unique and depends on the environment.

It is highly recommended that the engineering works hand in hand with the end user.

The aim is to analyse deeply the process in order to understand the energy needs, the process itself and define the best integration of the plant and the best control strategy. The location of the solar field and the balance of plant is also an important factor. Usually solar plants require large space available. Preferably, the solar field should be installed on the ground, face to the south, without shadowing and near to the process connection point. It is not easy to fulfil all these requirements and in most of the cases, it should be a compromise.

The most important point is to have the maximum space availability in order to increase the solar share. The engineering should take into account an easy maintenance. For example, do not install the solar field on a bare land because the weeds will grow between the panels and the panel maintenance and the weeding control will be more difficult.

In case of a rooftop installation, accessibility should be a priority for the maintenance as well as for the maintenance. In the case of concentration technologies, even if the mirrors structure itself is relatively light, a heavy substructure may be required in order to take into account the extra load induced by the local meteorological conditions (wind and snow). Depending on the roof shape and the steel structure, the required substructure can increase the total roof weight significantly and can even demand an enforcement of the existing structure. The cost for the substructure material and installation may have a decisive impact on the economic feasibility of the project. Therefore, it is recommendable to evaluate the roof load requirements in a very early project phase.

Concrete roofs tend to have a very high load carrying capacity and are therefore suitable for the installation of solar thermal collectors in most cases. Even compared to ground installations the construction of foundations can be simpler and at lower cost in the case of concrete roofs.

3.2.4 The local regulation

In the case of the engineering is abroad form the end user country, it is highly recommended to have the support from a local engineering. For example, construction permits and other regulatory/ environmental authorisations may be required or not depending on the country and location, type (rooftop, on the ground) and size of the installation, operational mode (hot water or steam), etc.

This building permit clearance can take a long time and should be anticipated as soon as possible. During SHIP2FAIR regulatory bottlenecks and uncertainty have affected the timeline of the demonstrations, especially in the case of the French demo-site. Further delays may be experienced during the installation of the solar thermal systems as a result of inspections in relation to safety requirements (e.g. for pressurized equipment).

Other technical regulation should also be applied. Especially the National/ European regulatory requirements and authorisations for pressure equipment should be met. Even if there is an European pressurised equipment directive, some countries can add more requirements. For this reason, it is advisable that local engineering consultants are involved in the process.

3.3 Control strategy applied

3.3.1 Overview of the monitoring & control system

In order to be aware of the status of the plant and to set control parameters (e.g. thresholds for switching of the pumps) a graphical user interfaces (GUI) is important. In Ship2Fair there exists the GUI application of the solar plant itself as well as the front-end of the Ship2Fair Control tool allowing to provide additional insights from data and advanced control Options. First, the GUI used on-site for RODA, LARNAUDIE and RODA is shown and described then the Front-end of the Ship2Fair Control Tool is shown.

3.3.2 GUI application of solar plant

RODA

The GUI application for RODA can be seen in the following figure. It allows to see the current values of the different collector temperatures, the solar radiation, the status of the pump and the valves.

Figure 9: GUI for RODA's plant

The logic operation is based on a simple switching on different modes, depending on the system temperature as well as on the temperatures within the storages. The control of the pump is limited since it is only switched on at a given speed when a certain threshold is reached in the solar primary circuit. The parameters of the control of the pump which can be set for that purpose are shown in the next figure:

Figure 10: Possible settings for the pump in the solar primary circuit

This strategy cannot provide a "matched flow" mode, which in particularly is necessary for RODA in order to drive an absorption chiller for cooling purposes. Therefore, Module A of the Ship2Fair control tool was implemented to modulate the pump in order to achieve a desired temperature to drive the chiller.

Since Module A has to react in approximately real time to changes of the ambient conditions (solar radiation and ambient temperature) as well as operating conditions (inlet temperature). It has to be implemented on the PLC installed on-site, which is of the manufacturer of SCHNEIDER. The data flow is therefore simple. The PLC receives the measurements regarding the solar radiation, the ambient temperature, the inlet- and desired outlet temperature of the solar collector and then computes the actuator value of the solar primary pump. The used program language on the PLC is *structured text,* which has a block structure and is a high-level language designed for PLCs.

On a high-level control basis a state-machine is implemented which switches between different modes depending on the temperature of the solar systems as well as on the two storages (*Caldera, Altillo*) installed in RODA. The schematic of the state machine for RODA is given in the following figure:

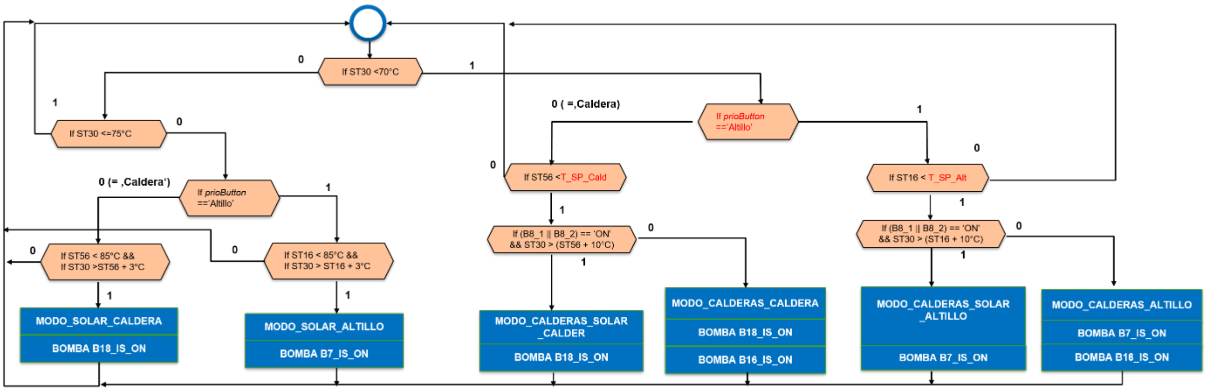


Figure 11: Schematic of the state machine for RODA's plant

The modes and the meaning of them are the following:

- MODO_SOLAR_CALDERA: heat up the *Caldera* storage by solar only
- MODO_SOLAR_ALTILLO: heat up the *Altillo* storage by solar only
- MODO_CALDERAS_SOLAR_CALDER: heat up the *Caldera* storage by solar and the installed gas boilers (meaning the solar preheats it for the gas boiler)
- MODO_CALDERAS_CALDERA: heat up the *Caldera* storage only by the installed gas boilers
- MODO_CALDERAS_SOLAR_ALTILLO: heat up the *Altillo* storage by solar and the installed gas boilers (meaning the solar preheats it for the gas boiler)
- MODO_CALDERAS_ALTILLO: heat up the *Altillo* storage only by the installed gas boilers

The switching between the modes happens depending on the temperature of the solar thermal plant, the temperature within the storage and which of storages should be prioritized.

M&R and Larnaudie

As shown in the following figure, at M&R and Larnaudie the GUI of the solar thermal plant is provided by the Partner TVP. The control logic operation is based on a simple switching on different modes, depending on the system temperature during the day & night.

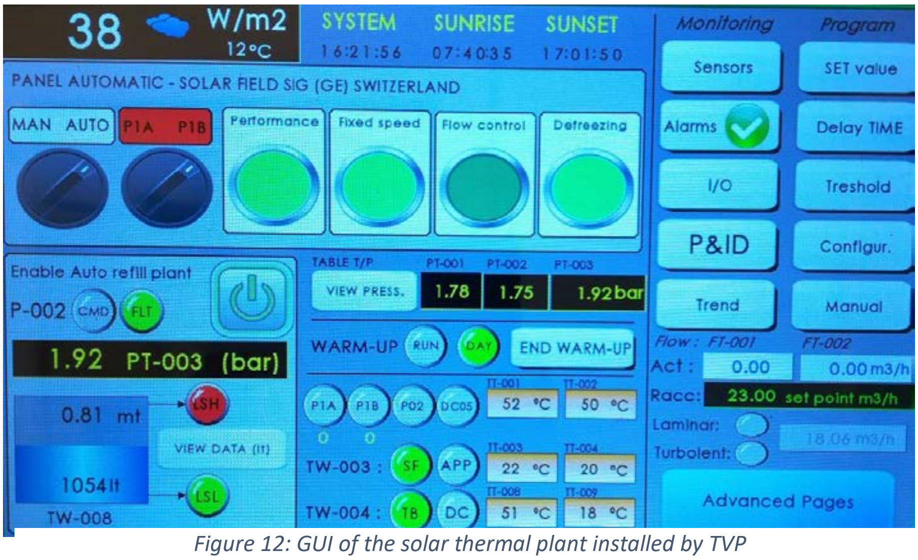


Figure 12: GUI of the solar thermal plant installed by TVP

It's possible to manage, change and operate with these parameters by the HMI of the PLC cabinet, as the one shown in the Figure below:

The principle operation logics, which allow the solar field to work optimally, are shown below:

a) Pre-heating mode: This mode typically applies in the morning when there are the conditions for which the pump switches on (Irradiation>=Threshold [W/m2]; the time is between Sunrise and Sunset). The temperature to be reached and the frequency of the pump are set by the HMI. Once the desired temperature is reached, the system switches, if activated, into "Application mode".
b) Application mode: Once the temperature set point is reached, the system switches into "Application Mode". In this mode, fluid starts to flow. The electro-actuated ball valves modulate their opening according to the solar irradiation. The flowrate is regulated by an algorithm that optimizes speed pump according to the solar irradiation measured by the pyranometer. All the parameters are settable from the HMI.
c) Defreezing mode: This mode avoids the freeze of the fluid inside the system. During the night, or during the day if the Irradiation<Threshold [W/m2], if the temperature of the system is lower than a set value (settable from HMI), the solar field pump switches on, and allow the movement of the fluid.
d) Dry cooler mode: This mode operates if the system temperature is greater than a threshold value (safety limit). In this case, the respective system valves are closing/opening, to send all the fluid to the Dry Cooler, which will bring the system temperature below the safety limit. All the parameters for this mode are editable in HMI page.

3.3.3 Front-end of the Ship2Fair Control tool

A schematic overview of the different components of the information, communication and technology infrastructure and the related partners (BEST, LINKS and RODA) as well as where the different modules of the Ship2Fair Control Tool are implemented is given in the following figure:

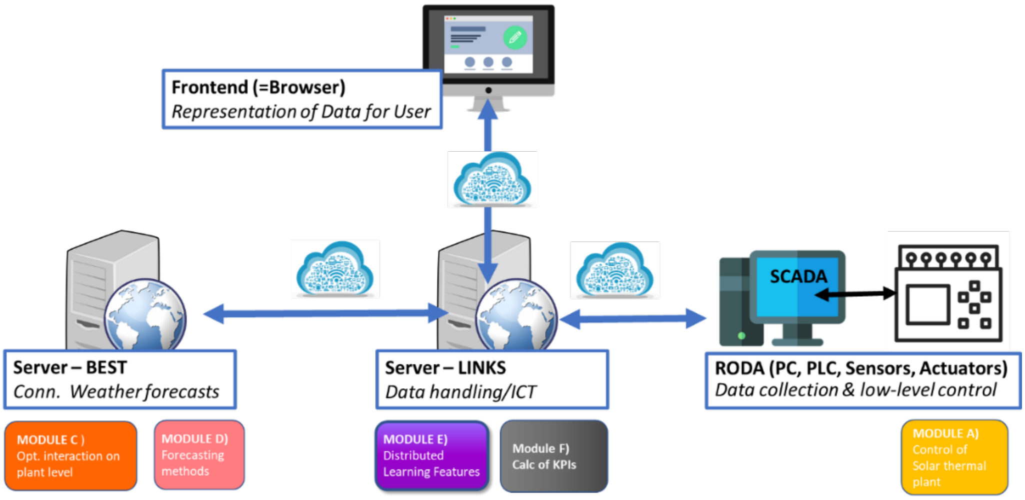


Figure 13: A schematic overview of the ICT infrastructure, the involved partners and where the different modules have to be implemented.

Before the front-end of the Ship2Fair Control Tool is described, the structure of the installed and necessary infrastructure for RODA and M&R, Larnaudie are described.

RODA

Based on the control tool related analysis regarding available sensors and the structure of the thermal energy system of RODA, the existing SCADA was adjusted and a connection to the Ship2Fair ICT Infrastructure had to be established as shown in the following figure:

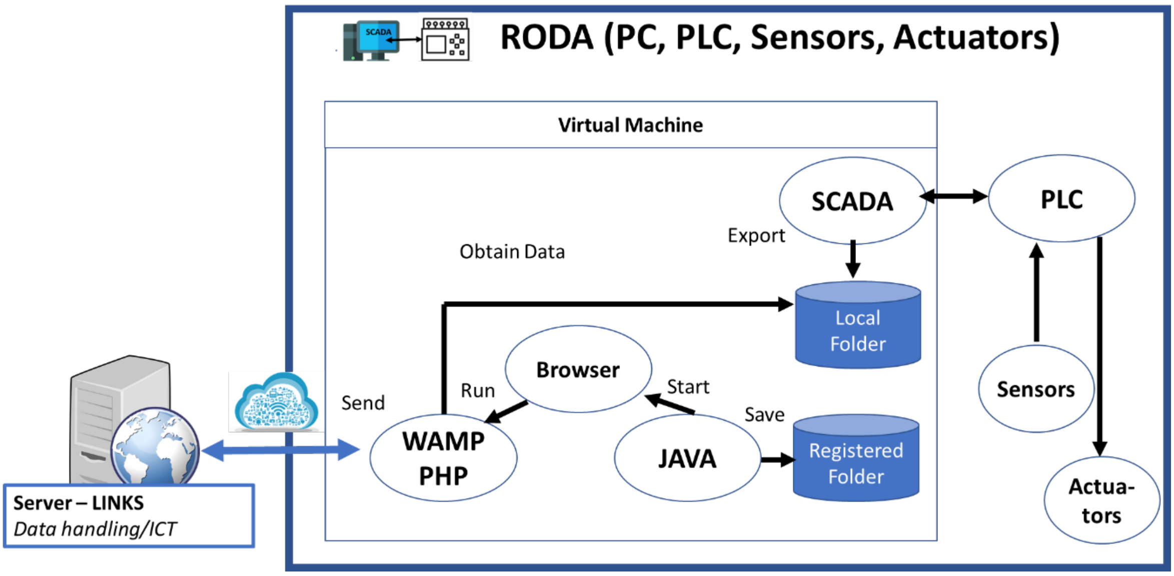


Figure 14: Description of the data infrastructure at RODA to the ICT Infrastructure of LINKS.

- The Scada installed on RODA's servers collects the data provided by the automata and users from the GUI.
- All the data of the entire system is stored in files within the Scada.

- Within the Scada, a script had been programmed that is executed every minute and is in charge of exporting the data required by BEST/LINKS. This data is exported in .txt format and temporarily stored in a folder inside the virtual machine where RODA's SCADA is installed.
- At the virtual machine the software *Wamp* is installed, that works as a local web server.
- Within *Wamp*, there had been several scripts written in PHP language that are responsible for sending the data by HTTP POST protocol to the ICT infrastructure of LINKS which handle the data stream and provide the data to BEST (see also Deliverable 5.1 control and monitoring ICT infrastructure and Management)
- For sending the data over HTTP POST a program in Java was written and implemented on the virtual machine, whose function is to start the web browser with a page from the *Wamp* server, where the HTTP sending script is stored. This procedure is called every minute. At the time the browser is started and the page is loaded the file is sent.
- Subsequently, the Java program copies the file that has just been sent to a history folder to store it and afterwards closes the browser. This copy is done because every time the data is exported from the SCADA, the .txt file is overwritten.

The most important technical details about the transfer of data are given in the following table:

Transfer Rate	1 min. (data is transmitted every minute)
Used protocol	HTTP POST (see POST (HTTP) - Wikipedia)
Number of transferred data points	154 data points as well as date and time value
Used program languages	• Program language specific for the SCADA system, similar to Visual Basic • PHP • Javascript

M&R and LARNAUDIE

In order collect the data locally at the central data storage system several adjustments had been necessary specifically for M&R and LARNAUDIE. For example, the solar field PLC had to be updated by a new network card in order to communicate with the SCADA systems since the originally network address was not compliant with the internal M&R network. Furthermore, it was not possible to add the PLC directly to the plant's SCADA as the PLC's modbus communication port is only able to exchange data with a single server. Therefore, a link had been established between the SCADA and the *central data storage system* for sharing the PLC modbus registers in real time.

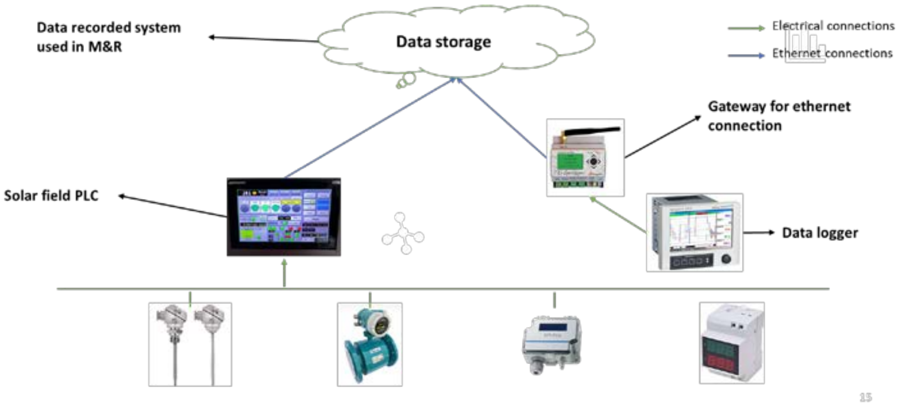


Figure 15: Overview of the different necessary connections in order that the data of the solar field PLC and the data logger can be received at the central data storage system.

In following the data flow is descripted in more detail:

- From the solar field PLC all solar related data is collected and sent via Modbus protocol to the central data storage system of M&R
- All other data from the secondary loop of the solar field are collected by a different data logger, which sends the data over a gateway for ethernet connection to the central data storage of M&R
- The SCADA System of M&R infrastructure, installed on a local server, collects all data
- Within the Scada, a script had been implemented that is in charge of exporting the data to the ICT of LINKS, where it can be accessed also by BEST

The most important technical details about the transfer of data are given in the following table:

Transfer Rate (frequency)	15 min. (data is transmitted every 15 minutes)
Used protocol	HTTP POST (see [POST (HTTP) - Wikipedia])
Number of transferred data points	44 data points as well as date and time value
Used program languages	• Program language specific for the SCADA system • Python

The front-end of the Ship2Fair Control Tool

The front-end of the Ship2Fair Control Tool can provide the following functionalities as described in the previous section:

- Access to monitoring data
- Suggestions by a model predictive controller (Module C)
- Forecasts of weather and the solar yield of the plant (Module D)
- Mode detection & Fault detection (Module E)
- KPIs (Module F)

The Tool provides these functionalities for all demos (RODA, M&R, LARNAUDIE) and is therefore only exemplarily described for the different functionalities which can be accessed over the browser from everywhere.

Monitoring

In the monitoring section a specific sensor (in this case the ambient temperature at M&R) can be shown for a selected time range.

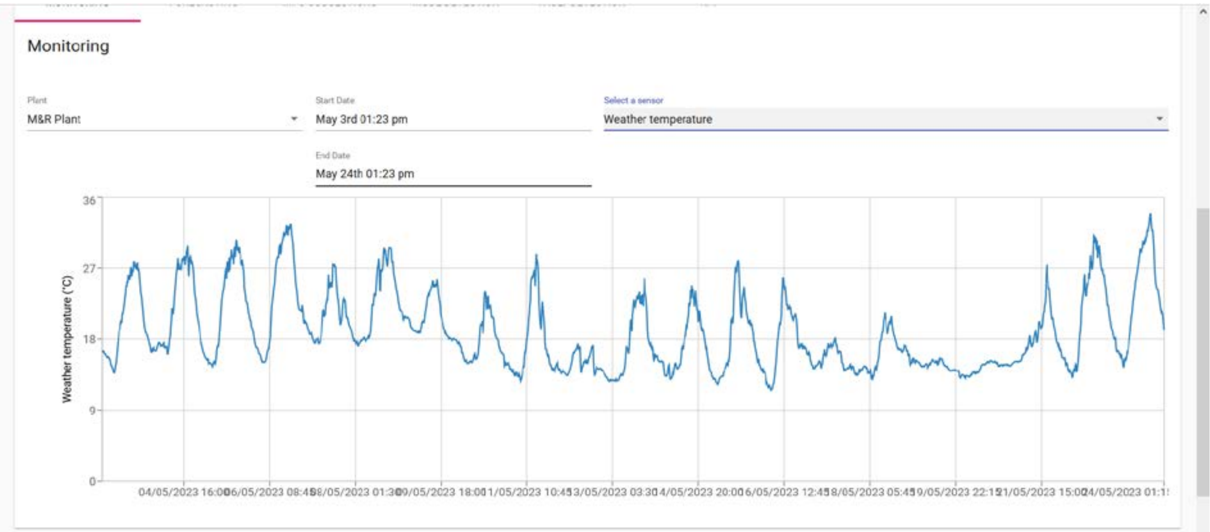
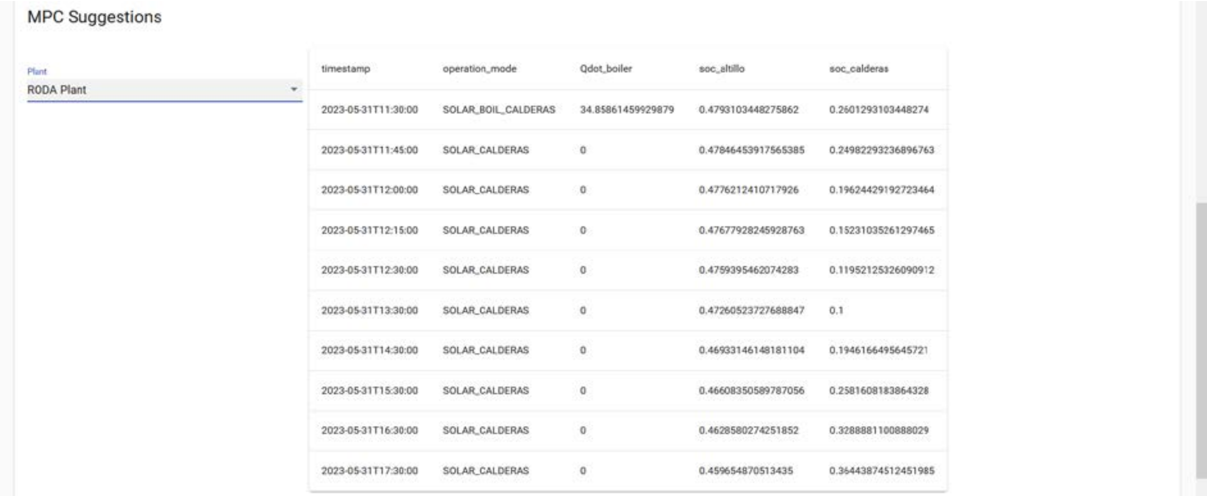


Figure 16: Example of data monitoring.

MPC suggestions (Module C of Ship2Fair Control Tool)

In the section the suggestions given by an MPC controller are given, providing the plant operator, in this case RODA, with input regarding which operating mode should be used for the plant. The operating modes are described in the previous section of RODA and are typically determined by a state machine not making use of forecasts from the expected heat output of the collector as well as the to be expected heat demand of the consumers. It further tells him about the state-of-charge (soc) of the different storages *Altillo* and *Calderas*. The operator has then to decide if he follows this information.



MPC Suggestions

Plant
RODA Plant

timestamp	operation_mode	Qdot_boiler	soc_altillo	soc_calderas
2023-05-31T11:30:00	SOLAR_BOIL_CALDERAS	34.85861459929879	0.4793103448275862	0.2601293103448274
2023-05-31T11:45:00	SOLAR_CALDERAS	0	0.47846453917565385	0.24982293236896763
2023-05-31T12:00:00	SOLAR_CALDERAS	0	0.4776212410717926	0.19624429192723464
2023-05-31T12:15:00	SOLAR_CALDERAS	0	0.47677928245928763	0.15231035261297465
2023-05-31T12:30:00	SOLAR_CALDERAS	0	0.4759395462074283	0.11952125326090912
2023-05-31T13:30:00	SOLAR_CALDERAS	0	0.47260523727688847	0.1
2023-05-31T14:30:00	SOLAR_CALDERAS	0	0.46933146148181104	0.1946166495645721
2023-05-31T15:30:00	SOLAR_CALDERAS	0	0.46608350589787056	0.2581608183864328
2023-05-31T16:30:00	SOLAR_CALDERAS	0	0.4628580274251852	0.3288881100888029
2023-05-31T17:30:00	SOLAR_CALDERAS	0	0.459654870513435	0.36443874512451985

Figure 17: Example of MPC suggestions.

Forecasting (Module D of Ship2Fair Control Tool)

The following screenshots shows the provided forecast for the solar field together with the forecasted solar radiation as well as ambient temperature.

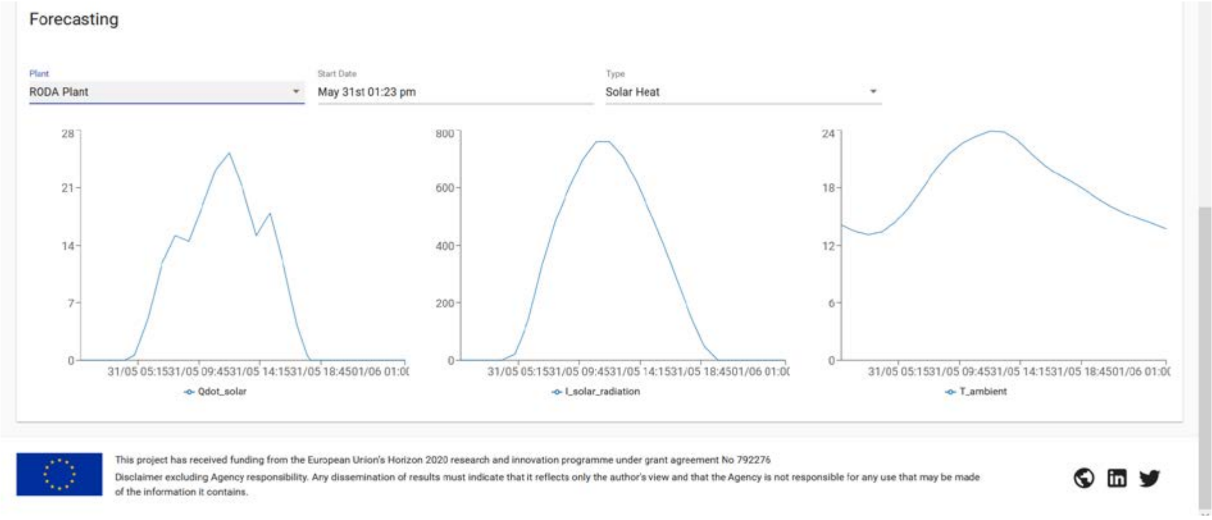


Figure 18: Example of Forecasting.

<u>Mode detection (part of Module E of Ship2Fair Control Tool):</u>

This section a MODE DETECTION algorithm has to be started directly in the web surface which calls the respective Python scripts, loads the data from the database and run the data-driven approach dividing the time of operation of the plant in different modes. When the algorithm has finished, the table is shown constructed depending on the different pumps available in the system as shown in the following figure:

Figure 19: MODE DETECTION - Truth table regarding the different modes existing at RODA from the 23rd of to the 25th of January.

After displaying all the modes existing at RODA, some information displayed informing the operator

- what these modes mean,
- how often they occur,
- how much (total) energy is transferred during the specific mode
- what is the time spent in each mode per day
- how much energy is transferred per mode per day
- what is the number of switches to a certain mode per day

An example is shown in the following figure.

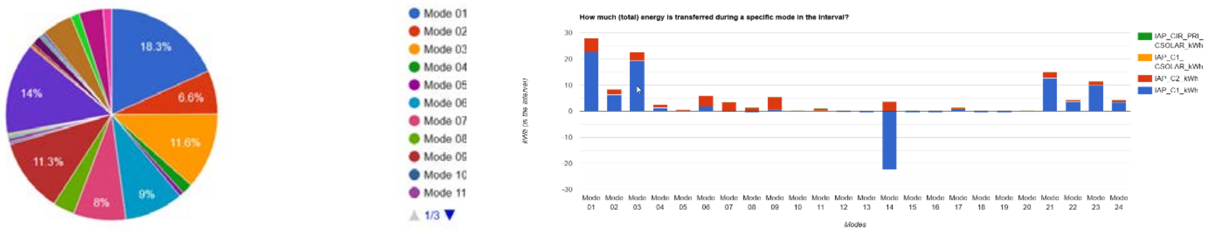


Figure 20: on the left side it is visualized how often modes occur in the selected interval and on the right side it is visualized how much energy was transferred during a specific mode in the chosen interval.

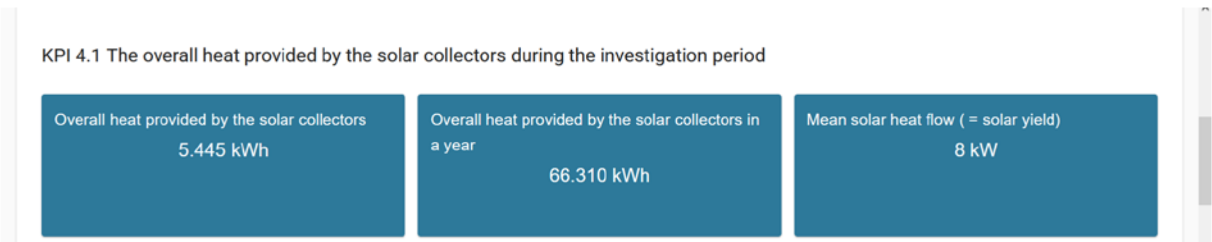
<u>Fault detection (part of Module E of Ship2Fair Control Tool)</u>

For using the FAULT DETECTION sub-module, a certain time period has to be selected by the user then the fault detection code algorithm is called and calculates if there had been possible faults during this period regarding the outlet temperature of the collector field. This is indicated as an orange dot in graph as shown in the following figure.

Figure 21: FAULT DETECTION - visualization of the fault within the data together with the measured value (=actual), the predicted value, the upper and lower threshold for that value and the fault indicated when the actual value exceeds the threshold.

<u>Calculation of KPIs:</u>

In this section the most reasonable KPIs are calculate for the plant and are shown to the operator, as shown in the following figure.



3.3.4 Main lessons-learned

The main lessons-learned from the control installation at RODA, M&R and LARNAUDIE are:

- **Complex system results in error-prone state machines:** from A take away from the installation of RODA is that in case the system gets more and more complex as for RODA, this state machine is only handling the solar side, an efficient control by state machines or simple if-else rules can be error-prone and hard to understand.
- **Positioning of sensors is important:**
  - For solar radiation sensors it has to be assured that it is never shaded with surrounding objects else this can result in problems for the control strategy and can lead to false results when evaluating the plant's performance.
  - Temperature sensors are installed in nearly each measuring circuit and plays a crucial role in the performance evaluation as well as regarding control aspects. It is therefore important that they need to be calibrated regularly. If not, calculated heat flows can be incorrect or even lead to negative values as well as control strategy reacting on a temperature sensor can lead to negative results.
- **Validation phase of the measurements must be scheduled:** after the automation level of a plant has increased by for example installing new sensors, making them digitally available or changing the ICT infrastructure a reasonable validation phase must be scheduled before the control strategies can be implemented. Meaning that it has to be assured that each sensor is correctly installed, has the right naming as in the P&ID, is working properly and is correctly calibrated.

- **Care must be taken if new sensors are integrated:** in case new sensors are integrated to an already running systems, care must be taken that regarding the protocol compatibility of the sensors.

- **Attention has to be paid to data security:** when raising the automation level of a system and make the measurements available for the control tool or other applications, data security becomes an important issue. Therefore, it must be assured, that respective protocols are used (e.g. https) or that some crucial information of the plant is not available from outside or can not be changed from outside the system. Besides the technical parts the personnel must be trained so that a proper handling of the important data can be guaranteed.

- **Reasonable data basis is essential for designing control strategies:** in order to design and develop control strategies for a system a reasonable data basis have to be available. This means that measurement data for a long period of time (in the best case a year), in reasonable quality (e.g. with a time step of one minute) and of the most important influencing variables (e.g. heat flows, solar radiation, consumption quantities). Additionally it is important that the staff operating the system share their thoughts on what they have experienced (e.g fluctuating behaviour in case of action A) with the control strategies developers.

- **Interfaces are crucial:** in case of more advanced control strategies interfaces play a major role, e.g. Sensor ➔ PLC, PLC ➔ SCADA System, SCADA System ➔ Database to name just a few. These interfaces must be properly implemented and extensively tested.

3.4 Procurement, and installation

3.4.1 Aspects to be addressed

- Clear allocation of responsibilities & scope of work need to be agreed between the involved parties (per demo site)
- A large time gap between decision making and implementation may end up in revised decisions

- Low familiarization of the industrial users and their local contractors related to solar thermal poses further challenges; a more systemic approach to training should be applied
- Unexpected events occur more often (pandemic, supply chain disruptions, natural disasters); production and EPC systems should embed resilience
- Insuring the whole system (installation & operation) against natural disasters or other unexpected events can be proved critical.

3.4.2 Component procurement (how to reduce the delay, have identified providers, …)

A SHIP plant consists of a large number of parts. For example, we can mention: the solar collectors, pumps, valves, pipes, insulator, sensors, HMI, PLC, ….

The plant is supposed to work for at least 25 years. Therefore, the components should be chosen regarding their reliability and the availability of spare on the long term. The components of the Balance of Plant (BoP) must be as much as possible standardised and the respective suppliers in place.

Parts with long delivery times must be prioritized in the procurement process. The supply chain records a dramatic increase of the time procurement after the pandemic. In order to ease the component procurement, it is recommended to give priority to regular and locally sourced suppliers.

3.4.3 Factory pre-assembly

In order to reduce costs and time on site, it is recommended to give priority to factory pre-assembly. This is particularly relevant for the BoP which contains a pump station and most of the sensors, valves and other hydraulic components as well as the main switchboard which includes the control interface. The pre-manufacturing of the BoP in a standard sea container increases the shipping volume not significantly but shortens the installation time and complexity onsite.

The PLC pre-assembly is also a very important aspect. A pre-commissioning phase should be done in the factory. It could avoid losing time on site searching for electrical misconnection or eventual bugs program in the logical sequences.

Similarly, a set of pre-assembly panels could reduce the on-site time and save extra costs.

3.4.4 Logistic

The whole solar thermal system is being packed into standardised crates, which are placed and shipped in containers.

Most collector parts can be shipped directly from the manufacturer to the installation site. This reduces both, shipping volume and transport duration.

The subcontractor in charge for installation of the allocated material provides substructure and piping material including insulation locally and usually.

3.4.5 On-site assembly

A detailed installation guide must be written by the techno-provider in order to facilitate on-site works for the installation and commissioning of the solar system.

On-site assembly – installation of the solar field starts after the necessary pre-construction (civil) works (including the installation of substructure, if required) are finished.

There are two organisational options for the installation of the solar field:

- The whole installation is performed by the techno-provider (this may be the case of smaller systems)

- The techno-provider trains and supervises the technical personnel of local contractors, who perform the installation. The techno-provider undertakes the testing and commissioning of the solar systems. Depending on the complexity of the integration, this may be carried out by a specialised subcontractor.

Installation may be divided into the following stages:

- Placement of the panel support structure;
- Installation of the panels;
- Connection of the panels and installation of the piping;
- Installation of the BoP and the electrical & control cabinet (including the sensors).

3.5 Commissioning

The commissioning phase is an important step of the project. The supplier performs the commissioning of the thermal solar plant and the evaluate its performance.

During this phase, the supplier fills the solar system circuit with the working fluid (typically a water – glycol solution). The loading should be done methodically, in order to avoid lo let air in the piping.

Once the circuit is filled, the commissioner must test the pressurisation system and the pump functionalities. At this step a check of potential leaks must be done.

After this step passed, the heating phase should start. The heating should be perform at low, medium and high temperature by changing the temperature setting point on the HMI. The first test should be done in manual mode. The functionality of various components (e.g. dry cooler, sensors, …) is checked.

After the test passed in manual mode, the solar system operation is shifted to automatic mode. In this mode, the local control of the automation is checked. After one (or some) heating/cooling (day/night) cycle, the system is checked for leakages or pressure drop.

Then mechanical works are finalised (e.g. piping insulation- for this part of the piping that is not pre-insulated).

The operation of the solar system is closely supervised for the first couple weeks for troubleshooting and fine-tuning. This period may be extended to ensure the solar systems operates according to expectations under various operating and weather conditions, as well as the anticipated operating modes.

3.5.1 Useful things to know

- Commissioning and troubleshooting requires time and causes delays particularly where there is no local physical presence of the technology provider (direct or indirect)
- Operation of the solar thermal system close at the edge of its capabilities may reveal design failures; this should be reflected in the risk assessment
- Operational integration with other energy solutions may require changes in the operating set-points of the solar thermal system and its control logic
- Data exchange solutions are not always straightforward; the architecture of the data exchange infrastructure and mechanism should be agreed early enough
- There may be experienced coordination challenges and delays due to multi-party involvement (demo site owners; solar thermal technology providers; control tool developers & cloud infrastructure operators; local contractors).

3.6 Maintenance

Solar thermal plants need a minimal maintenance. Even if the maintenance does not require huge work, trained people are needed. It could be an issue for small companies. Usually workers in small companies are dedicated in the production of goods and don’t have specific knowledge in the maintenance of thermo-hydraulic plants. Medium and big companies are more familiar with the maintenance of such components.

In any case, in order to ensure a proper maintenance, it is highly recommended to choose one of the following option:

- train a technician in the industry,
- have an agreement with the plant provider,
- have an agreement with an energy company.

Usually the maintenance is limited to:

- Visual inspection
- Leakage inspection
- Heat transfer fluid loading
- Pump maintenance
- Sensor replacing (in case of failure of one of them).

In case of concentration technologies (parabolic trough, linear Fresnel), a regular mirror cleaning operation should be considered. Dust on the mirror can affect the performance the plant up to 15%.

Even if the plant is sized to face weather events, it is recommended to ensure the solar system against natural hazards and disaster to cover potential damages from e.g. extreme weather events.

In case of a land installation, the land should be well prepared before the building. The land should not be a bare land. The maintenance operations will require to move around the solar field and the balance of plant and the weed growth can interfere in the maintenance.

4 CONCLUSION

This document is a set of lessons learnt during SHIP2FAIR project.

The SHIP guide develops all the necessary steps to develop a SHIP project and maximize its benefits in the less possible complex way.

This document gives practical advice for the 2 mains phases of a project:

- The feasibility study
- The onsite building

The use of the Replication Tool in 10 uses cases demonstrates that the cost of Solar Heat is already competitive regarding the current price of fossil fuel. We explained the different business model possible as well as the possible incentives regarding the country considered.

During the project, we enlighten the very important aspect of the control strategy. This aspect should be addressed from the beginning of the project. We explained the different level of control possible for optimizing the integration of solar energy in the existing process.

The preparatory phase is very important to avoid misunderstanding between the end user and the techno provider. The detailed engineering is probably the most important aspect for a successful project. We should pay a particular attention to the connection point, the functioning modes, the data transfer between the existing sensors and the new controller, the temperature setting point and the local environment.

The on-site building should be as short as possible in order to avoid disturbance in the existing process. The more the preparation phase is meticulous, the less the impact on-site on the industrial process will be. Some advice for the commissioning and the maintenance phases are presented.