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DESIGN OF ORC SYSTEMS UNDER VARIABLE INPUT PARAMETERS: A MULTI-SCENARIO APPROACH

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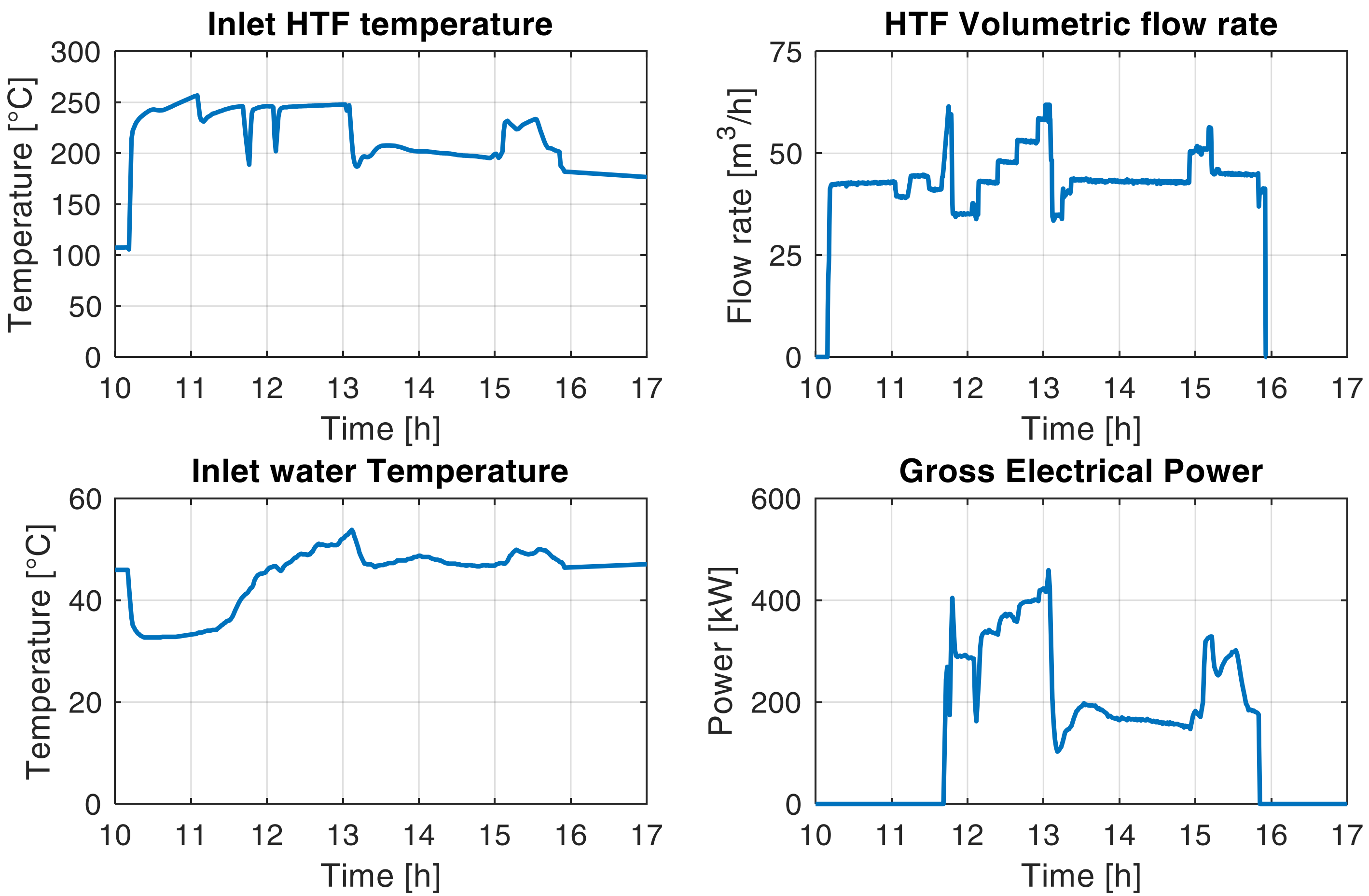
MOTIVATION

Experimental data during a daily operation of the ORC unit in a CSP-ORC plant:



Data collected at the Ottana solar facility on 07/08/2019

MOTIVATION

The proper characterization of the **heat source and heat sink**, including their **foreseen variation**, could be beneficial even during the **ORC design process**, leading to more robust design solutions able to achieve better mean performance during the overall plant operation phase.

A robust design is obtainable if the **uncertain input parameters** can **be characterized** and their variability is **predictable** in a certain way

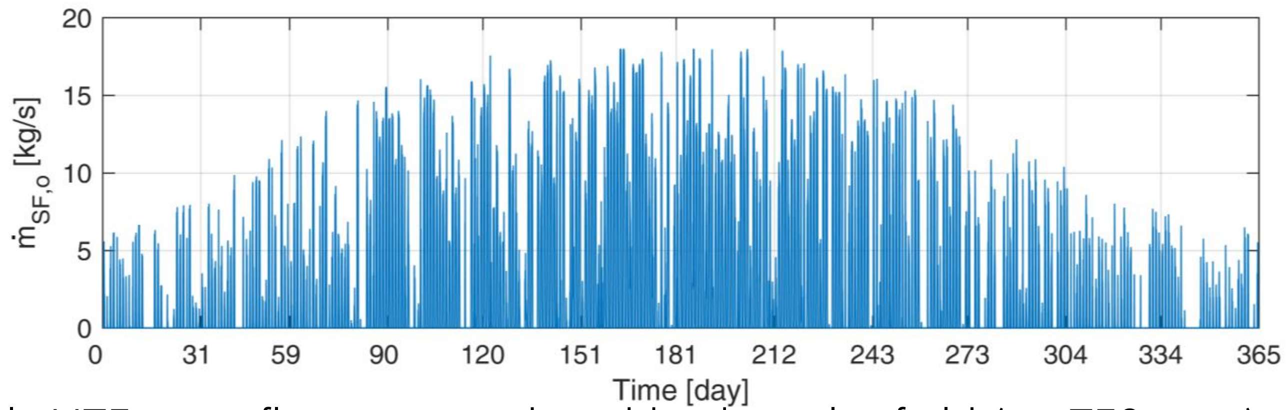
Goal

Novel methodology for the preliminary design of an ORC unit based on the minimization of the expected LCOE under variable input conditions.

A **multi-scenarios approach** is used to characterize the uncertainty of the input parameters, where a given number of scenarios with their corresponding probability is generated based on the annual expected fluctuations in the heat source and heat sink.

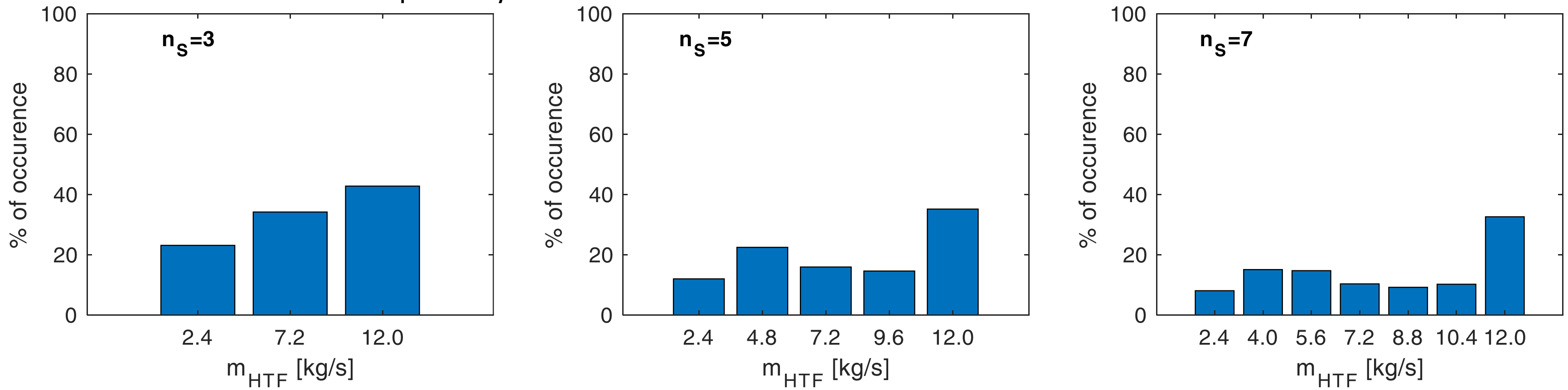
METHODOLOGY

Multi-scenario approach for the heat source characterization:



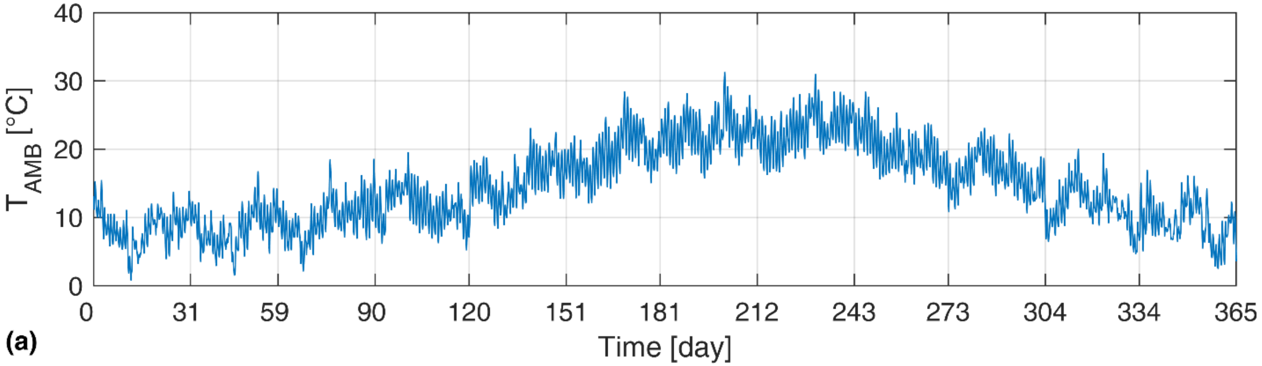
Hourly HTF mass flow rate produced by the solar field (no TES case)

Frequency distributions of the HTF mass flow rate



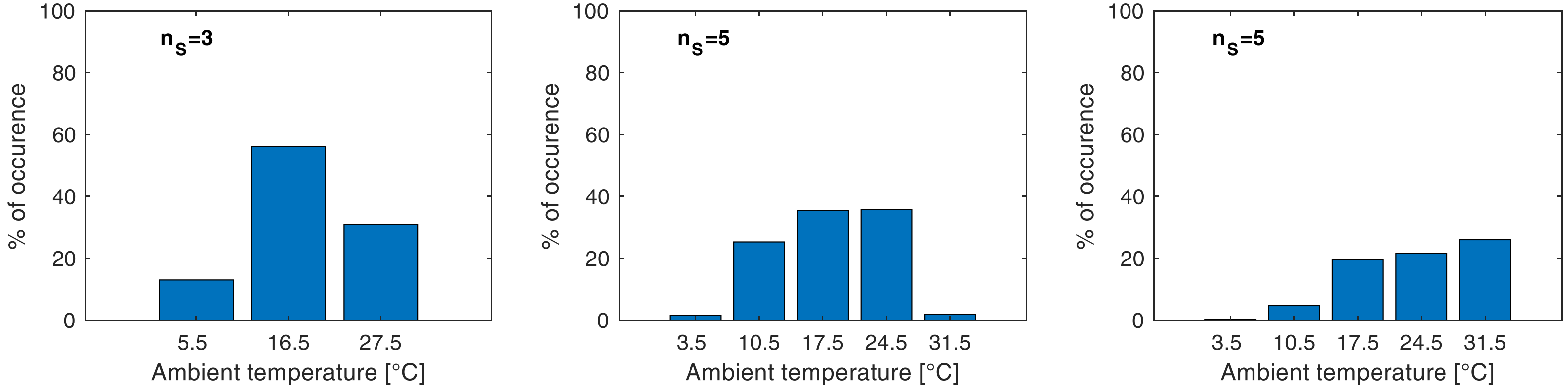
METHODOLOGY

Multi-scenario approach for the heat sink characterization:



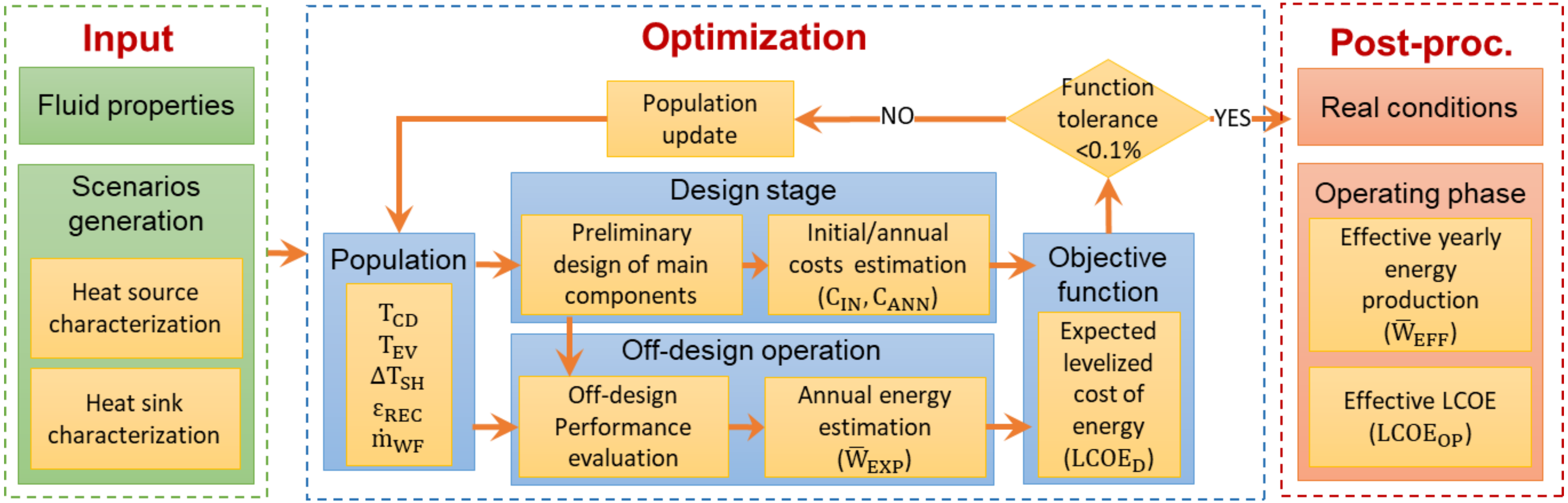
Ambient temperature variation on the ORC condenser temperature

Frequency distribution of ambient temperature during ORC operating time



METHODOLOGY

Schematic procedure adopted:



$$\overline{W}_{EXP} = t_{OP} \cdot \sum_{s=1}^{n_S} p_s \cdot \dot{W}_{NET}(s)$$

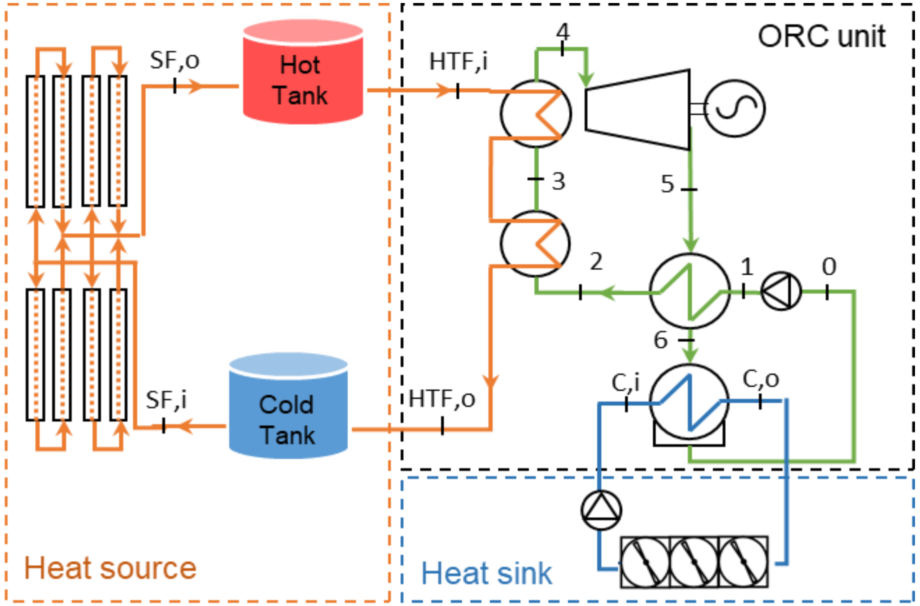
$$\overline{W}_{EFF} = \sum_{t=1}^{8760} \dot{W}_{NET}(t) \cdot \Delta t$$

$$LCOE_D = \frac{C_{IN} + \sum_{n=1}^{N} \frac{C_{ANN}}{(1+i)^n}}{\sum_{n=1}^{N} \frac{\overline{W}_{EXP}}{(1+i)^n}}$$

$$LCOE_{OP} = \frac{C_{IN} + \sum_{n=1}^{N} \frac{C_{ANN}}{(1+i)^n}}{\sum_{n=1}^{N} \frac{\overline{W}_{EFF}}{(1+i)^n}}$$

CASE STUDY

Medium-size CSP-ORC plant chosen for the application of the methodology:



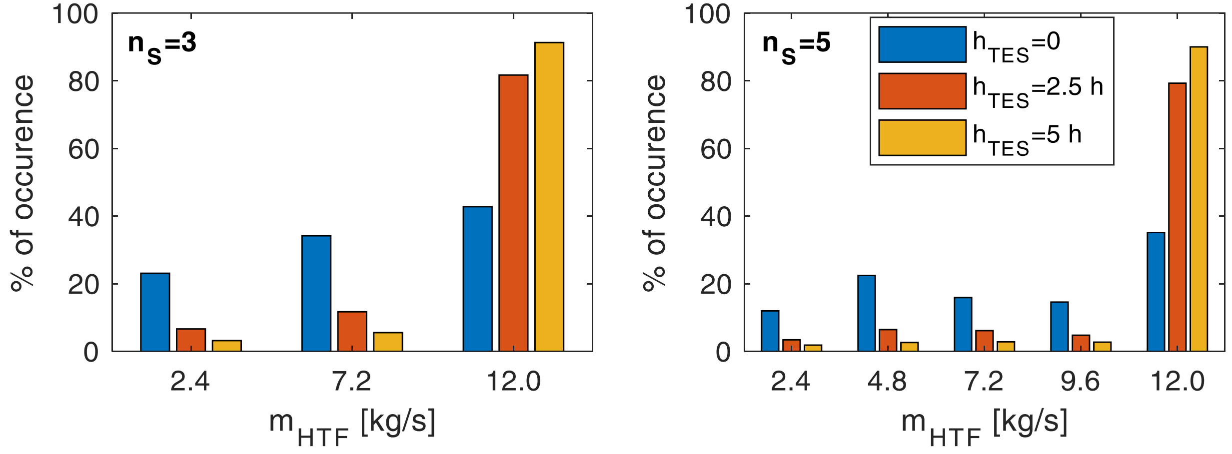
Fluid	Molar mass [kg/kmol]	T_{CRIT} [° C]	No. of atoms
Benzene (i)	78,11	288,9	12
Cyclopentane (i)	70,13	238,6	15
MM (d)	162,38	245,6	27
Octane (d)	114,23	296,2	26
Toluene (i)	92,14	318,6	15

d: dry, i:isentropic

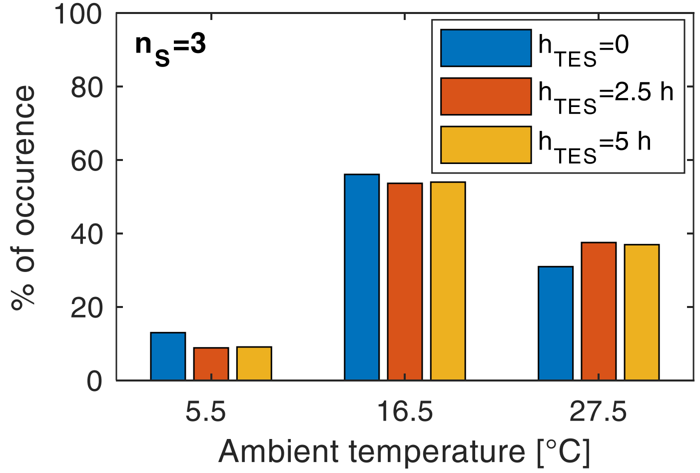
Heat source	
Heat Transfer Fluid	Therminol SP-I
Net collecting area	8600 m^2
Solar field inlet temperature	275°C
Solar field outlet temperature	165 °C
Design HTF mass flow rate	18 kg/s
TES capacity (h_{TES})	0 – 2.5 h – 5 h
ORC unit	
Design HTF mass flow rate	12 kg/s
Pump isentropic efficiency	0.8
Pump electromechanical efficiency	0.86
Turbine electromechanical efficiency	0.88
Heat sink	
Ambient temperature (design stage)	19 °C
Temperature difference of cooling fluid	15 °C

CASE STUDY

Percentage of occurrence of the HTF mass flow rate feeding the ORC unit:



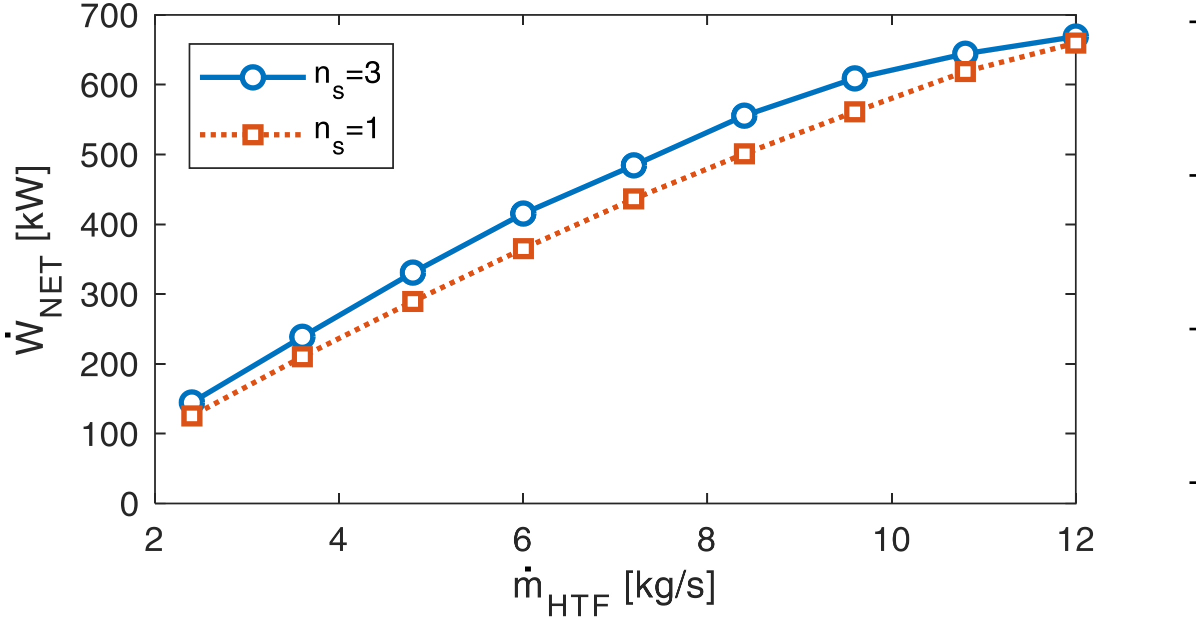
Percentage of occurrence of ambient temperature during ORC operating time



RESULTS

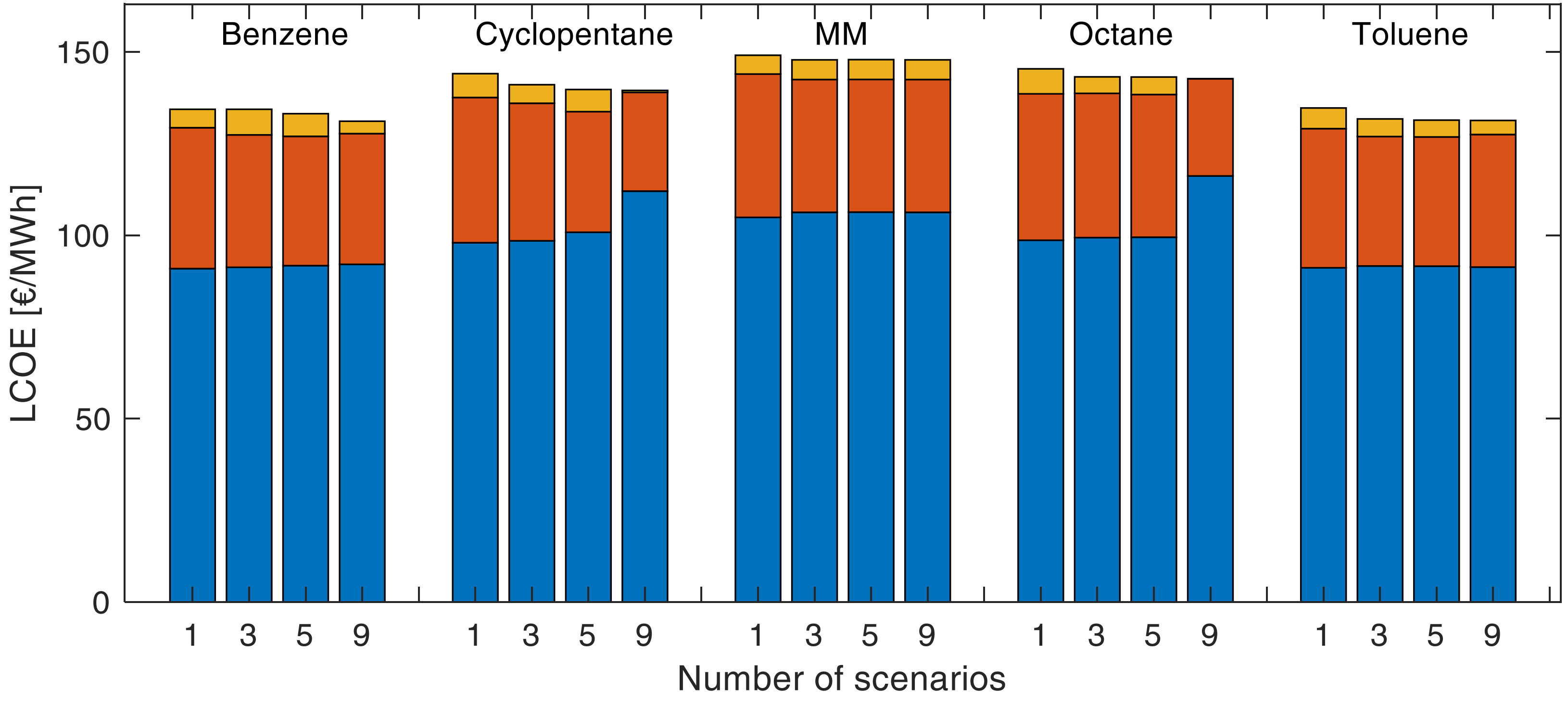
Optimal ORC preliminary design fluids by adopting the multi-scenarios approach (no TES case – h_{TES}=0):

Working Fluid	Number of	T_{CD}	T_{EV}	ΔT_{SH}	ε_{REC}	$\dot{m}_{WF}$	Design LCOE	Operating LCOE [€/MWh]
Benzene								134.4
								134.3
								133.1
								131.5
Cyclopentane								144.0
								141.0
								139.7
								138.9
MM								149.1
								147.8
								147.8
								147.8
Octane								145.4
								143.1
								143.1
	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	142.7
Toluene	1	49.4	201.1	6.4	-	5.6	91.1	134.7
	3	47.4	207.0	28.1	-	5.2	126.4	131.7
	5	47.4	207.0	27.6	-	5.2	124.5	131.4
	9	46.4	213.8	12.2	-	5.3	129.0	131.3



RESULTS

Operating levelized cost of energy obtained for the five working fluids:



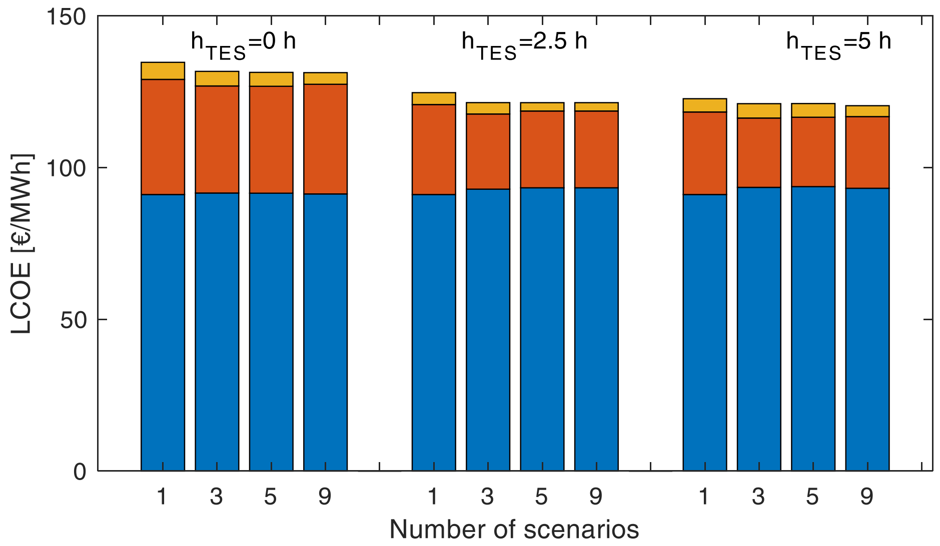
Blue bar: design LCOE obtained if ORC operate always at nominal conditions
Orange bar: negative effects due to reduced mass flow rate
Yellow bar: negative effects ambient temperature fluctuations

RESULTS

Optimal ORC preliminary design and LCOE as a function of TES capacity:

TES capacity	Number of scenarios	T_{CD} [°C]	T_{EV} [°C]	ΔT_{SH} [°C]	ε_{REC} [-]	$\dot{m}_{WF}$ [kg/s]	Design LCOE [€/MWh]	Operating LCOE [€/MWh]
2.5 h	1	49.4	201.1	6.4	-	5.6	91.1	124.7
	3	47.9	214.3	11.9	-	5.4	118.5	121.4
	5	49.4	220.1	5.5	-	5.4	118.5	121.3
	9	49.2	221.1	4.5	-	5.4	120.5	121.3
5 h	1	49.4	201.1	6.4	-	5.6	91.1	122.7
	3	47.3	215.0	11.8	-	5.3	116.7	121.1
	5	47.2	214.1	12.7	-	5.3	116.0	121.1
	9	49.1	221.0	1.4	-	5.4	119.2	120.4

Toluene is used as working fluid:



CONCLUSIONS

1. The adoption of a multi-scenario approach leads to an ORC configuration less sensitive to the variation of external parameter and with an operating LCOE lower than that obtained with a single scenario approach;
2. The advantages in using a multi-scenario approach instead of a single scenario approach is common to all the working fluids examined and becomes more and more evident with the increase of the uncertainty of the input parameters. Important economic benefits could therefore arise from the adoption of the proposed design methodology;
3. A reduction of the operating LCOE is achieved with the rise of the number of scenarios considered even if the marginal increment becomes more and more negligible with an important rise in the computational time required to find the optimal solution.

THANK YOU FOR YOUR ATTENTION

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