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Off-design study of a waste heat recovery ORC module in gas pipelines recompression station

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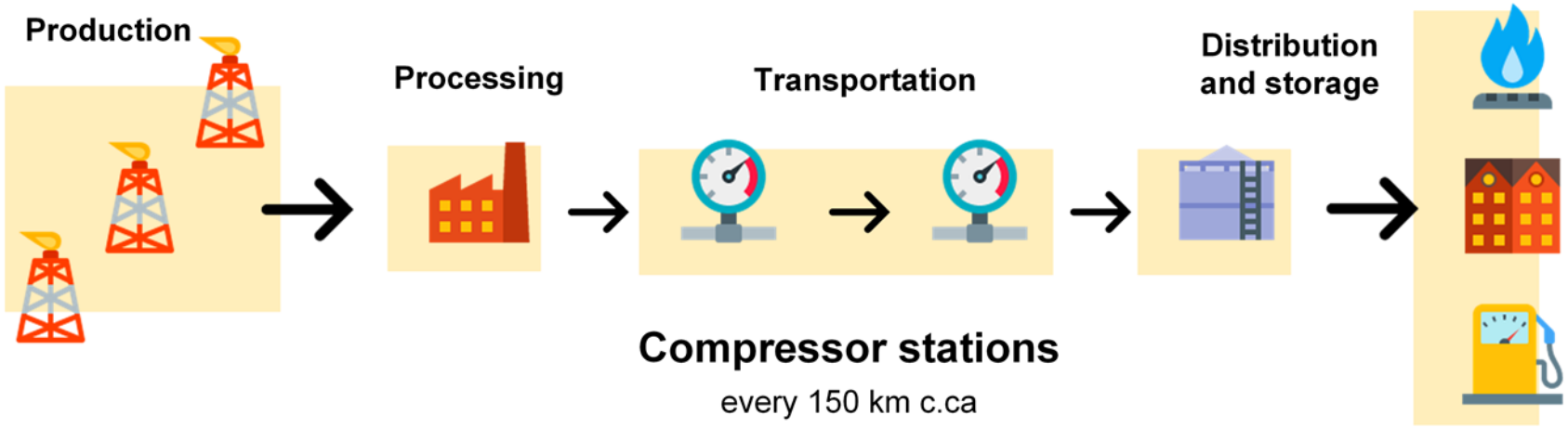
Outline

- Introduction
- Modelling of the natural gas compressor station
- Design conditions and modelling of the ORC
- Off-design conditions and modelling of the ORC
- Results
- Conclusions

Natural gas pipelines and recompression station

- Natural gas accounts for 21.6% of the world electricity generation and more than 15% of the world total final energy consumption
- Total length of NG pipelines worldwide: >2.7 million km.
- Compressor stations are needed every 100-200 km.

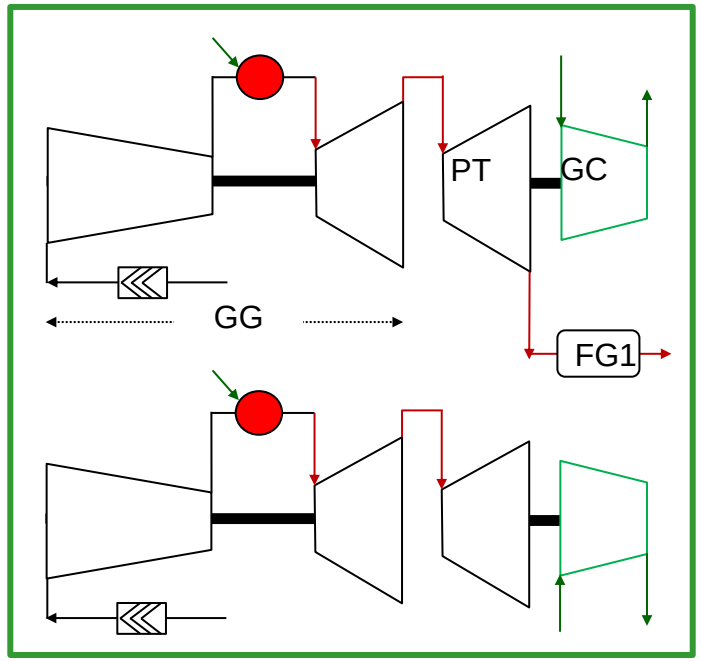


- A compressor station consists in small GTs (5-35 MW) that mechanically drive NG compressors to increase pressure.
- From the GT exhausts, a large amount of heat at relatively high temperature (400-600°C) is available for heat recovery.

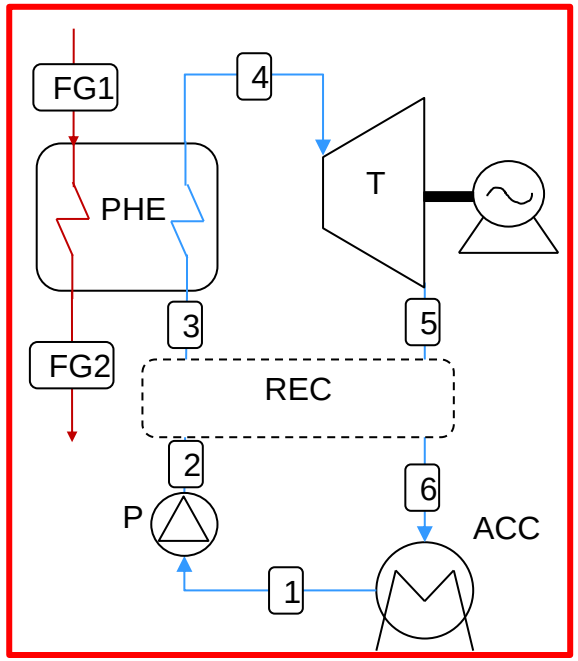
Compressor station and bottoming ORC layout

- Centrifugal compressor: 2 x PCL801
- Gas turbine: 2 x PGT25
- The HRSG collects the exhausts from a single GT of the compressor station.
- The ORC drives an electric generator.

Compressor Sets



ORC Power Block

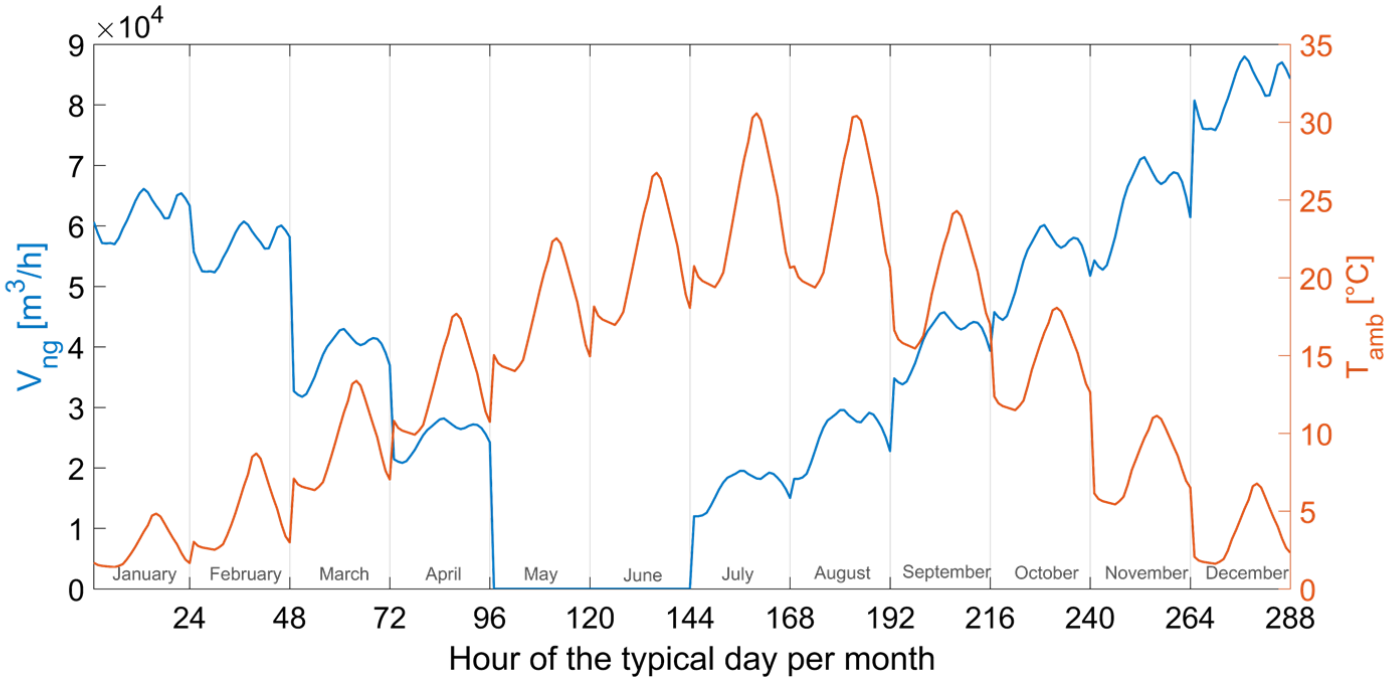


Legend

→ Flue Gas
→ Natural Gas
→ORC Fluid
PT: Power Turbine
GC: Natural Gas Compressor
GG: Gas Generator
PHE: Primary Heat Exchanger
REC: Recuperator
T: ORC Turbine
P: Pump
ACC: Air Cooled Condenser

Annual profiles of the compressor station conditions

- The synthetic trends selected for the annual simulation consist in 12 different 24 hours data sets, representing a typical day for each month.
- The ambient temperature and NG processed volume flow rate profiles are based on experimental data of Poggio Renatico compressor station

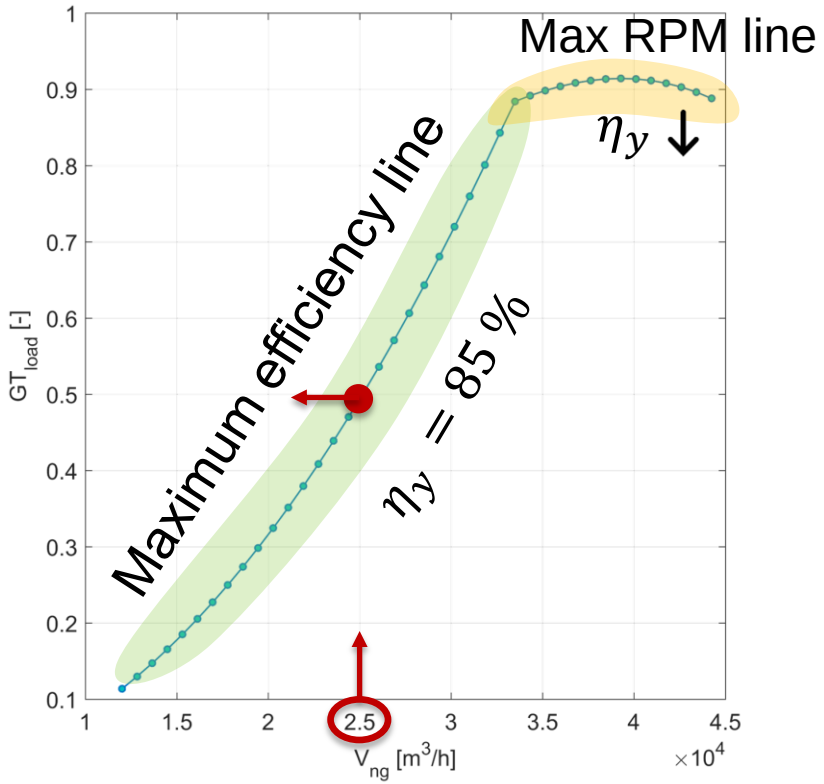


- The compressor station considered in the study is characterized by a high variability of both NG processed by the station and ambient temperature.
- This leads to a **high variability of the topping GT load**: the bottoming cycle has to be sized to **maximize the annual energy output**.

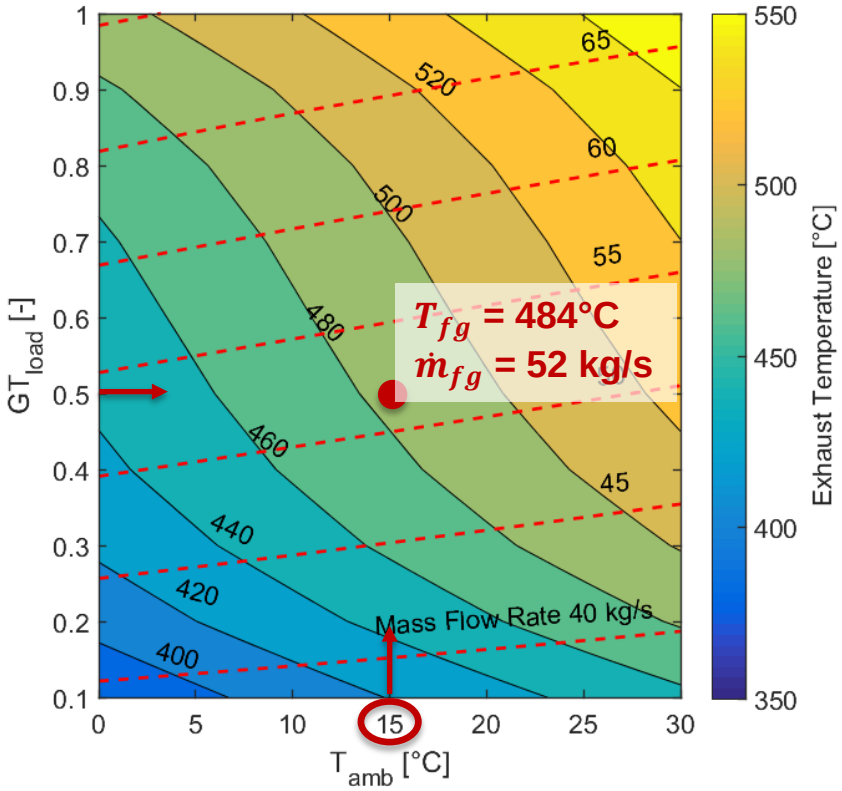
NG compressor and GT modelling

- Starting from the annual NG profile, it is possible to obtain **the profile of the GT load** through the matching between NG compressor and the power turbine.
- Then, through the GT performance map, **the exhaust conditions** are computed.

NG compressor operating points

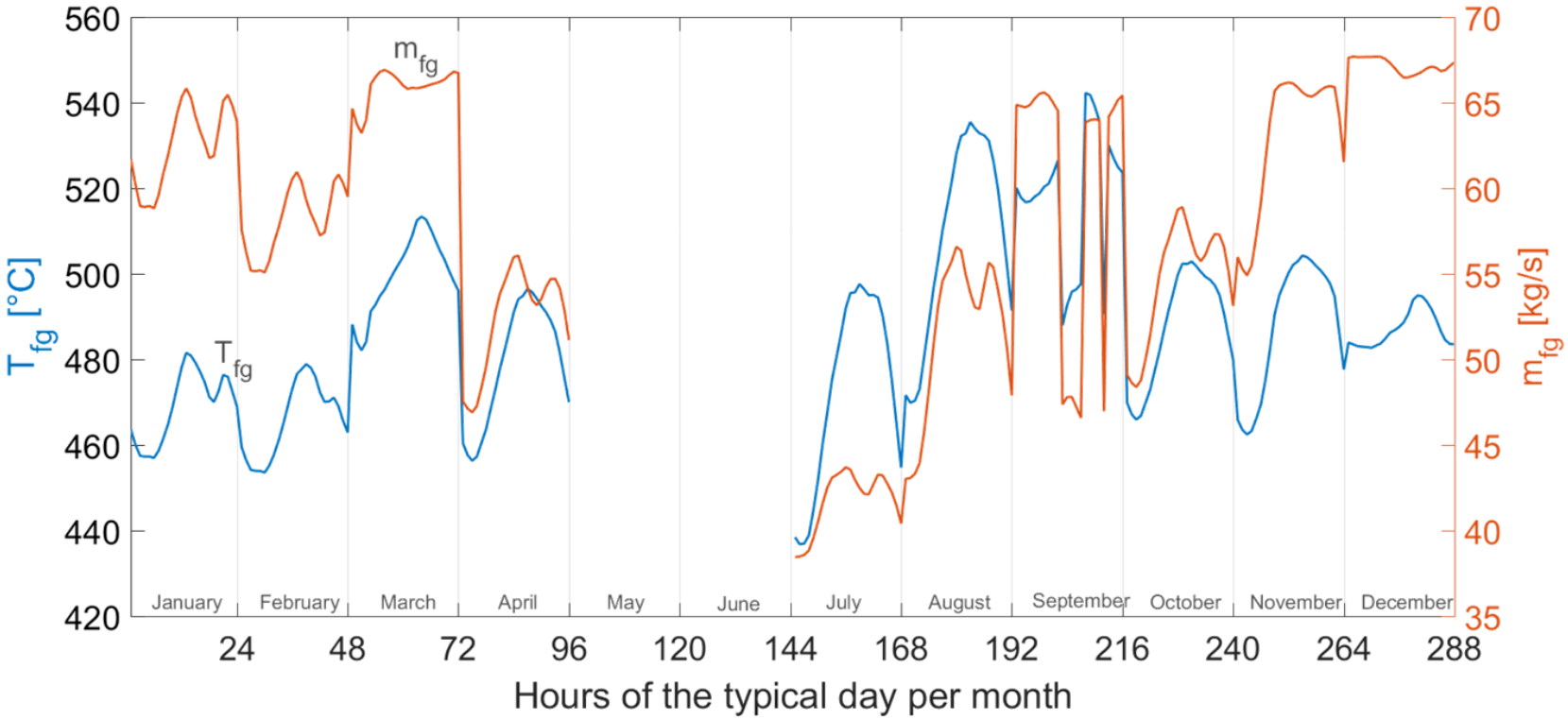


GT performance map



Annual profiles of the exogenous conditions of the ORC

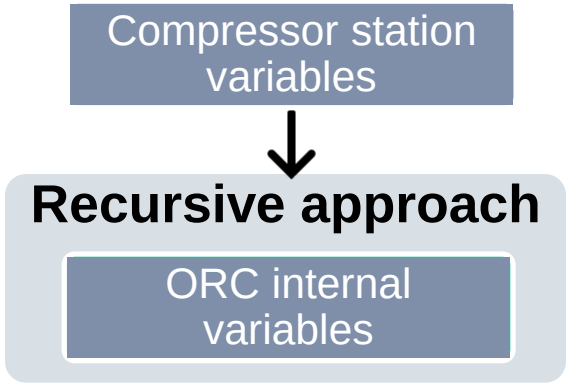
- The resulting values of $\dot{m}_{fg}$ and T_{fg} hourly values can be adopted for the annual simulation of the plant.
- From these profiles it is possible to select a nominal condition to be used as inputs in the design optimization tool and evaluated through the annual simulation.



Objective of the study: Maximization of the energy output of the bottoming cycle (**final energy output optimization**)

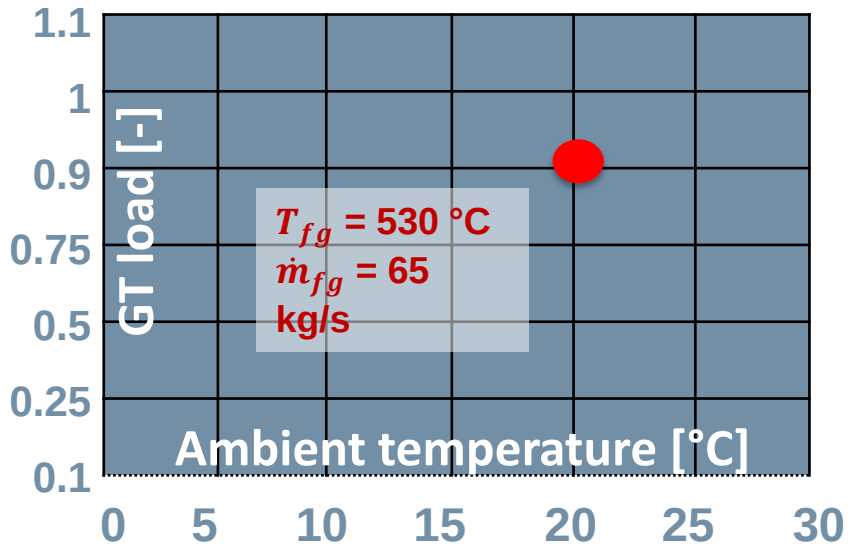
The **nominal configuration of the ORC** has to be selected in order to maximize the annual energy output rather than maximize the nominal power output.

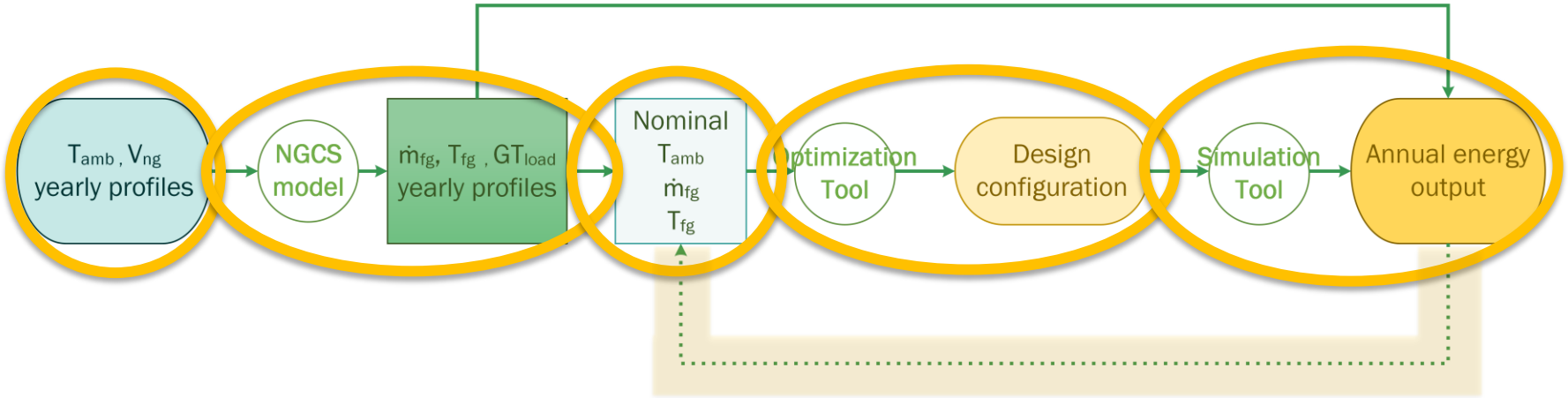
Necessity to model the ORC for both the **design configuration** and **annual off-design simulation**, to evaluate the **effects of the nominal conditions selection** on the total annual energy production.



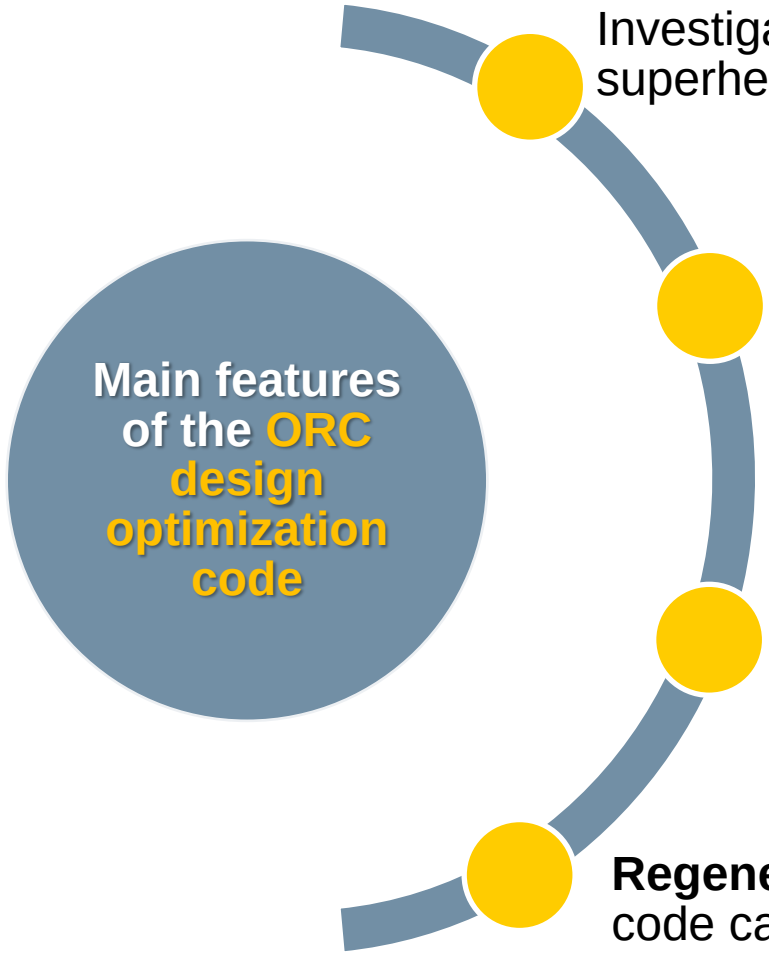
Selection of nominal input conditions for the ORC

- Implementation of parametric maps
- The maps are built on a 7x7 grid of $\boldsymbol{T_{amb}}$ and $\boldsymbol{GT_{load}}$ values.
- For each couple of values, $\dot{m}_{fg}$ and T_{fg} have been computed, and a design configuration + off-design simulation has been performed.





On-Design bottoming ORC optimization tool



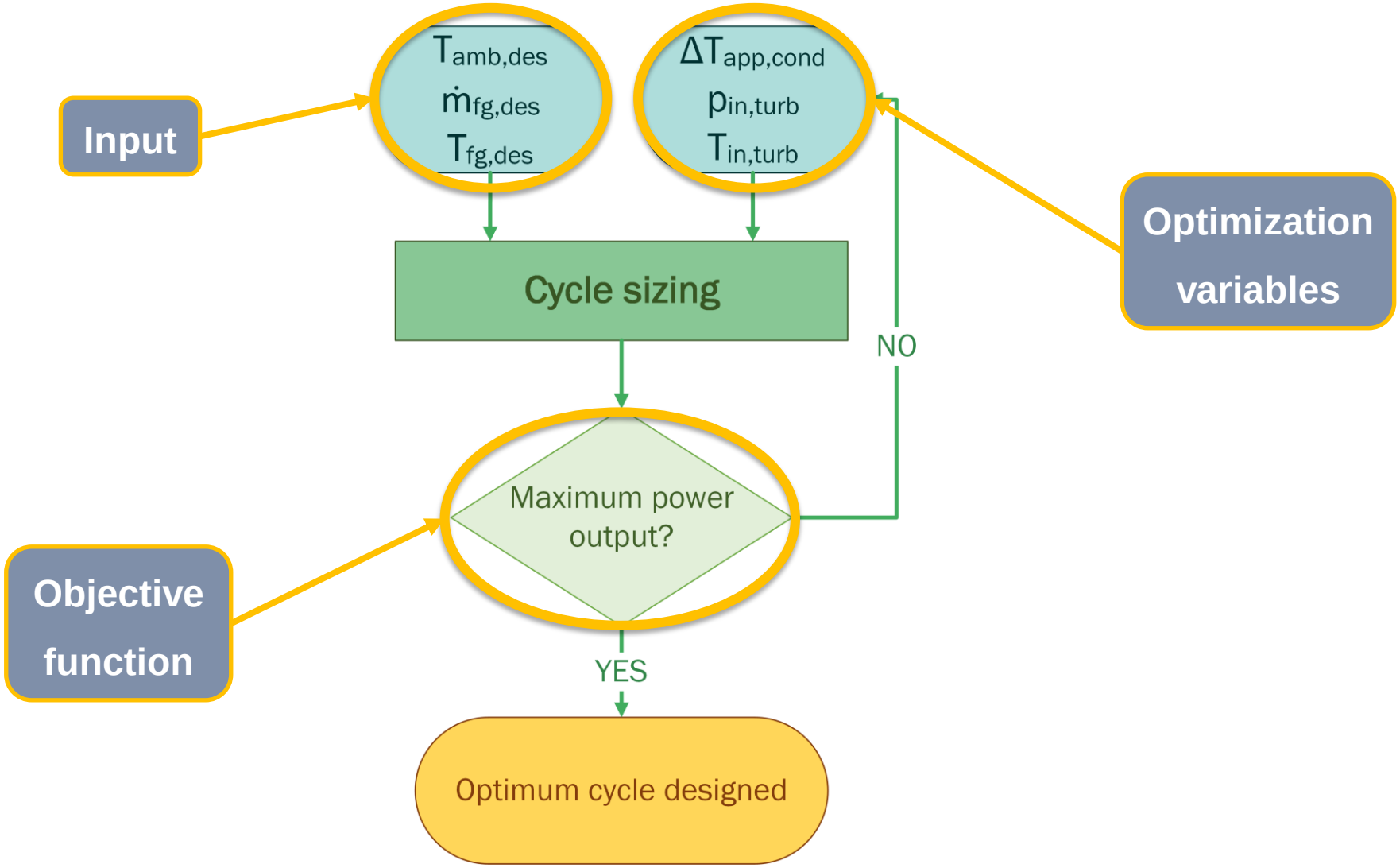
Investigation on **subcritical** (both saturated and superheated) and **supercritical** cycles

Turbine efficiency not fixed and computed through a proper correlation as a function of the turbine **size parameter** and **volume ratio**

Proper **localization of pinch point** temperature differences through heat exchangers **discrete modelling**

Regenerator is optional and, if present, the code can investigate its **feasibility**

On-Design bottoming ORC optimization tool

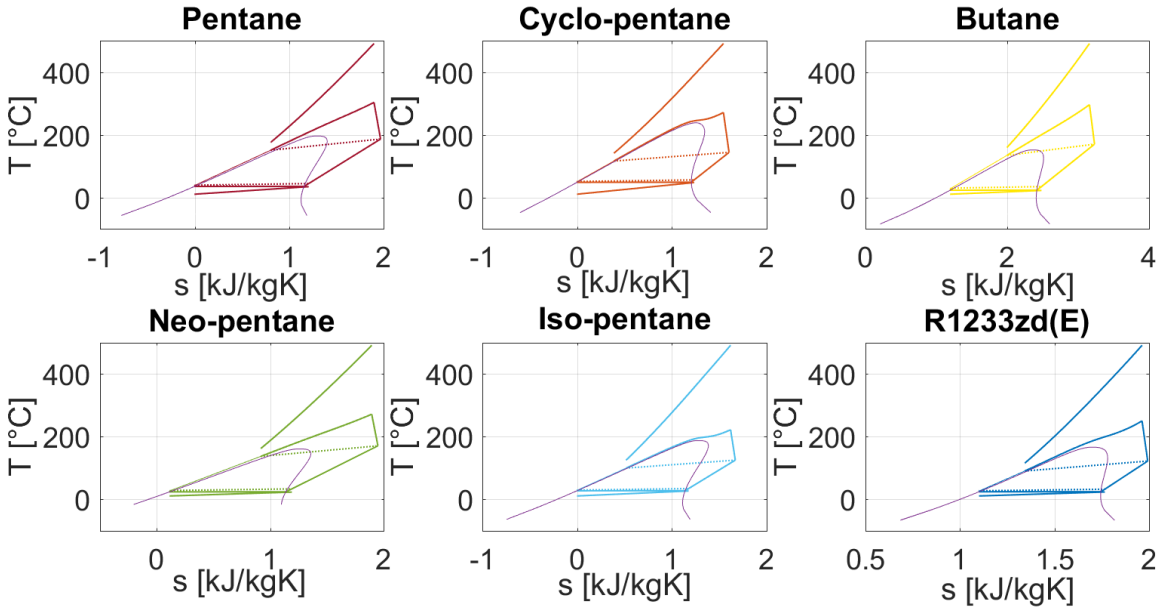


Design configuration for different fluids considering weighted averages for the input

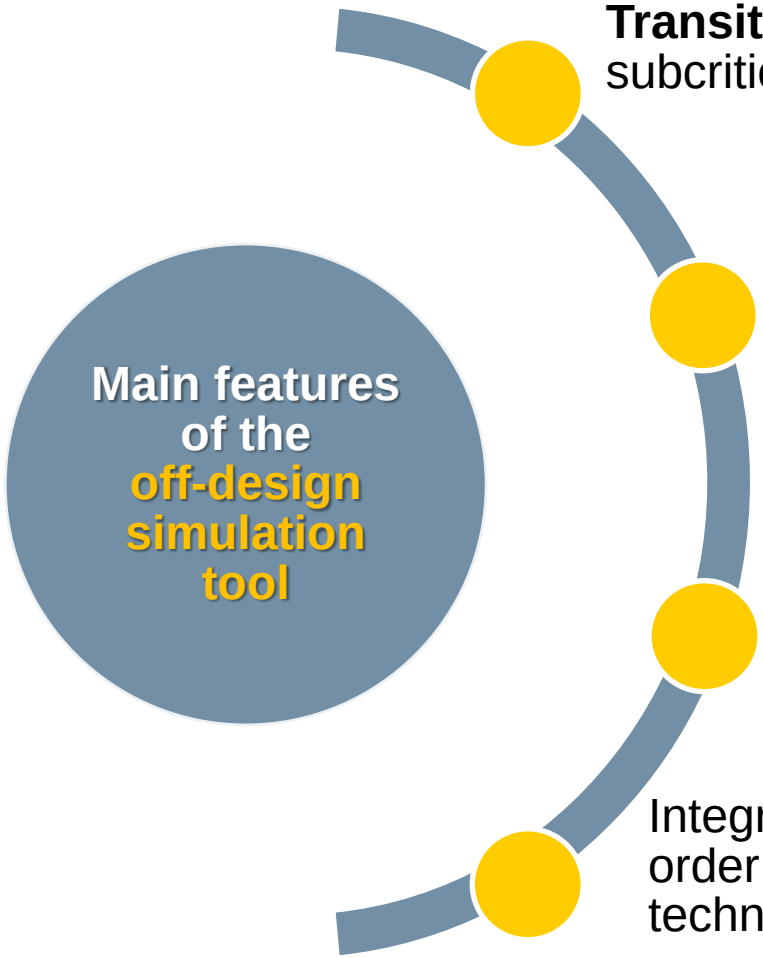
	R1233zd(E)	Cyclo-pentane	Pentane	Butane	Neo-pentane	Iso-pentane	
W_{net}	6.31	6.14	6.03	6.39	6.10	6.03	MW
η_{rec}	23.14	22.5	22.11	23.45	22.38	22.11	%
p_{max}	59.44	77.8	50.24	110.5	75.85	39.09	bar
T_{max}	250	303.67	271.35	296.1	271.35	221.85	°C
p_{cond}	1.26	1	1	2.33	1.65	1	bar
$\dot{m}_{wf}$	90.02	38.29	41.84	38.9	46.9	49.63	$\frac{kg}{s}$

Non-flammable
0 ODP
0 GWP

Flammable
0 ODP
20 GWP



Off-Design simulation tool



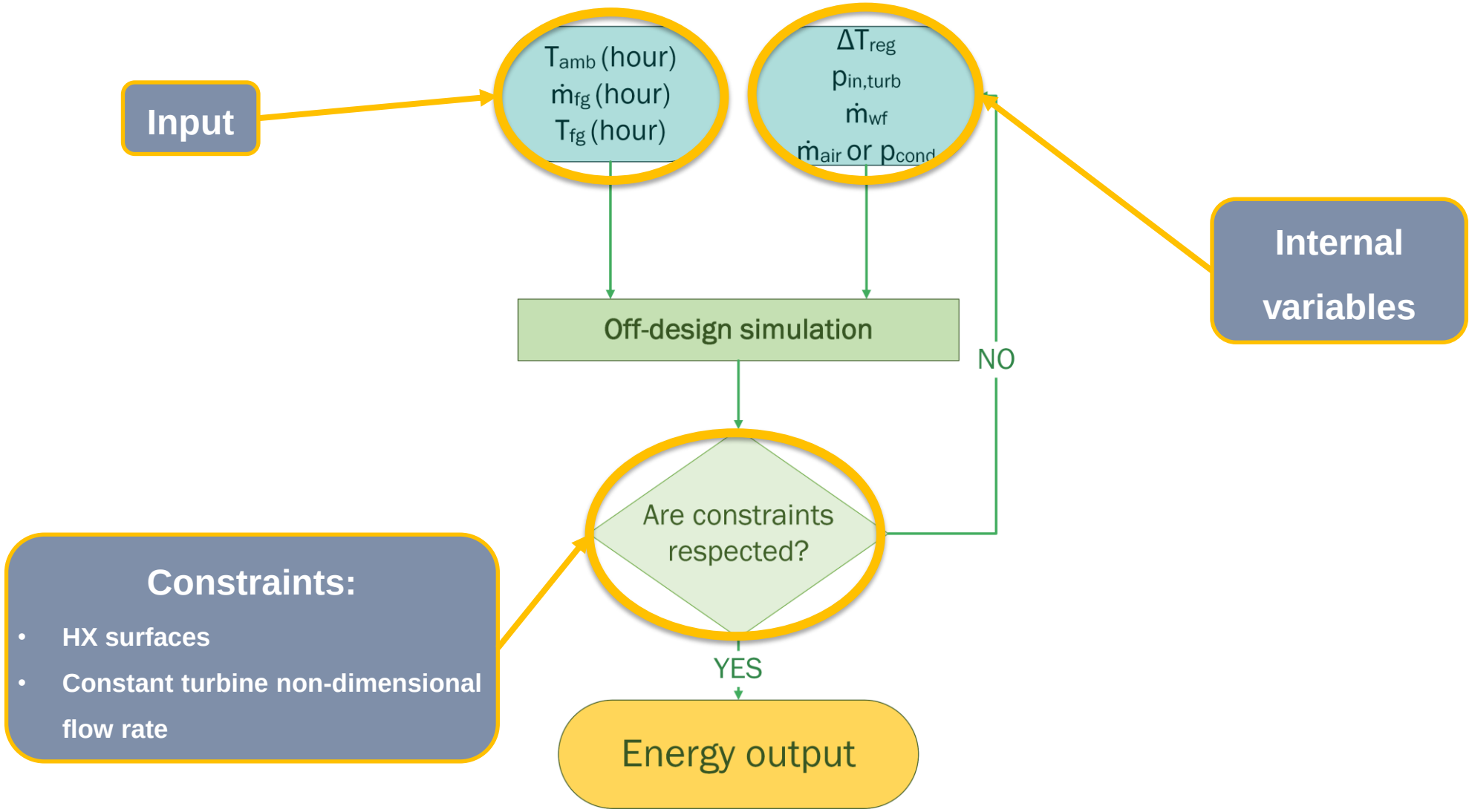
Transitions between supercritical and subcritical cycles are possible

Turbine efficiency during off-design operations computed through a proper correlation

Investigation on **technical limits occurrences,** namely sub-atmospheric condensation pressure and choking at turbine discharge

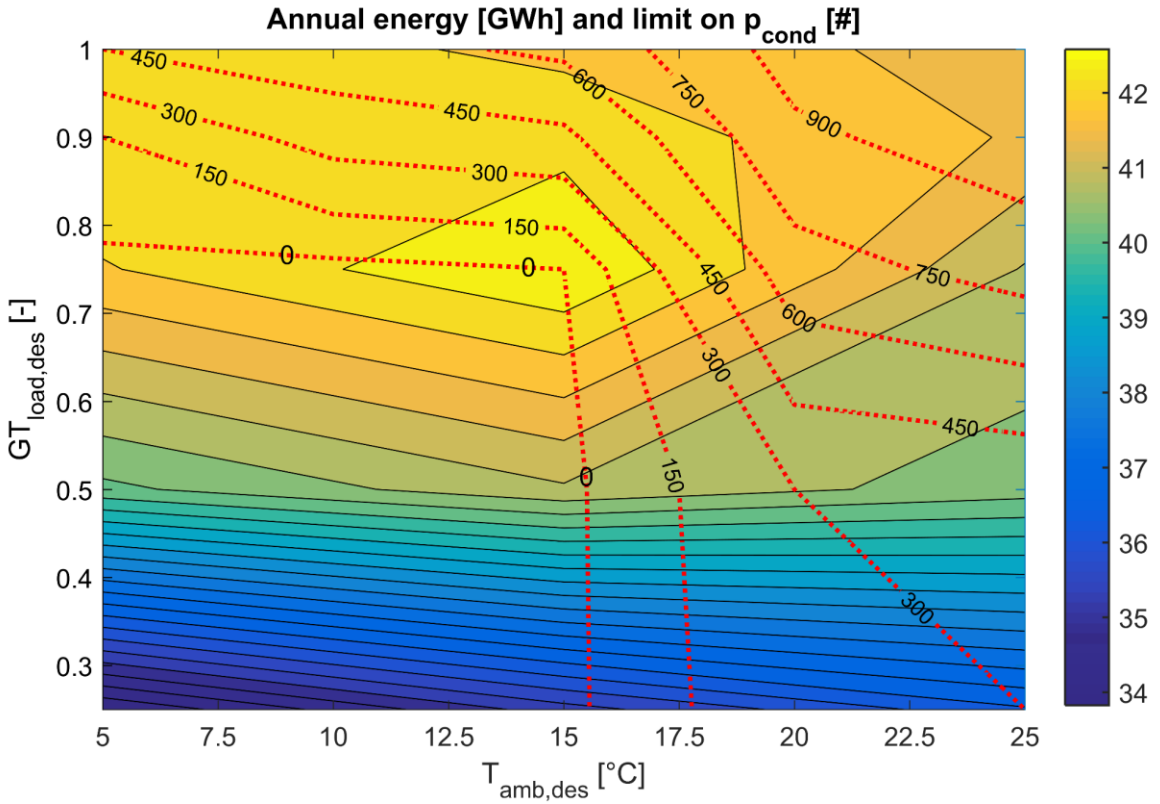
Integration of an **ACC control strategy** in order to avoid the occurrence of these technical limits

Off-Design simulation tool



Selection from the cycle performances and energy output

Final energy output for each design configuration at different nominal GT_{load} and T_{amb}.

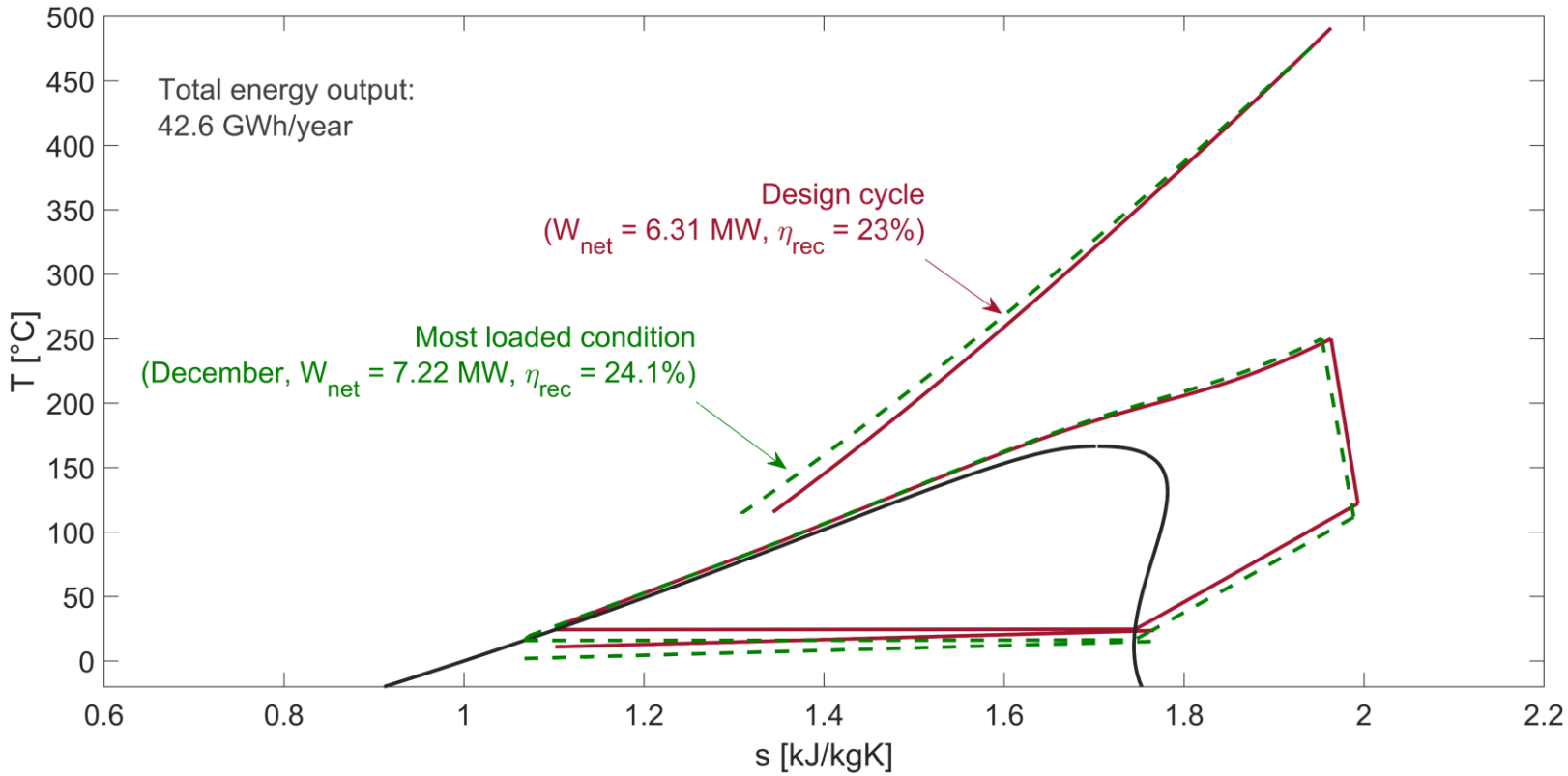


The red lines represent the **number of hours** per year when the p_{cond} reaches the **0.8 bar limit.**

- Best nominal exogenous selection lies in the zone with $GT_{load} = 75 \div 100\%$ and $T_{amb} = 10 \div 15°C$.

Annual simulation

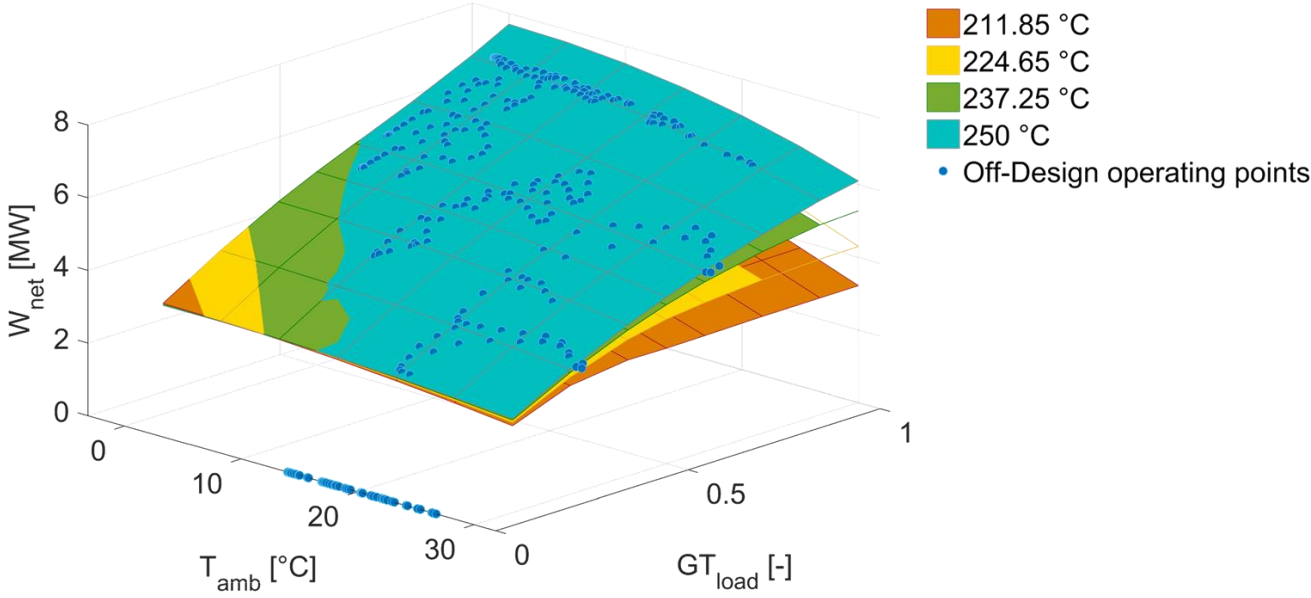
- The cycle **strongly varies** at partial load.
- During the least loaded hour (**July**, h 2:00) the cycle is **subcritical**.
- In **December**, during the most loaded hour, the turbine inlet pressure is slightly higher than the design one.

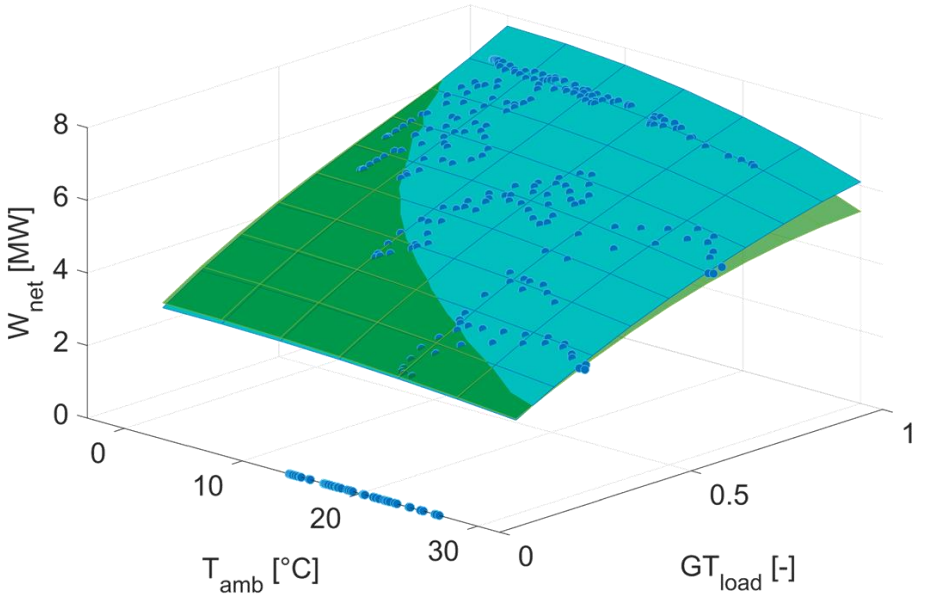


Annual simulation – sensitivity analysis

W_{net} maps for cycles operating at different maximum cycle temperature T_4 at partial load.

Operating the cycle at lower T_4 is **never convenient** for the compressor station + ORC analyzed.





W_{net} maps for cycles operating at lower fan rotational speeds, so at lower V_{air} at partial load.

Operating the cycle at lower fan rotational speed is **convenient** but the energy gain is of around 30 MWh_{el}/year (<1%).

Conclusions

Conclusions

- Study of the behavior of a real compressor station
- NG compressor station has been modeled
- Flexible Matlab® suite for bottoming **ORC design configuration** with optimization
- Flexible Matlab® suite for **off-design annual simulation**
- **High potential** of regenerative supercritical ORC for the WHR of compressor station
- $\mathbf{W_{net}}$ **= 6.31 MW$_{el}$** with $\boldsymbol{\eta_{rec}}$ **= 23%** from 25 MW$_{th}$ of $\dot{Q}_{in}$
- $\mathbf{E_{year}}$ **= 42.6 GWh$_{el}$**

Future developments

- Optimization tool to **maximize energy output**
- Optimization tool to **evaluate** and **minimize LCOE**
- Libraries of **fluids** and **compressor sets**
- **ORC mechanically drives** another compressor
- Study of the **dynamics**

THANK YOU FOR YOUR ATTENTION!

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