



Solar Heat for Industrial Processes
towards Food and Agro Industries
commitment in Renewables

The SHIP2FAIR Control Tool Webinar, 01/06/2021

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BEST – Bioenergy and Sustainable Technologies



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GOAL

The Control Tool is a tool able 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)
- through an **high-level optimization of the whole system**
- to advanced **data-mining techniques** (e.g. fault detection, forecasts, ...)

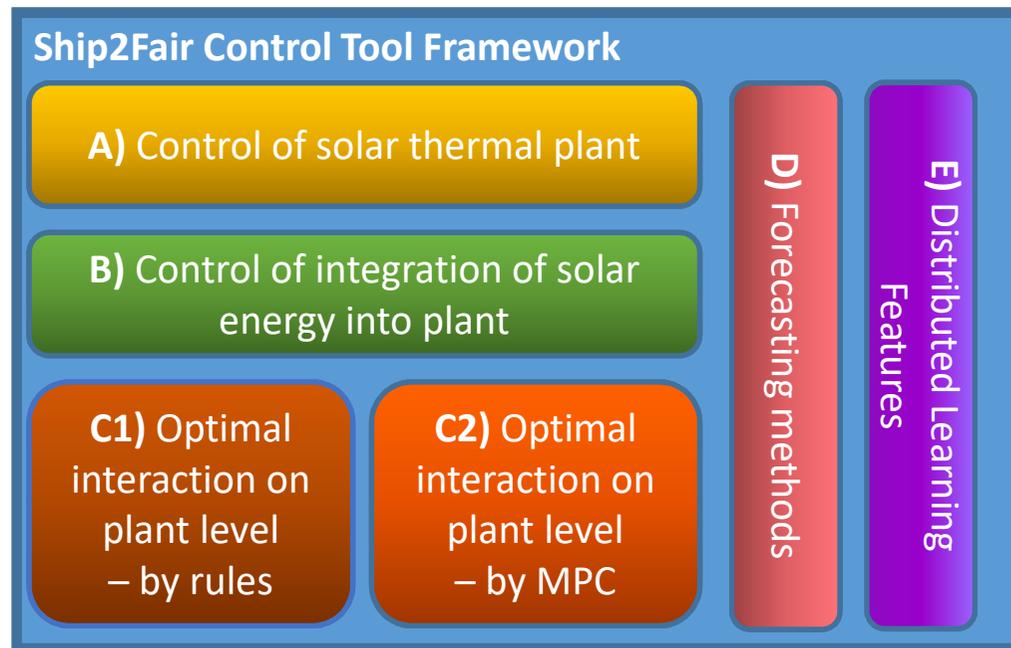
DESIGN

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)

Design of the Control Tool

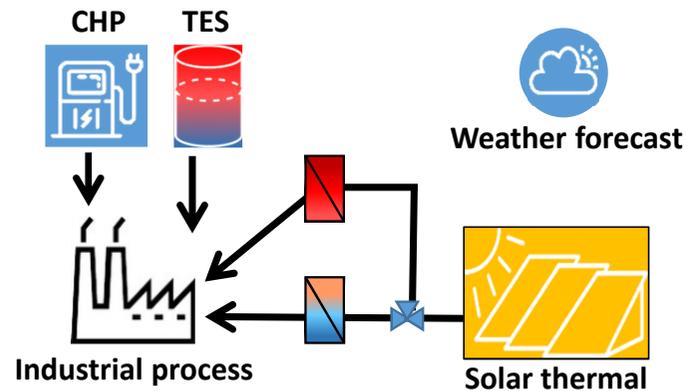
- Consists of a Framework of 5 MODULES which allow to make the most of the solar production.
- MODULES are chosen based on the possibilities available on-site
- Chosen MODULES form specific CONTROL TOOL for a plant



Low level of automation
(less sensors, manual readings, ...)

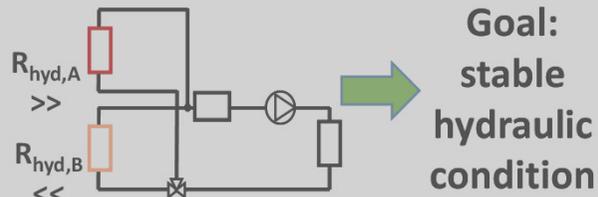
High level of automation
(many sensors, digital recorded, ...)

Control Tool Framework modules related to plant level

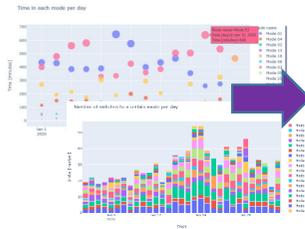


Control Tool Framework modules related to plant level

B) Control of integration of solar energy into plant

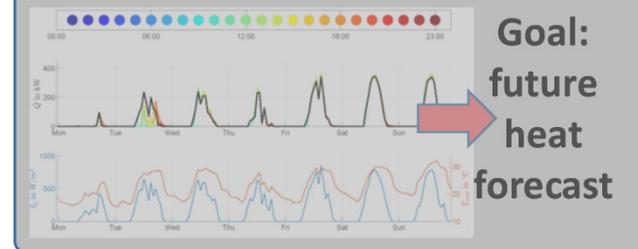


E) Distributed Learning Features



Goal: efficient & smart monitoring

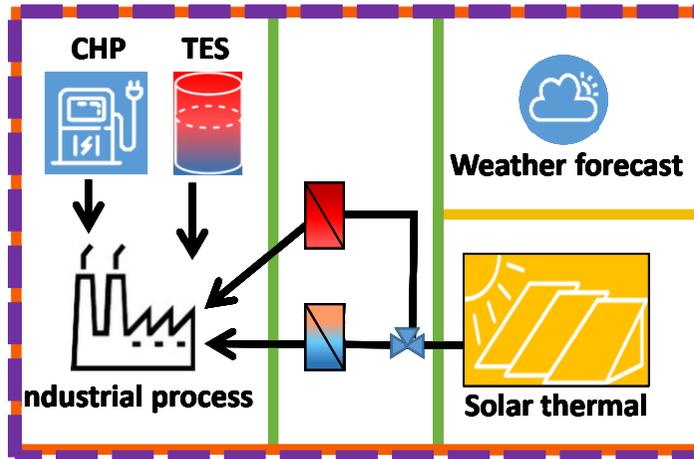
D) Forecasting methods



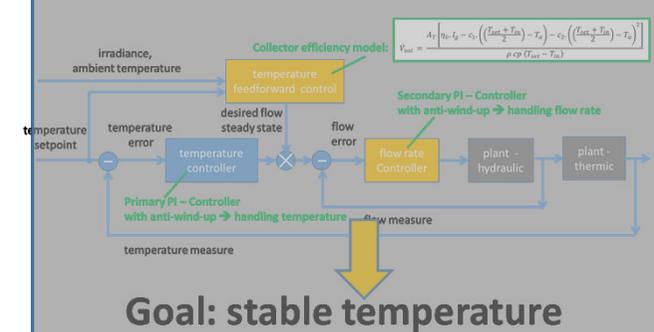
C2) Optimal interaction on plant level



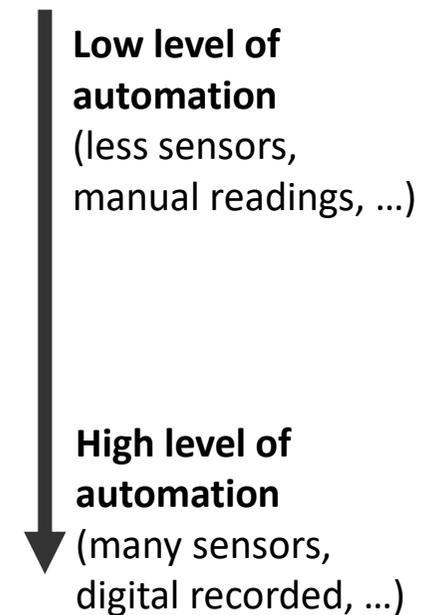
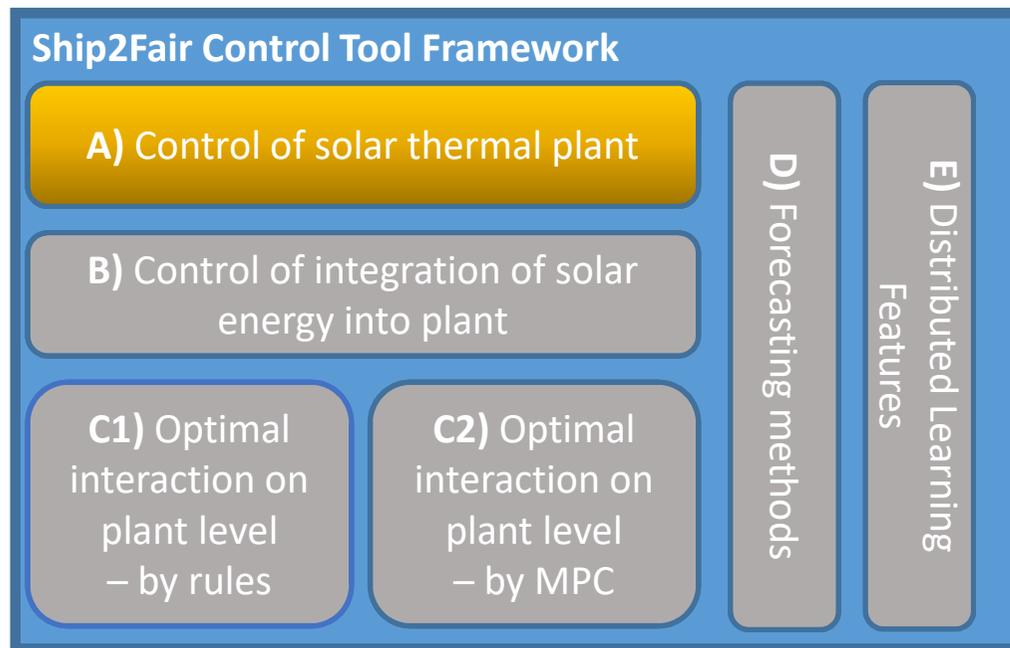
Goal: optimal overall control



A) Control of solar thermal plant



Exemplarily explanation Module A

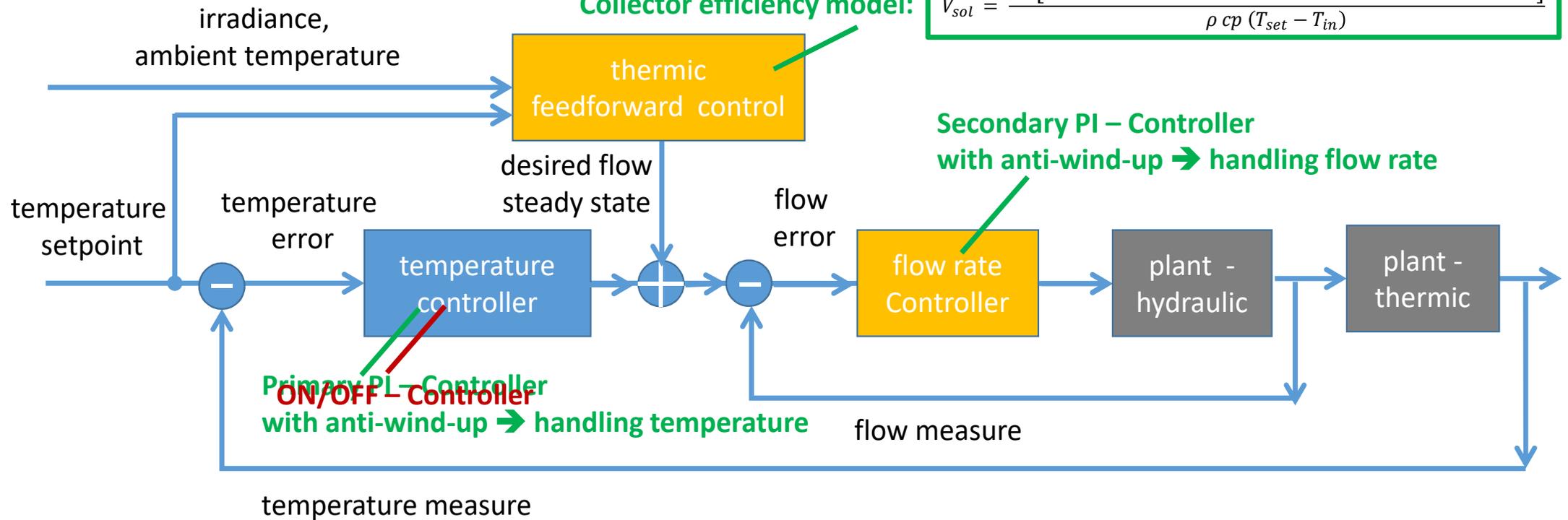


Further explanation of Module A – Control of solar thermal plant

Model-based controller for non-concentrating collectors

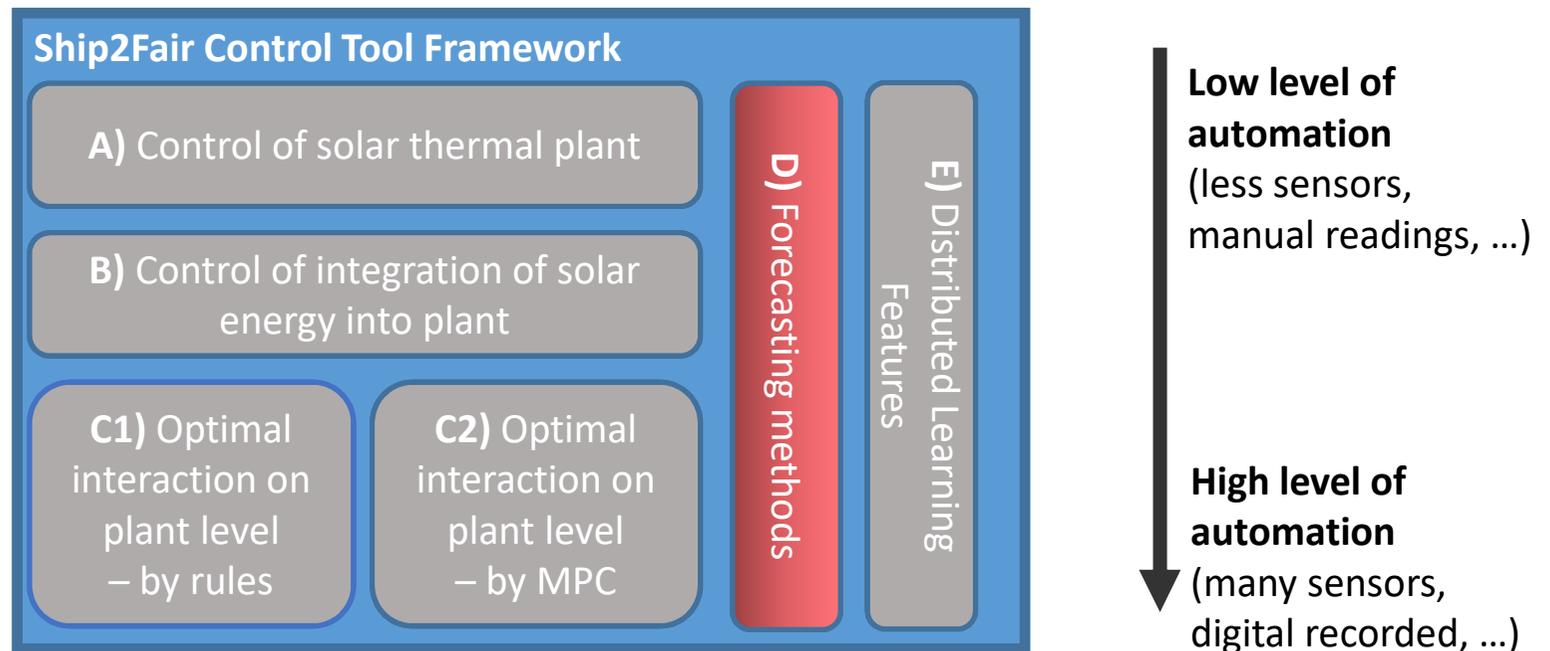
$$\dot{V}_{sol} = \frac{A_T \left[\eta_0 \cdot I_g - c_1 \cdot \left(\frac{T_{set} + T_{in}}{2} - T_a \right) - c_2 \cdot \left(\frac{T_{set} + T_{in}}{2} - T_a \right)^2 \right]}{\rho \cdot c_p \cdot (T_{set} - T_{in})}$$

Collector efficiency model:



MODULE A - focuses on the optimal operation of the solar plant, e.g. control the outlet temperature → handles disturbances (e.g. fluctuating solar radiation), reacts in real time Implemented on PLC

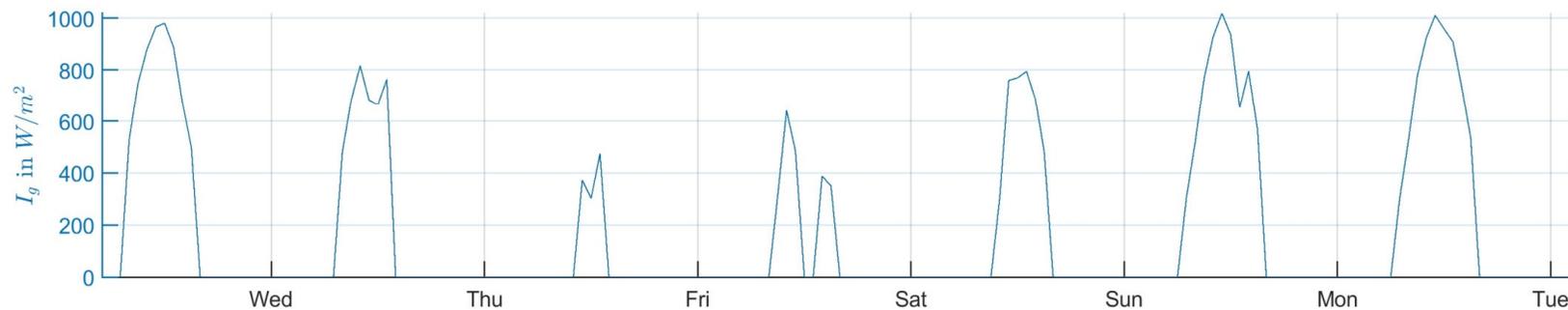
Exemplarily explanation Module D





D) Forecasting methods

Adaptive forecasting method for forecasting the solar heat



→ Accuracy of about 95%

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

OPEN ACCESS:

<https://www.sciencedirect.com/science/article/pii/S0306261921003779?via=ihub>

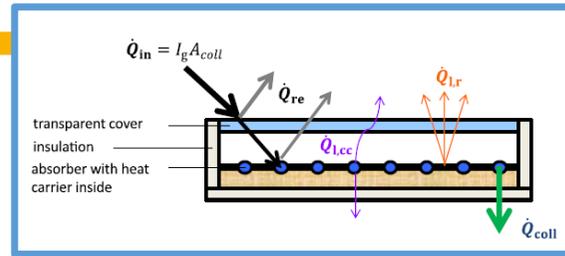
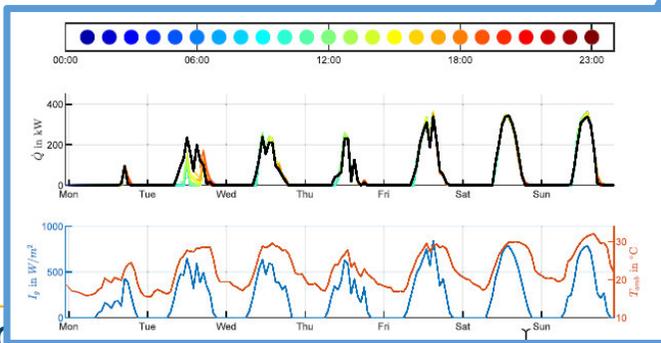
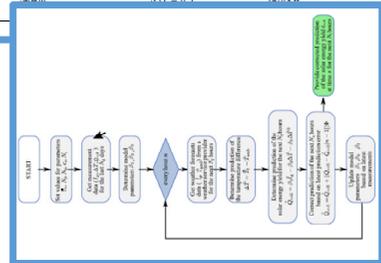


Table 1
Table of the different solar collector systems investigated with their application, net collector area, orientation, nominal solar heat production and location.

Abbreviation	Application	Net collector area	Orientation	Nom. heat production	Location
SFR _{1,5,5}	Process heat	215 m ²	SE ($\gamma = -5^\circ$)	150 kW	Kuwait
SFR _{1,5,30}	Hot water	286 m ²	SW ($\gamma = 30^\circ$)	172 kW	Austria
SFR _{1,5,SE}	Hot water	782 m ²	SE ($\gamma = 15^\circ$)	469 kW	Austria
SFR _{1,5,S}	Hot water	2464 m ²	S ($\gamma = 0^\circ$)	1478 kW	Austria



An adaptive short-term forecasting method for the energy yield of flat-plate solar collector systems
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ARTICLE INFO

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 Solar thermal
 Adaptive
 Flat plate collector
 Experimental validation
 Weather forecasts

ABSTRACT
 The number of large-scale solar thermal installations has increased rapidly in Europe in recent years, with 70% of these systems operating with flat-plate solar collector. Since these systems cannot be easily switched on and off but directly depend on the solar radiation, they have to be combined with other technologies or integrated in large energy systems. In order to most efficiently integrate and operate solar systems, it is of great importance to consider their expected energy yield to better schedule heat production, storage and distribution. To do so the availability of accurate forecasting methods for the future solar energy yield are essential. Currently available forecasting methods do not meet three important practical requirements: simple implementation, automatic adaption to seasonal changes and wide applicability. For these reasons, a simple and adaptive forecasting method is presented in this paper, which allows to accurately forecast the solar heat production of flat-plate collector systems considering weather forecasts. The method is based on a modified collector efficiency model where the parameters are continuously reestimated to specifically consider the influence of the time of the day. In order to show the wide applicability the method is extensively tested with measurement data of various flat-plate collector systems covering different applications (below 200°C/colou), sizes and orientations. The results show that the method can forecast the solar yield very accurately with a Mean Absolute Range Normalized Error (MARNE) of about 5% using real weather forecasts as inputs and outperform common forecasting methods by being nearly twice as accurate.

1. Introduction

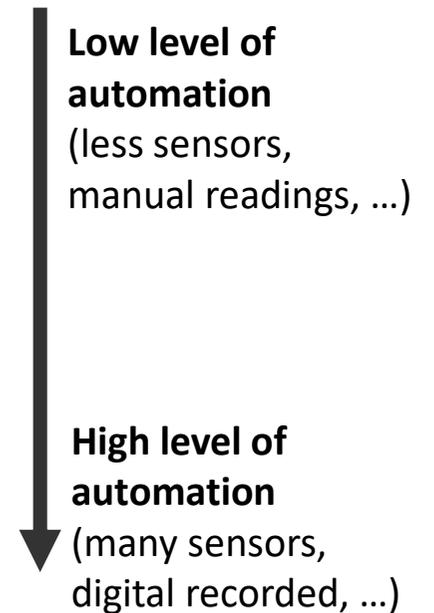
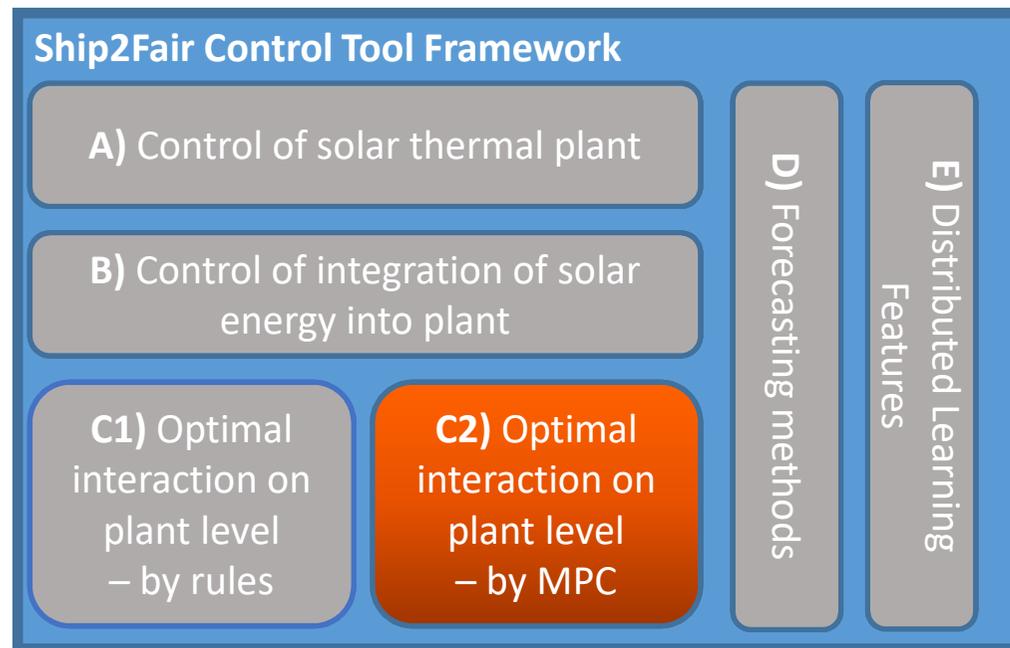
In 2019, solar thermal heat represented one of the top three renewable sources driving climate protection, together with wind power and photovoltaics [1]. In this context, the number of large-scale solar heating installations has increased rapidly in European countries, e.g., in Denmark [2], but also worldwide in the last couple of years, leading to the installation of about 400 large-scale solar thermal systems (>350 kW_{th}, 500 m²) by the end of 2019 [1]. In Europe, about 70% of all solar thermal systems installed are flat-plate solar collectors [1], making them an important technology in this sector.

Even though the systems are mature and achieve high efficiency rates, they cannot be simply switched on and off but directly depend on the solar radiation. For this reason, these systems have to be combined with other technologies or integrated into large energy systems. In both cases, it has been shown that a significant potential exists for improvement when considering the future solar yield in their high-level controllers, e.g. energy management system (EMS), see [3], in order to optimally schedule heat production, storage and distribution for the near future, e.g. [4]. For example, by considering the predicted solar energy yield, the number of unnecessary operations performed by other heat production units (e.g. gas boilers) can be reduced, while managing the heat storage and the distribution in ways that always allow the full solar yield to be used, saving money and increasing the overall system performance. Furthermore, critical overheating problems in the solar plant can be eliminated since knowing the predicted solar yield enables night-cooling strategies to be applied well ahead of time (e.g., see [5]).

In view of practical applicability, the forecasting method of the future solar energy yield should meet three requirements:

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<https://doi.org/10.1016/j.apenergy.2021.116691>
 Received 16 December 2020; Received in revised form 1 March 2021; Accepted 28 March 2021

Exemplarily explanation Module C



Further explanation Module C – Overview

MODULE C focuses on the optimization of the **whole plant**, based on **rules** or by a **Model Predictive Controller (MPC)**.

The MPC

- considers a **mathematical models** of the whole system (including thermal storages, heat producers, etc.),
- takes into account **forecast data** (e.g. **production** and **energy demand**)
- and calculates the **optimal operation strategy** for a prediction horizon (e.g. 24h) based on a **cost function** (e.g. overall costs, CO₂ emissions)

Further explanation Module C – mathematical model for MPC

- Models developed for **different components** of a system and programmed in Julia ([LINK](#))



Further explanation Module C – mathematical model for MPC

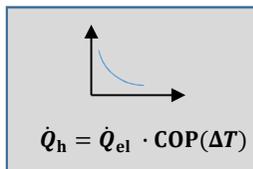
- Models developed for **different components** of a system and programmed in Julia ([LINK](#))



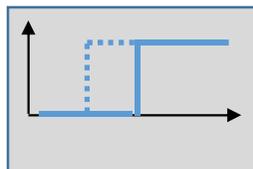
→ for a **modular approach** these models can be **combined to form a model of the whole system** (see next slide)

- Models have to have a **certain mathematical structure** to be used in **MPC** and consider:

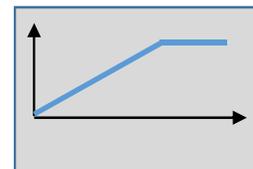
Input/output relationship



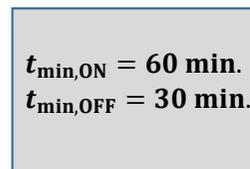
Transport delays



Ramp speed

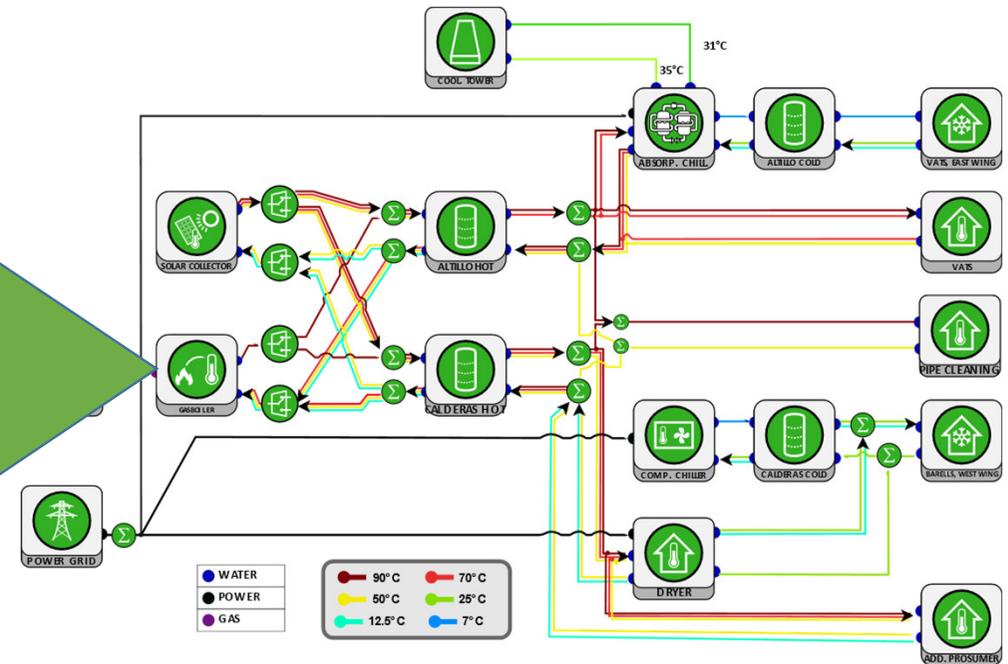
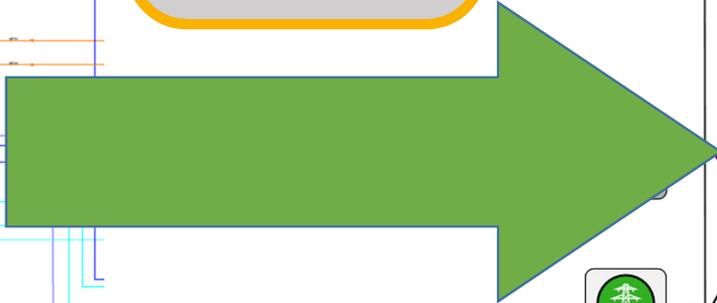
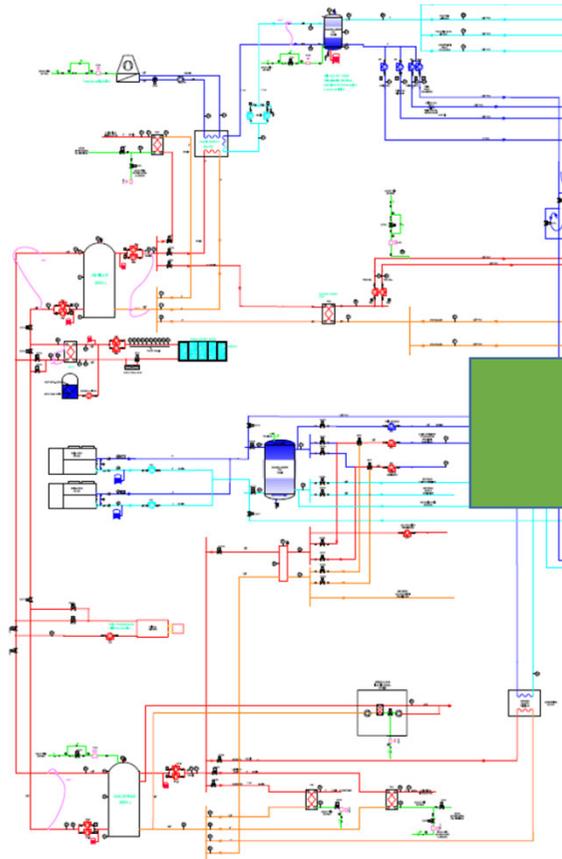


Constraints



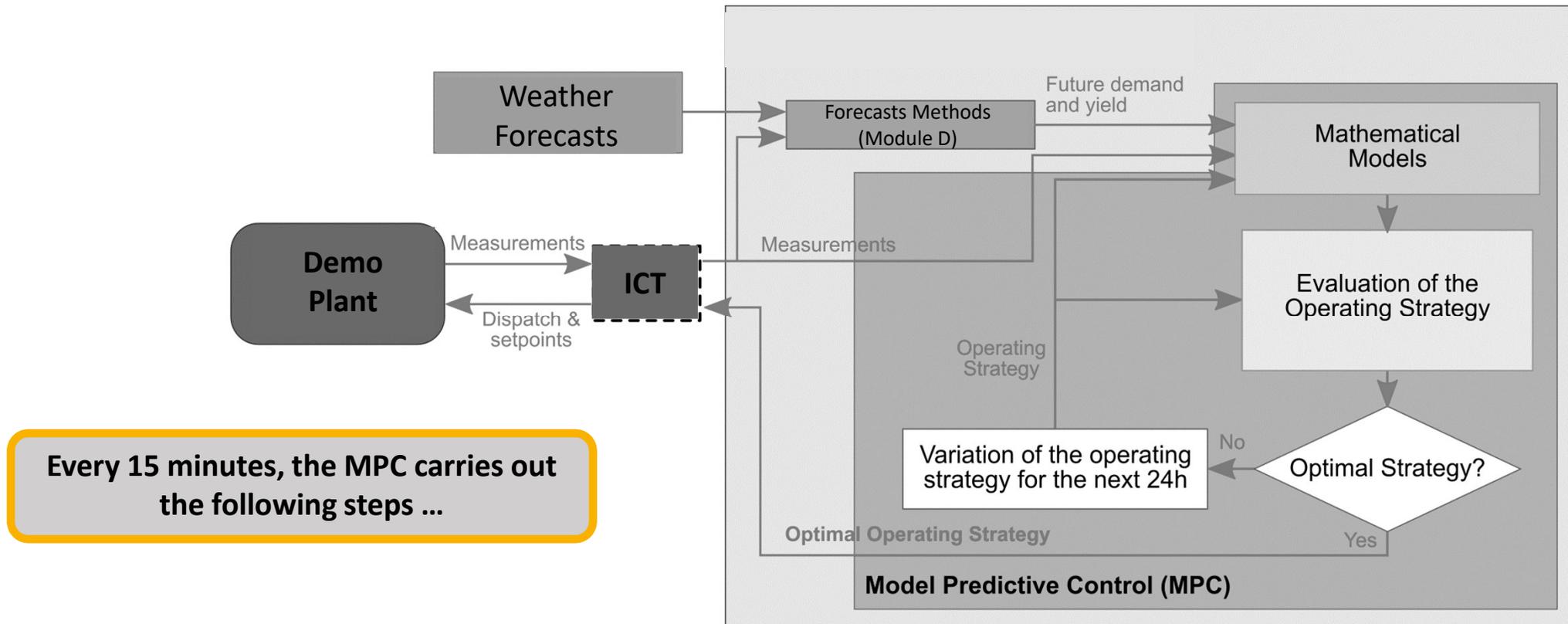
Exemplarily application of the MPC

Based on the real structure of the system, the right models are combined



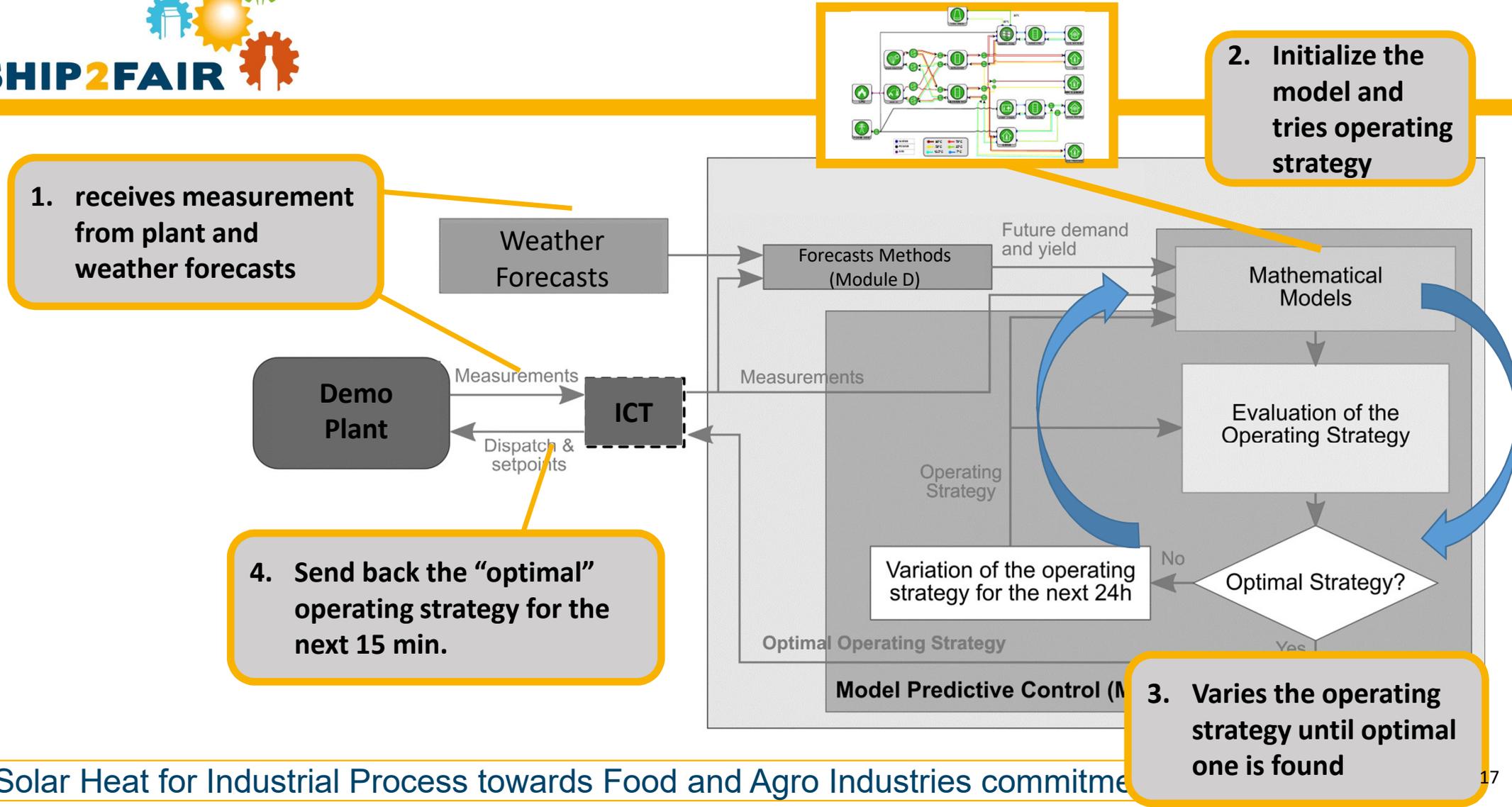
Model represents the whole system and its connections and considers prices for heat, gas, electricity, ...

Simulation of MPC

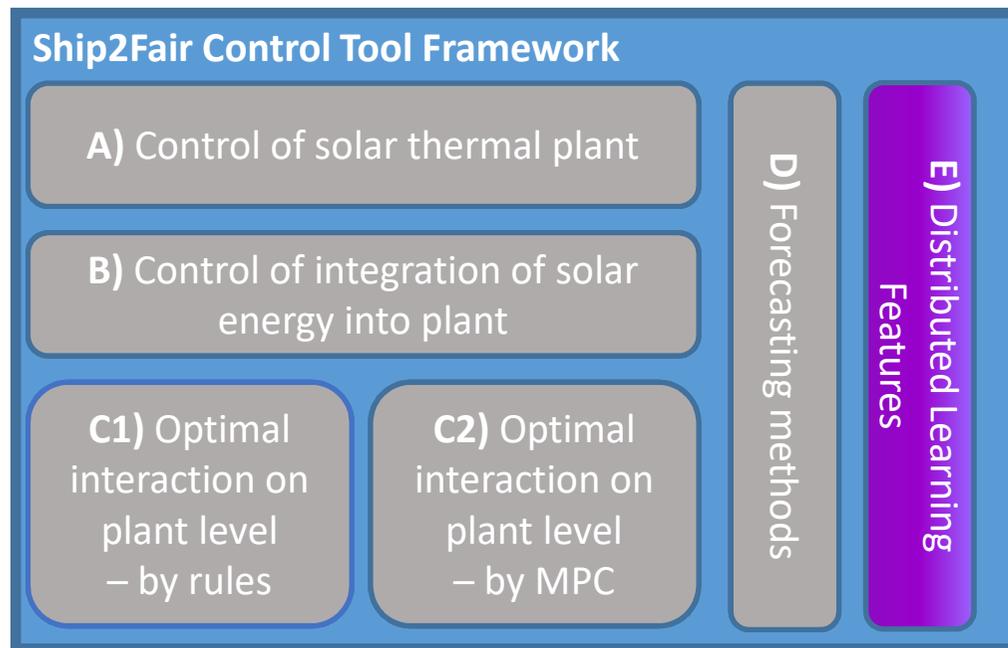


Every 15 minutes, the MPC carries out the following steps ...

Simulation of MPC



Exemplarily explanation Module E

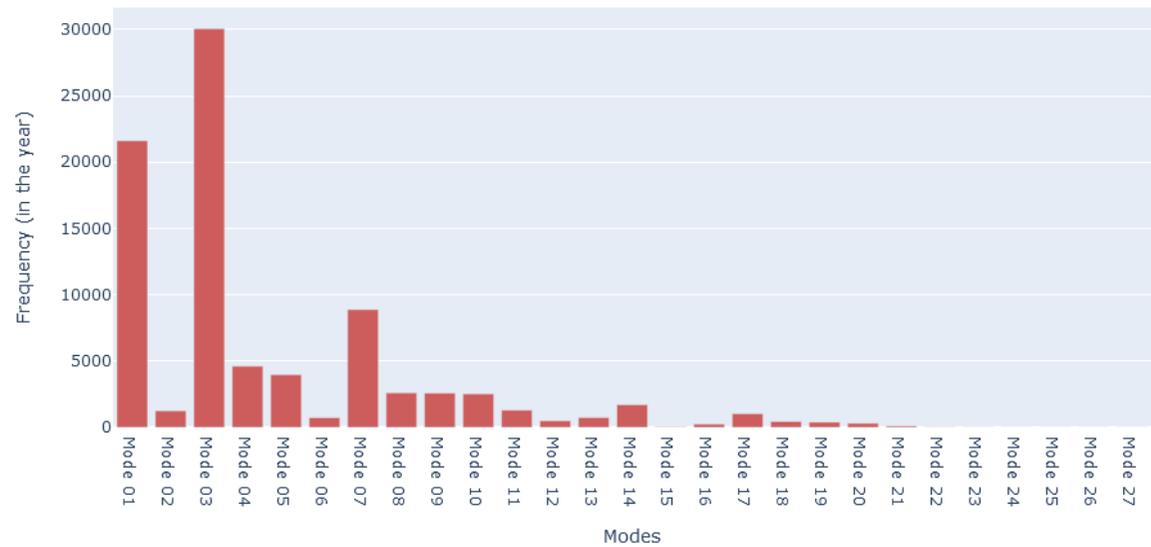


Low level of automation
(less sensors, manual readings, ...)

High level of automation
(many sensors, digital recorded, ...)

Example - Pattern recognition

- Complete data driven approach to detect patterns which exist on-site



pumps	Mode 01	Mode 02	Mode 03	Mode 04	Mode 05	Mode 06	Mode 07	Mode 08	Mode 09	Mode 10	Mode 11	Mode 12	Mode 13	Mode 14	Mode 15	Mode 16	Mode 17	Mode 18	Mode 19	Mode 20	Mode 21	Mode 22	Mode 23	Mode 24	Mode 25	Mode 26	Mode 27
0 roBlrPmpHexHst02Ret	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1 roChiPmpCmrRet	0	0	0	0	0	0	1	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	0	0	1
2 roHst01PmpChiFlo	0	0	0	0	0	0	1	1	1	1	1	0	0	0	1	0	0	0	0	1	0	1	0	0	1	1	1
3 roHst01PmpHexRcoRet	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4 roSolHexHst02PmpRet	0	0	1	0	1	1	0	1	1	0	1	1	0	0	0	1	0	1	1	1	1	1	0	0	0	1	1
5 roSolPmpHexHst02Flo	0	1	1	0	1	0	0	1	0	0	1	1	1	0	1	0	0	1	0	0	0	1	1	1	0	1	1
6 roSolPmpHst01Ret	0	0	0	1	1	1	1	1	1	0	0	0	1	1	1	0	0	1	1	0	0	0	1	0	0	0	0



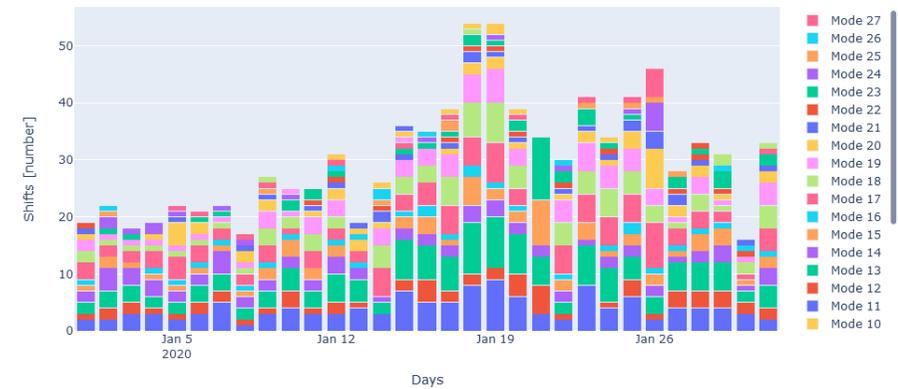
Example - Pattern recognition

Task 5.4

Time in each mode per day



Number of switches to a certain mode per day

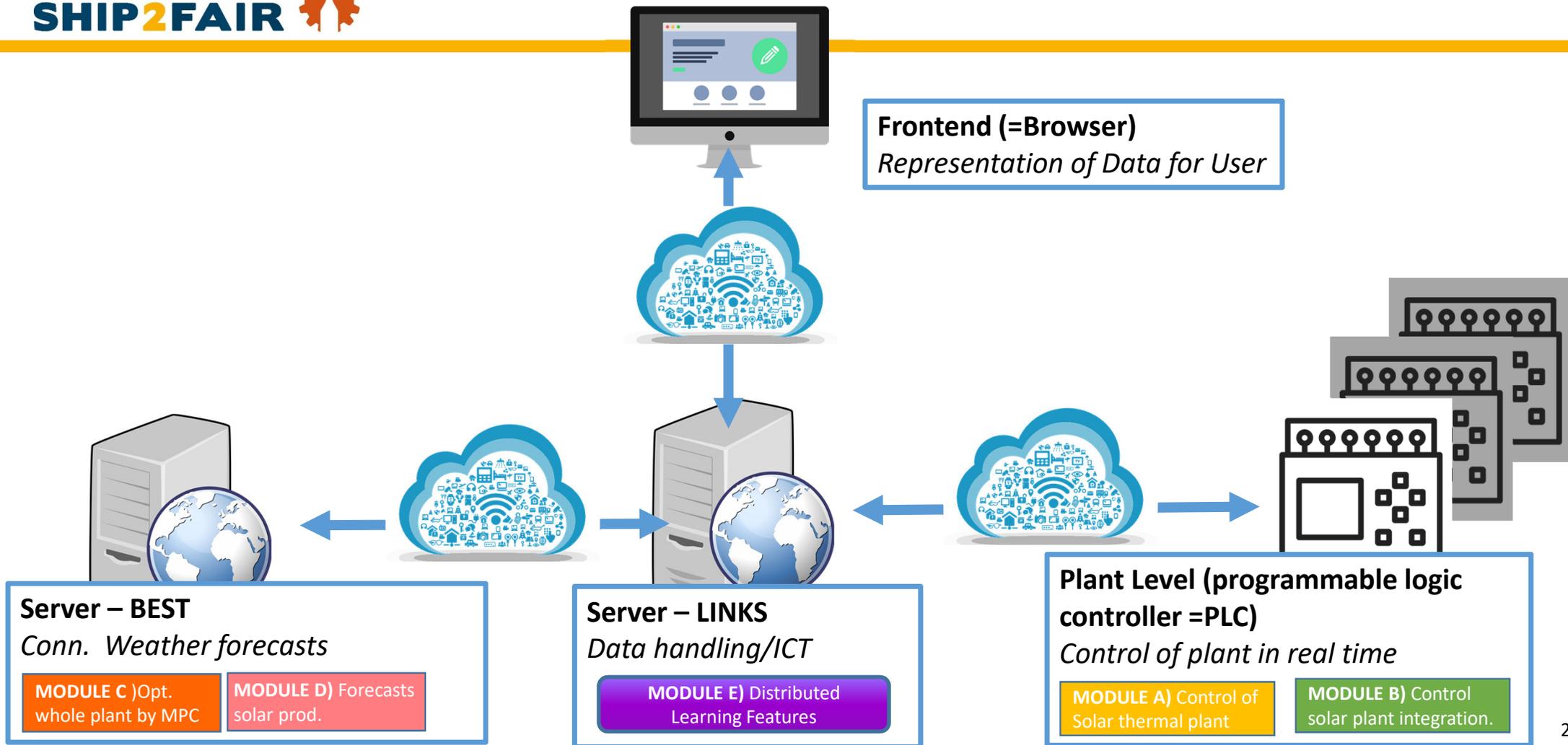


	pumps	Mode 01	Mode 02	Mode 03	Mode 04	Mode 05	Mode 06	Mode 07	Mode 08	Mode 09	Mode 10	Mode 11	Mode 12	Mode 13	Mode 14	Mode 15	Mode 16	Mode 17	Mode 18	Mode 19	Mode 20	Mode 21	Mode 22	Mode 23	Mode 24	Mode 25	Mode 26	Mode 27		
0	roBlrPmpHexHst02Ret	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1	roChiPmpCmfrRet	0	0	0	0	0	0	1	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	0	0	0	1	
2	roHst01PmpChiFlo	0	0	0	0	0	0	1	1	1	1	1	0	0	0	1	0	0	0	0	1	0	1	0	0	1	1	1	1	
3	roHst01PmpHexRcoRet	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
4	roSolHexHst02PmpRet	0	0	1	0	1	1	0	1	1	0	1	1	0	0	0	1	0	1	1	1	1	0	0	0	1	1	1	1	
5	roSolPmpHexHst02Flo	0	1	1	0	1	0	0	1	0	0	1	1	1	0	1	0	0	1	0	0	0	1	1	1	0	1	1	1	
6	roSolPmpHst01Ret	0	0	0	1	1	1	1	1	1	0	0	0	1	1	1	0	0	1	1	0	0	0	1	0	0	0	0	0	

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

Implementation and Integration of the Control Tool

Planned integration of Control Tool





Example of Front-end - Current implementation

MONITORING

FORECASTING

MPC SUGGESTIONS

INNOVATIVE FUNCTIONALITIES

KPI

Monitoring

Plant
LINKS Solar Plant Tes

MODULE C: "Model Predictive Control" commands and displayed + sent to the plants

MODULE E: "Distributed learning features"

A subset of Technical Key Performances Indicators available

End Date
April 22nd 02:00 am

- Select a sensor...
- Tank temperature (down)
 - Tank temperature (up)
 - Inlet fluid temperature to the solar field
 - Outlet fluid temperature to the solar field

- Select a plant...
- LINKS Solar Plant Test
 - LINKS Process Plant Test

Start Date
April 21st 02:00 am

End Date
April 22nd 02:00 am

Select a sensor
Please select a plant first

CANCEL OK

industries commitment in Renewables



Front-end - Demo

http://ripley.polito.it/CT_video.mp4

A screenshot of a web browser window showing the login page for the SHIP2FAIR Control Tool. The browser's address bar displays the URL "https://controltool.ship2fair.cloud/login". The page features a central "Sign in" form with a red lock icon above the title. The form includes an "Email Address" field containing "carlo.neri@linksfoundation.com" and a "Password" field with masked characters. A blue "SIGN IN" button is positioned below the fields. At the bottom of the page, there is a copyright notice: "Copyright © SHIP2FAIR 2020." and a footer containing the European Union flag, a disclaimer about funding from the Horizon 2020 programme, and social media icons for YouTube, LinkedIn, and Twitter.



Summary of the Control Tool

- The SHIP2Fair Control Tool consists of a **modular framework** of different MODULES A to E
- The different MODULES can be 'plugged together' to form a ***specific Control Tool*** tailored to the needs of the demo plants and the possibilities on-site
- Parts of this specific Control Tool has to **implemented on plant level** and **some on a higher level** (e.g. a server with access to large amount of data and higher computational resources)
- A **front-end (GUI)** can be accessed by the **plant operator** to **investigate their data**, see the **forecasts** and **suggestions by the MPC**
- The Control Tool will be **implemented in the next months** and tested **on-site** to evaluate its performance in practice.



Thank you!

Viktor Unterberger

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