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FLExibilize combined cycle power plant through power-to-X solutions using non-CONventional Fuels

D7.1 – "Results of flexibility impact of FLEXnCONFU on the electrical market compared with other existing solutions"

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[1] PU = Public
CO = Confidential, only for members of the consortium (including Commission Services)

Executive Summary

This document constitutes a deliverable of the FLEXnCONFU project, included in the European Union's Horizon 2020 research and innovation programme (Grant Agreement No 884157). The Deliverable D7.1 titled: "**Results of flexibility impact of FLEXnCONFU on the electrical market compared with other existing solutions**", has been developed within Work Package 7.

This report wants to highlight - through the presentation and the analysis of pros and cons of each widespread technologies in terms of flexibility - where Flex'n'Confu have to focus to become a competitive flexibility asset. It shows the point of view of a real power plant like Tirreno Power CCGT Vado Ligure Unit 5 (VL5), operating in the Italian Energy Market.

Tirreno Power, as partner involved in the project and player in the energy market as well, has selected flexibility assets which can bring advantages in terms of performance, cost and environmental improvements.

Each flexibility asset is described in terms of layout, reporting peculiarity in operation and maintenance, explaining the performances improved and the problems that could arise.
As a starting point it has been selected a list of KPIs among those included in the MS1 of Task 1.3 as reference in an industrial CCGT (similar to VL5) scaled-up scenario.
Each KPI provides the measure of a particular aspect linked to the positioning and competitiveness of the CCGT on the electricity market.
They shall be used to understand how the flexible assets could influence VL5 operations and help to dispatch its capacity.

The proposed flexibility assets are not implemented in VL5 CCGT Unit, but they are the widespread and well established over the years. It is important to notice that all assets, excepted for the suggested Pump-Heat and FlexTurbine, are commercial assets.
Pump-Heat and FlexTurbine are H2020 projects. Due to high confidentiality of data, the analysis of Flexturbine has not achieved.

The result of the study will highlight the suggested features that the Flex'n'Confu project will bring to be successful in the flexibility assets' Market.

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Table 1: Acronym table

Acronym	Definition
AIA	"Autorizzazione Integrata Ambientale" Environmental Authorization issued by the Authorized Body (Minister) to each specific industrial site. It is a set of measures that aims to verify the environmental compatibility of a complex industrial activity. AIA assignation is a pre-condition to operate a CCGT
AmbHX	Ambient Air Heat Exchanger
CAPEX	CAPital EXpenditure
CCGT	Combined Cycle Gas Turbine
CDP	"Capacità Disponibile in Probabilità" Available capacity in probability. Amount of available daily capacity on the energy markets expected for all year long. It is calculated by TSO from the average capacity sold on MGP by the production unit in the previous year. It is expected to be available for each day of the year.
CM	Capacity Market. The CM is a mechanism by which TSO procures capacity through yearly procurement contracts awarded through competitive bidding. The Operators permitted to the CM must always guarantee - with their production units - an amount of available daily capacity on the energy markets for all year long (the so-called CDP). For this service, they have the right to receive an annual fixed premium from TSO or must repay TSO the difference in case of unit unavailability
CrodaThermTM 5	Fluid cooling vector used in Heat Pump's Inlet Conditioning Unit
CSS	Clean Spark Spread. CCGT unit's revenue net from NG cost and carbon allowances cost
EOH	Equivalent Operating Hours. The EOH are calculated as the sum of GT operating hours plus the value of the start and stop cycle that corresponds to 10 operating hours
GME	"Gestore Mercati Elettrici" Energy markets operator
GT	Gas Turbine
HP	Heat Pump
HR	Heat Rate
HRSG	Heat Recovery Steam Generator
ICU	Inlet Conditioning Unit
IGV	Inlet Guide Vain. Inlet stator blades used to control the GT's load
KPI	Key Performance Indicator
MEL	Minimum Environmental Load

Acronym	Definition
MGP	"Mercato del Giorno Prima" Day-Ahead Market managed by GME. The MGP hosts most of the electricity sale and purchase transactions. In the MGP, hourly energy blocks are traded for the next day. All the supply offers and the demand bids pertaining both to production units and consuming units belonging to foreign virtual zones that are accepted in the MGP are valued at the marginal clearing price. This price is determined, for each hour, by the intersection of the demand and supply curves
MSD	"Mercato dei Servizi di Dispacciamento" Ancillary Services Market. The MSD is the venue where TSO procures the resources that it requires for managing and monitoring the system relief of intra-zonal congestions, creation of energy reserve, real-time balancing. In the MSD, the TSO acts as a central counterparty and accepted offers are remunerated at the price offered (pay-as-bid). In the MSD, the TSO corrects - for the current day - the hourly quantities of energy defined in the MGP.
MSD down	Price offered by production units' supplier to purchase (a part or all) energy sold in the MGP. This price is usually lower than the MGP price for a defined hour.
MSD up	Price offered by production units' supplier to sell more energy than that sold in the MGP at a different price. This price is usually higher than the MGP price for a defined hour.
NG	Natural Gas
OEM	Original Equipment Manufacturer
OPEX	OPerational EXpenditure
RES	Renewable Energy Sources
SCR	Selective Catalytic Reduction
ST	Steam Turbine
TES	Thermal Energy Storage
TSO	Transmission System Operator

1. Introduction

The present document constitutes the Deliverable D7.1 “Results of flexibility impact of FLEXnCONFU on the electrical market compared with other existing solutions”, developed within Work Package 7 - FlexnConfu impacts and benchmarking.
Objectives of WP7 are to evaluate the impact of FLEXnCONFU solutions from both economic and environmental point of view and evaluate the benefit in terms of flexibility increase respect to other flexibility assets. In addition, the societal readiness of the proposed solutions will be evaluated as well. From the experience of WP3 and WP5, together with the results of WP6, lessons learnt will be provided as well.
In particular Task 7.1 is focused on the first part of the WP: evaluate the FLEXnCONFU benefit in terms of flexibility increase respect to other flexibility assets.

To targeting the goal of the task, Deliverable D7.1 is structured in the following sections:

- KPIs determination to easily compare asset by asset.
- Identification and definition of flexibility assets.
- Understand the relationship between KPIs and flexibility assets identifying improvements introduced by each flex.
- FLEXnCONFU benchmark with other existing flexibility assets

The goal of the Deliverable 7.1 is to highlight features in terms of flexibility that the Flex'n'Confu project must have to be successful in the assets' Market.

NG gas stream data are available to T6.2 in order to show the potential replicability and the techno-economic viability.

2. Task planning

2.1. Dependencies on other tasks

The performances of other flexibility assets are compared with the FlexnConfu's performance resulted from Delivery 1.2.

The Annex n.1 provides NG data at the inlet of the VL5 CCGT useful to understand FlexnConfu potential in the virtual demo-site useful to Task 6.2.

Task 7.1 asks to capitalize results from other HZ2020 projects like PumpHeat and FlexTurbine with the aim to compare respective performance with FlexnConfu.

FlexTurbine deserves a separate mention. The information was only confidential and no one partner was involved enough in the project to support that kind of analysis.
Unfortunately, Flexturbine's technical deliverables had the Dissemination level set to “Confidential, only for members of the consortium”. TP received a list of publications that should be available. These articles listed in the "FlexTurbine_publication_list" don't match with the target of the task.
In accordance with RINA-C and CERTH it has been decided to remove the analysis of FlexTurbine cause to lack of information. No one partner has the authorization to share FlexTurbine data.

2.2. Contribution from partners

BH verified the accuracy of the KPIs suggesting improvements in the definitions of some parameters and supported TP for the investigation - together with RINA-C - on the FlexTurbine project.
UNIGE provided the complete description and results of the Pump-Heat project and the SWOT analysis in terms of flexibility performance.
CERTH and RINA-C supervised the structure of the final document, they helped TP to manage the schedule of the task and provided contributions for the analysis of the flexibility assets.

3. Selected KPI

The KPIs included in the MS1 of Task 1.3 have been taken as reference and integrated in an industrial CCGT (similar to VL5) scaled-up scenario.
The following KPI are useful if considered to operate a CCGT that sell energy in the Italian Energy Market. They shall be used to understand how the flexible assets can influence operations and help to dispatch the generation units.

Reduction of Minimum Environmental Load
The reduction of MEL helps to decrease the grid rotating reserve, with the benefit to reduce GT start-ups (then the ageing of the fleet). A CCGT available on the grid at MEL, gives back a faster response to the primary/secondary/tertiary regulation.
A typical MEL is near 50% of the Maximum Load and it guarantees the CO emission limit compliance. In the Italian GT fleets this value depends on the Environmental Authorization (AIA) of each CCGT and has a value between 10÷30 mg/Nm^3.

Increase of Maximum Load
The increase of Max Load allows a total higher quantity of energy sold on Markets (MGP & MSD). It has a primary effect on MGP market doing the possibility to put higher volumes for each daily hour, and so higher revenues. It has effect on MSD as well, increasing the MSD down range giving a secondary effect on revenues.

Increase of Load Gradient
The Load Gradient value generates a power range to fulfill the primary and secondary energy request. The Grid Code assesses that the load gradient shall be supplied in a 200 seconds span of time.
The secondary bandwidth has a selling price different from the energy price in MGP and MSD. It is useful to TSO, giving fast response to stabilize the grid.

Reduction of CCGT Heat Rate
The Heat Rate (HR) affects the gas consumption at equal power conditions. HR reduction in value leads to savings, therefore higher competitivity on Energy Market.
HR is different at different GT power output according to a characteristic curve that is the opposite of the GT efficiency.
The calculation to obtain the NG saved relating to the HR decreasing is:
$Q_{NG} = m_{NG} / \rho_{NG} = HR * P_{gross} * (1/3600) * (1/LHV_{NG}) * (1/CF)$
Where:
Q_{NG} = NG volumetric flowrate (Nm^3/s)
m_{NG} = NG mass flowrate (kg/s)
ρ_{NG} = NG density (kg/Nm^3)
HR = Heat Rate (kJ/kWh)
P_{gross} = CCGT gross power (kW)
LHV_{NG} = NG lower heating value (kJ/ Nm^3)

CF = ISO correction factor

Reduction of CO_2 Specific Emissions

CO_2 is subjected to a specific market where the value is expressed in €/t. Every day the price changes and in the last year it increased by 185%.

The CO_2 influences the cost of production, typically by 30% and its reduction is an economical drive as well as the most important parameter to improve the environmental sustainability.

Lower is the Heat Rate (higher efficiency), lower is the NG consumption and lower is the CO_2 Specific Emission.

The calculation to obtain the CO_2 specific emission (kg_{CO_2}/Nm^3_{NG}) on NG volume is:

CO_2 = DA * FE * FO * H / $Q_{NG\ day}$

Where:

DA = daily NG energy content (TJ/day). In case of better efficiency, for the same amount of energy produced, the DA is reduced

H = Hydrogen volumetric content [0-1]; H is obtained by interpolating the CO2vsH2 content curve

FE = Emission factor (tCO_2/TJ)

FO = Oxidation factor (dimensionless coefficient = 1)

$Q_{NG\ day}$ = daily NG volumetric flowrate (Nm^3/day) consumption

The emission factor FE is:

FE = $\%_{fraz\ C}$ * ρ_{NG} / LHV_{NG} * 3.664 * 10^9

Where:

$\%_{fraz\ C}$ = Carbon fraction, calculated as the sum of the weight percentage of each NG component by the relative Carbon content percentage of each component.

ρ_{NG} = NG density (kg/Nm^3)

LHV_{NG} = NG lower heating value (kJ/kg)

3.664 is the conversion factor from C to CO_2.

Reduction of Start-ups

The reduction of start-ups affects the CCGT life consumption. Ansaldo assumes that each start corresponds to 10 EOH.

Less start-ups corresponds to less NG consumption.

Start-ups are split in three categories: hot, warm and cold.

Hot, up to 24h after the last shut-down (with the steam turbine rotor temperature over 370°C)

Warm, from 24h to 99h (with the steam turbine rotor temperature over 150°C)

Cold, after 99h (with the steam turbine rotor temperature less than 150°C)

Typical NG consumption for a TG start-up is:

- Hot: 35 kNm^3
- Warm: 45 kNm^3
- Cold: 60 kNm^3

The Energy Market in Italy could ask over 100 starts/GTyear, that corresponds to 1000 EOH of life consumption.

Availability

Unit availability is an important indicator that will increase importance with the start – in Italy since January 2022 – of the CM.
Only 1 week of unavailability causes the monthly benefit loss, while 3 weeks of unavailability spread across 3 different months can cause the loss of the entire annual economic benefit.

Auxiliaries consumption

The auxiliary consumption is already included in the calculation of unit efficiency.

4. Flexibility Assets

4.1. Fogging

The Fogging system is one of the flexibility solutions available on market. It is a reliable package widely applied on CCGTs.

It works pumping a selected amount of atomized water at the inlet of the GT compressor, in the air suction chamber. This atomized water, in particular environmental conditions – high temperature – can improve the GT performances through the increase in mass flow.

The amount of water sprayed with a Fogging system is calculated to recover the efficiency drop of the turbine operating at a temperature above 15 ° C, in practice to bring the maximum power delivered back to ISO conditions.

Fogging is a cooling system that exploits injection nozzles – commonly installed after the air inlet filter and silencer – to sprinkle atomized water at D_v90[2] <20μ in an air flowrate of 30cm/s.
The process consists in the mechanical introduction, into the axial flow of the GT compressor, of a humid mist of fine droplets that evaporate inside it with consequent cooling down of the combustion air.

It increases the load of the GT reducing the compression work due to the continuous evaporation along the compressor.

The following picture shows the typical installation of the injection nozzles grid at the suction chamber of the GT compressor.

[2] D_v90: the average diameter value of 90% of the droplets

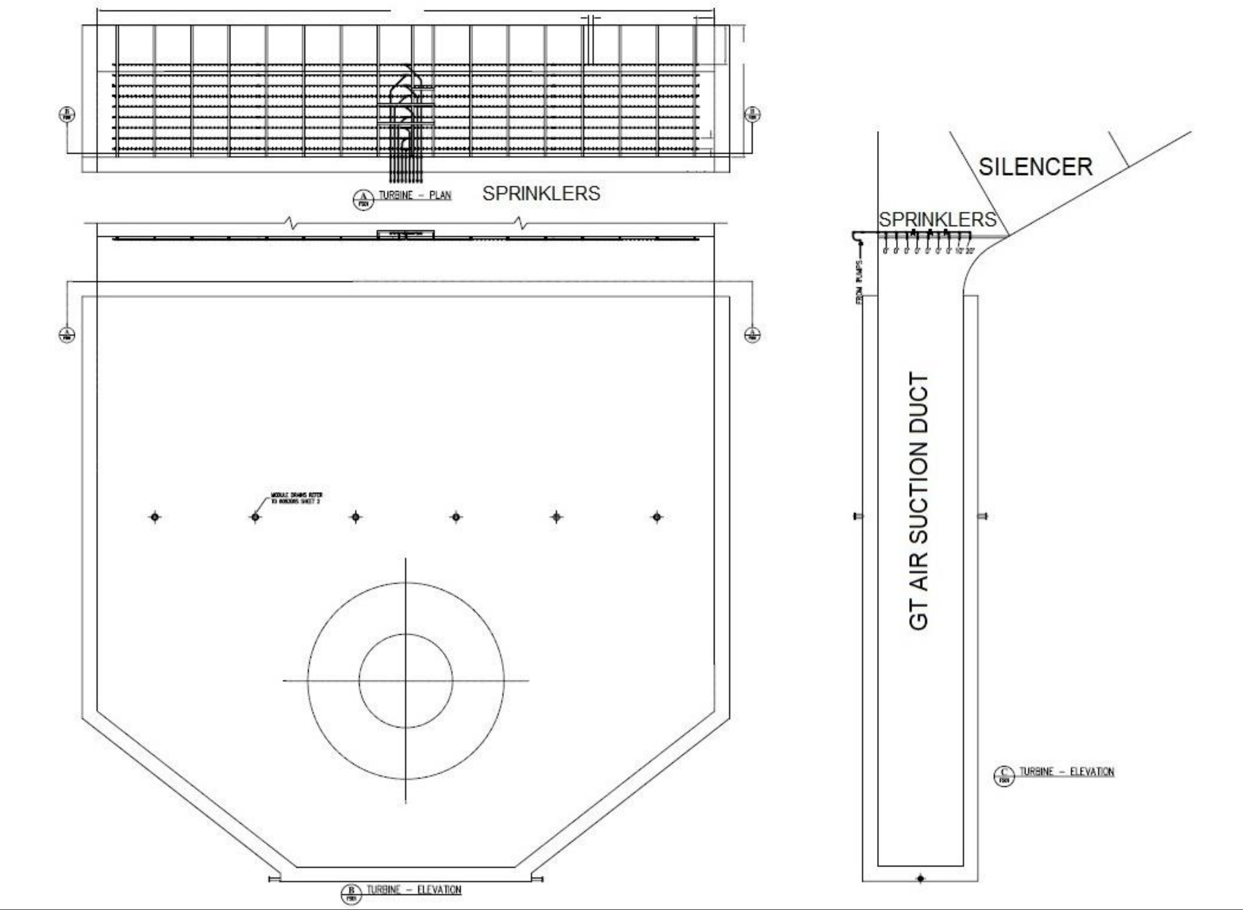

Figure 1 - Fogging system installation outline

Below the SWOT analysis to focus on the Fogging technology:

Table 2: Fogging system SWOT analysis

Strengths	Weaknesses
• Maximum load increase • Heat rate reduction	• Use of the system in a short period of the year • Higher water, reagents and electrical auxiliaries' consumption • Need to have special coatings on the first compressor blades • Negative influence on ST maximum load due to colder flue gas discharge • CCGT maintenance cost increase
Opportunities	**Threats**
• MGP Market bandwidth increase • MSD Market bandwidth increase • Increase of the CDP (available capacity in probability) in the CM	• Risk of catastrophic event due to FOD (Foreign Object Damage), • An incorrect position of the system can cause the silencers to malfunction

Strengths

In particular conditions, exclusively during the warm part of the year, the Fogging system gives to the GT an extra power, increasing the Maximum Load, that can regain values around 10% more of the current maximum capacity. It increases proportional to the temperature difference such as to bring the GT back to ISO power in a range of ambient temperatures from 15 ° C up to 30 ° C.

After reaching 30°C Fogging cannot improve performance furtherly and the GT maintains the acquired bias following its performances characteristic

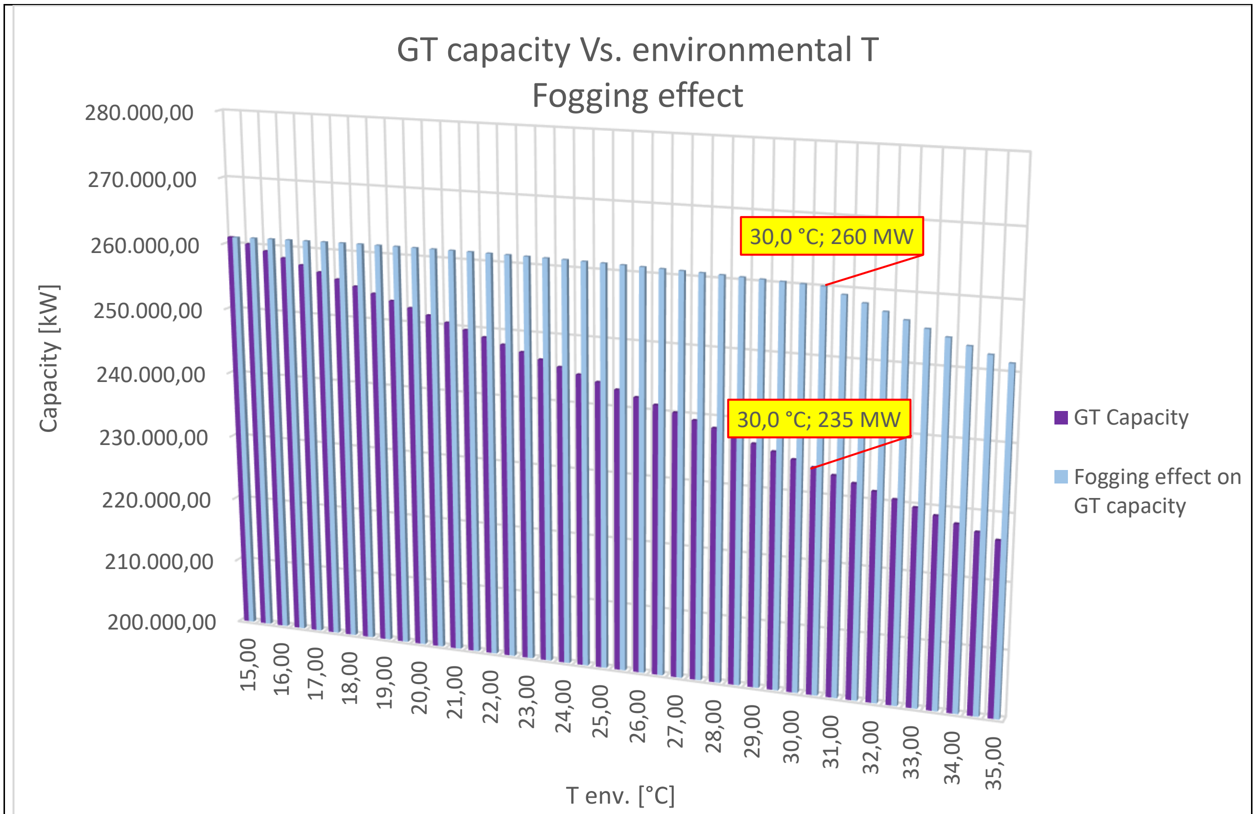

Figure 2 - Fogging effect: GT capacity VS Environmental T

The use of fogging allows for a lower heat rate than operating the GT without using the same system. Therefore, with the same load there is a lower fuel consumption.

The difference can be calculated by comparing the heat rate, at the same power, to the two different GT inlet air temperatures (real one and conditioned by fogging).

Opportunities

The main positive effect would impact providing new possibilities on the electricity markets.

On the MGP market it would allow to place larger quantities available to GME. This would be to the advantage of energy producers who could have an almost constant power band over the course of the year (however, note that the CCGT power which can be produced is a function of T, p, u.r., pci, density C/H, T sea water, network frequency).

Especially for those technologies, such as CCGT, whose load is very variable to support RES, fogging can give more space to the MSD market (both for MSD UP and for MSD DOWN) and to the secondary regulation requests that is remunerated.

It would benefit the CM as well as a constant increase in the producible load would affect the CDP of the following year.

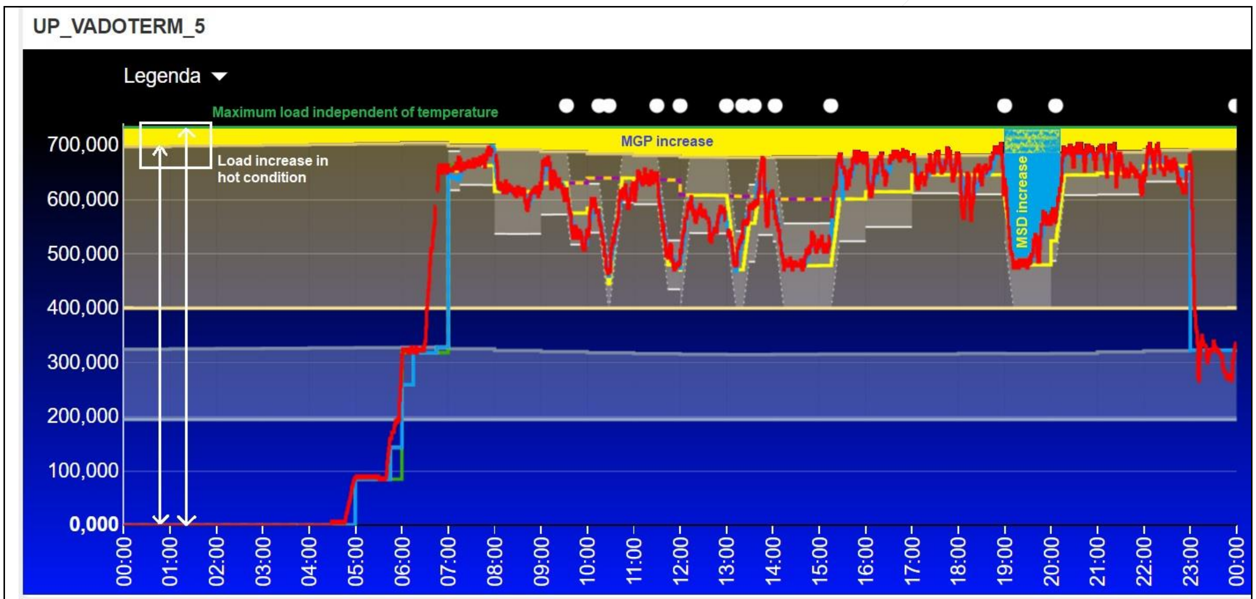

Figure 3 - Fogging effects on Energy Markets

Weaknesses

The limitation of the Fogging System derives from the possibility of use. The yield is effective at temperatures above 15 ° C, it follows that the system is more suitable for warm and temperate areas while it is necessary to verify, knowing the purchase costs, the opportunity of installation in colder areas.

The return on investment calculation is not included, but it is an important information on the installation opportunity. When the difference between production prices and energy costs are substantial, it could guarantee appreciable economic benefits and fast returns on investment.

The Fogging System, to preserve the GT blades and keep the system circuits as clean as possible, uses demineralized water in a great amount. This need falls on the operating costs of the plant in terms of water consumption (with a maximum value of 20 cm/h), cost of the necessary reagents (typically soda and acid) and electrical auxiliary consumption. Water use can therefore be more than the usual CCGT water standard (considering 6 cm/h for each HRSG) without considering the effects on drainage collection systems and the need to dispose of water in relation to the specific Environmental Authorization (AIA) of the site.

It should be noted that the Fogging manufacturer considers it essential that the first GT compressor blades be protected with a coating to avoid erosion phenomena. This need is known to GT suppliers, but it is not certain that this coating is native to the supply of the machine. The lack of the coating could be an important obstacle to the economic opportunity of installing the Fogging.

Threats

A possible threat, that arose in the first installations of these kind of equipment, concerns the effects that an incorrect installation of the spraying system can cause on the reliability of the GT.
The fogging system must be installed downstream of the silencer.
Cases in which this system was installed upstream has reduced the effectiveness of the silencer making the system unusable due to the high noise coming out of the GT. This issue must be carefully considered and is easily overcome in the design phase. On the other hand, once the system is placed upstream of the silencer, it is possible that it is unusable, revealing itself to be a loss-making investment.

In the installation analysis is important to consider the possibility to have a of catastrophic event due to FOD (Foreign Object Damage).
The current state of art allows the suppliers to strongly discard this hypothesis but could be useful to discuss about the eventuality with a Company’s insurance in order to cover any exceptional events.
The loss of a spray nozzle can be the cause of the destruction of GT blades and vanes.
It is important to notice that insurance costs can grow up.

4.2. Heat Pump

The Pump Heat Layout is one of the innovative flexibility solutions under study for CCGTs.
It is a TRL 7 technology (i.e. System prototype demonstration in operational environment) designed to control the Compressor Inlet temperature, with a high impact on the power generation, enhancing the operative range of the CCGT. The effectiveness of this solution is guaranteed by the invariancy of the CCGT efficiency with the intake temperature. The proposed layout integrates the CCGT with an Integrated Inlet Conditioning system (ICU) made up of: a heat pump (HP) and a cold thermal energy storage (TES), an heat exchanger at the inlet of the GT compressor (GTHX) and another ambient air heat exchanger (AmbHX) in an approach that is OEM independent.

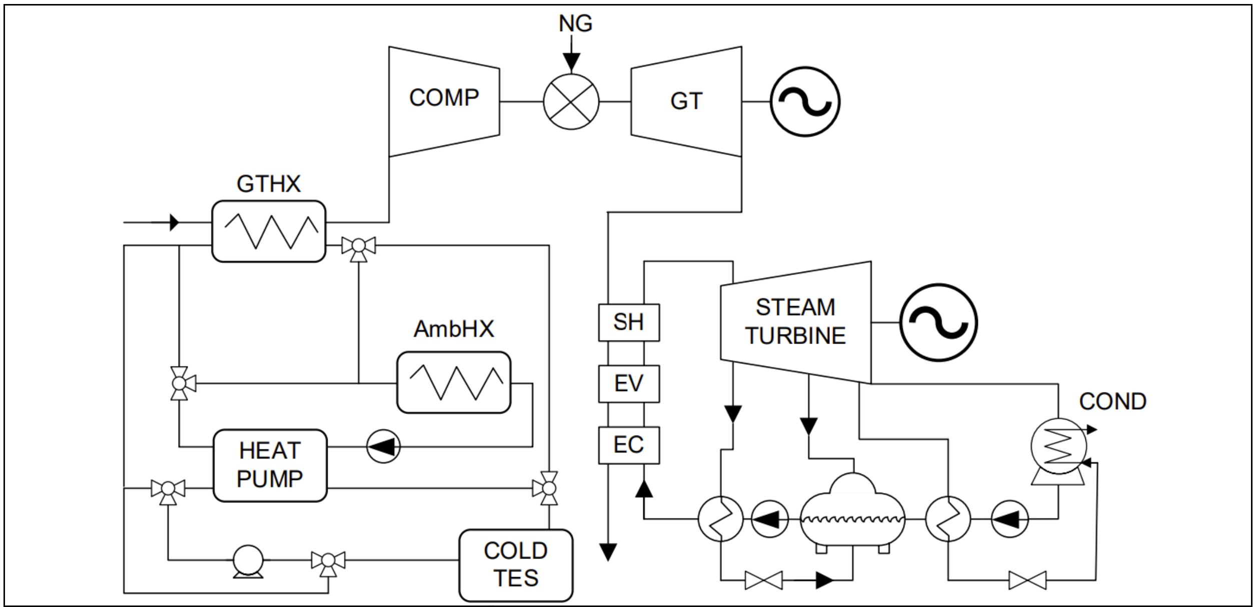

Figure 4 - Pump Heat Layout[3]

Even if the HP can be used for both cooling and heating, the presence of a cold TES greatly enhances the performance of the plant. In fact, thanks to the TES it is possible to decouple the refrigeration of the inlet air flow from the operation of the HP, avoiding electric consumptions when the prices are high. Then, the TES can be charged during low electrical price periods, when the HP is being used to heat the air flow and reduce the minimum environmental load of the CCGT.

[3] R. Guedez, J. Garcia, A. Nuutinen, G. Graziano, J. Chiu, and A. Sorce, "Techno-economic comparative analysis of innovative combined cycle power plant layouts integrated with heat pumps and thermal energy storage," in ASME Turbo Expo 2019, Phoenix AZ, USA, June 17-21, 2019

Table 3 shows the design parameter used in the study:

Table 3: CCGT and ICU technical features.

	Size	Additional Features		
GT	270 MW (400 MW in CC)	F-class	V94.3A4	
HRSG	c.a. 400 MW_{th}	3 pressure levels and reheat		
HP	3.5 MW_{el}	COP_{design}=3.5, COP_{max}=5		R600
TES	10 MWh_{th} (±10MW_{th})	PCM: 15.1 ton	CrodaTherm^{TM} 5	
AmbHX	17.5 MW	Finned tube coil heat exchangers		
GTHX	17.5 MW			

Therefore, to fully exploit the capacity of the power plant, it is necessary to design an integrated conditioning system, regulated by an advanced control system. This conditioning system is expected to increase the operation flexibility of CCGT in terms of[4]:
1) power augmentation: useful during high electricity price periods (peak periods), to increase the CCGT power output (+14% during TES discharging);
2) minimum environmental load reduction (-16%);
3) off-design efficiency enhancement (ca. +1%).

In particular, the ICU system allows increasing the operational flexibility of CCGT in terms of power augmentation, useful during high electricity price periods (Peak Periods) to increase CCGT power output, and minimum Environmental Load reduction, off-design efficiency enhancement. A CCGT-ICU integrated power plant operates according to 5 operational modes:

• **Continuous Cooling mode**, the GT inlet air is cooled down by the HP, and heat at the HP's condenser is dumped into the environment by means of AmbHX. The HP acts an additional auxiliary load that can results in an efficiency reduction.

• **TES discharging mode** the GT inlet air is cooled down by the TES. The TES temperature is assumed constant at 5°C because of the properties of the phase change material CrodaThermTM 5. The HP is switched off and does not require electricity, maximizing the electricity production.

• **Continuous heating mode** the GT inlet air is heated up by the HP, the ambient air is the HP's heat source, and thus the AmbHX is connected to the HP's evaporator. This mode can be realized also using the internal heat from the bottoming cycle.

[4] A. Sorce, A. Giugno, D. Marino, S. Piola, R. Guedez, and R. G. A.Sorce, A.Giugno, D.Marino, S.Piola, "Analysis of a combined cycle exploiting inlet conditioning technologies for power modulation," in *ASME Paper GT2019-91541*, Nov. 2019, vol. 3, doi: 10.1115/GT2019-91541.

• **TES charging mode**, the TES is charged and the ambient air represents the HP's heat sink, thus the TES connected to the HP evaporator and the AmbHX to the condenser. This mode does not require the GT to be on, in this case, the electricity from the grid feeds HP.

• **Heating and TES charging mode** the TES is charged and the GT inlet air represents the HP's heat sink, thus the TES is connected to the HP evaporator and the AmbHX to the condenser.

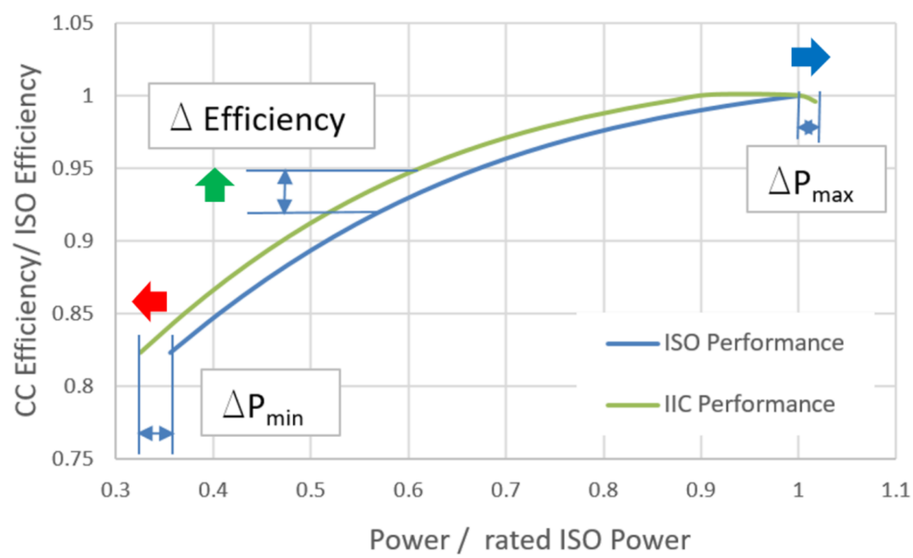

Figure 5 - Pump Heat Layout - Integrated Compressor Inlet Conditioning System: Range and efficiency enhancement

Below the SWOT analysis to focus on the Pump Heat technology:

Table 4: Pump Heat system SWOT analysis

Strengths • Maximum load increase not constrained by the ambient Humidity • Minimum Environmental load reduction • Heat rate reduction in part load • Emissions reduction (CO_2) • O&M Independent	Weaknesses • System Complexity • Need to insert a Heat Exchanger in the GT intake • Operation above the condensation line needs a coalescent filter • CCGT maintenance cost increase
Opportunities • Increase of the CDP (available capacity in probability) in the CM • Optimization of the compressor efficiency in a narrower ambient temperature range	Threats • Performing continuous Inlet cooling gives economic advantages with high electrical prices, but negatively affects total CO_2 emissions if performed without the TES • The system size is optimized on the market condition that are not constant on the long period of usage (20 years)

Strengths

In particular conditions, exclusively during the warm part of the year, the Pump Heat System gives to the GT an extra power that can regain values around 14% more of the current maximum capacity.
The following Figure 6 shows the range of possible cooling transformations, for a 400 MW F-Class CCGT, that can be performed starting from the range of 15-35°C of ambient temperature at 60% of Relative Humidity (RH) to reach a GT intake temperature in the 5-15°C range. The lower final temperature was chosen equal to 5 °C considering the ice formation problem, in fact a lower intake temperature can induce ice formation over the compressor intake due to the saturated air stream.

The dashed red line represents the saturation condition (dew point temperature), above this line condensation occurs up to a maximum of 10.29 kg/s of condensed water, cooling down from 35°C to 5°C. This amount of water needs to be collected through proper designed coalescent filters and represents one of the drawbacks of the close loop solution.

The solid line in colour represents the CCGT net power increase using a TES (left) or an HP (right) to cool down the inlet air.

Black lines represent the CCGT net efficiency variation.

The blue dotted lines on the left graph represent the TES power in MW that it is equal to the cooling energy requirements, while in Figure 6(b) those lines are scaled for the HP performance, showing the HP electrical consumption.
It can be noticed, from Figure 6(a) that the CCGT **efficiency increases** thanks to TES inlet cooling and tends to be lower for intake temperature approaching the 5°C, nevertheless the variation along all operative range is between –0.2 and +0.28 pt%. On the other side, using the HP, the efficiency constantly drops with the HP size (about -1pt% for a 7.5 MW HP solution).

Starting from summer conditions (nominally 35°C, 60% RH), imposing a reduction of temperature of 30K using the TES, the impact on the CC is positive not only under the increased capacity perspective, but also for the efficiency increase for Gross power output. During TES discharge in fact, CCGT Power grows of 50 MW (+14%) while efficiency slightly increases by 0.1 percentage point, which brings to lower CO2 Emissions.
In case of HP in operation, the continuous cooling effect reduces power enhancement to 39.2 MW with a loss of -1.42 percentage point of efficiency. Performing continuous cooling can provide economic advantages with high electrical prices but increases relative fuel consumption and thus CO2 emissions.

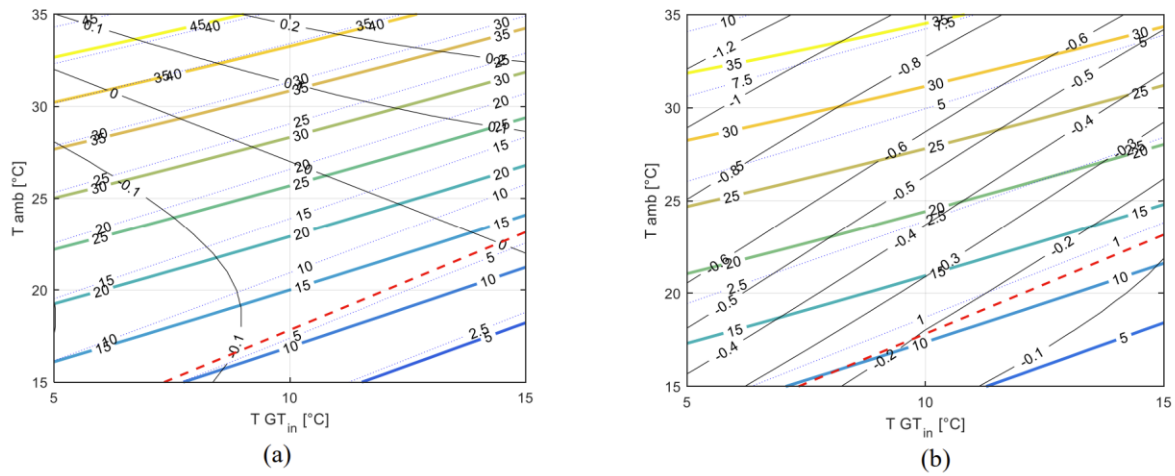

Figure 6 - Power Augmentation as function of ambient and intake temperature
Off-design average F Class based on 400 MW CCGT Performance: (a) TES case (b) HP case. Solid lines in colour: Power Output variation (MW); black line: Efficiency variation (pt%); dotted blue line: (a) TES thermal power output (MW), (b) HP electrical input (MW)

Opportunities

The main positive effect would impact providing new possibilities on the electricity markets.

On the MGP market it would allow to place larger quantities available to GME. This would be to the advantage of energy producers who could have an almost constant power band over the course of the year (however, note that the CCGT power which can be produced is a function of T, p, u.r., pci, density C/H, T sea water, network frequency).

Observing the MGP Market, the complete Pump Heat Layout is particularly effective in electricity market characterized by a high daily price variability even under average negative Clean Spark Spread. The daily electricity price spread turns out the best predictor of the economic performance, followed by the average ambient temperature since an higher temperature is associated with a larger advantage due to the cooling performance, confirming that is essential to consider both the climate and the market factors to properly assess the local potentialities of retrofitting a CCGT with an inlet conditioning unit.
Under the electricity market point of view the Pump Heat layout perform the same action of a storage, absorbing electricity during low price/demand period and increasing the capacity during the price/demand peak.

It would benefit the CM as well as a constant increase in the producible load would affect the CDP of the following year, thanks to a production potential almost independent by the ambient temperature.

Weakness

A possible weakness could be related to the complexity of the system that can cause reliability issue. The need to insert a Heat Exchanger in the GT intake introduce an additional pressure drop at the GT intake.
Above the dew point temperature line (red dotted line in Figure 6) condensation occurs up to a maximum of 10.29 kg/s of condensed water. This amount of water needs to be collected through proper designed coalescent filters and represents one of the drawbacks of the close loop solution.

Threats

Performing continuous Inlet cooling gives economic advantages with high electrical prices, but negatively affects total CO_2 emissions if performed without the TES. If the prevalent use of the system is the continuous cooling operation, other hybridization is suggested (e.g. fogging, absorption chiller).

The system size is optimized on the market condition that could vary on the long period of usage (20 years), however also a not optimized system was profitable in all day-ahead market investigated.

4.3. CO and NOx influence on operation

CO and NOx emissions characterize the operation of GTs at low and high loads respectively. Both constitute a constrain in term of energy production. CO emission is connected to the MEL and NOx emission to the Maximum Load.

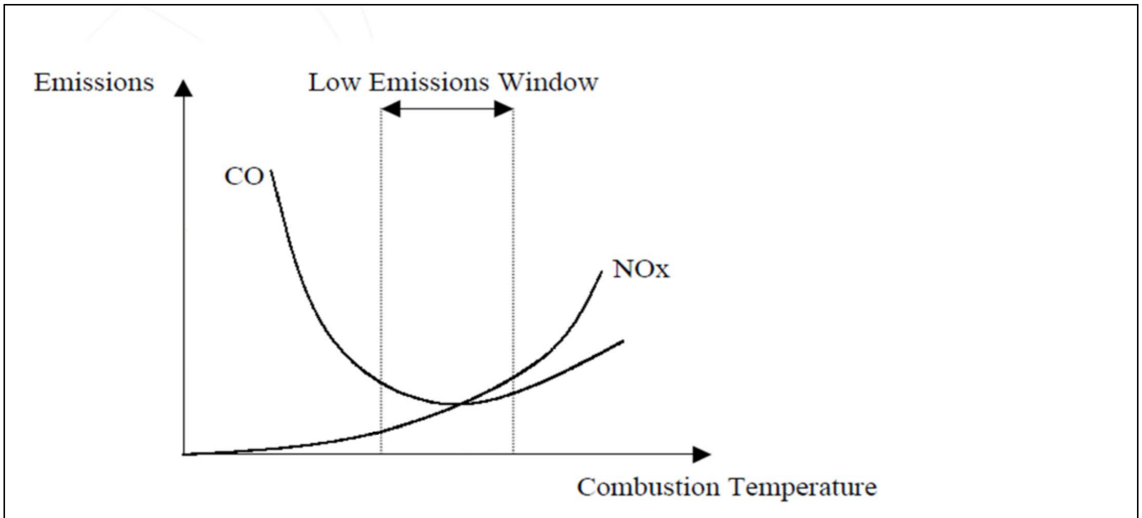

Figure 7 - Relationship between emissions and combustion temperature

The CO production during combustion can occur in case of oxygen insufficiency or lowering of the combustion temperature. The second one is a typical situation that happens during the GT start-ups.

NOx emissions are dependent on the combustion chamber temperature. To reduce the combustion temperature or to premix the fuel with the combustion air in order to avoid "hot spots" is the task of the OEM's installed burners. At high loads is more difficult to control these phenomena.

In VL5 operation experience, GT are tuned in order to be reliable, the exhaust gas temperature has regulated to prevent NOx emissions. This kind of tuning penalize the GT in term of Maximum Load.

When the combustion technology can't provide further improvement is possible to act on the discharge gases.

Controlling the production of these emissions opens up possibilities for making CCGT operation more flexible.

4.3.1. CO Catalyzer

Each CCGT has a CO environmental limit that is controlled by the burners in the combustion chamber of the GT.

Usually GT's OEM tunes burners' natural gas and air flowrates in order to guarantee the CO emission beyond a certain capacity (115MW for VL5's GTs) controlling the fuel/air blend.

The maximum permitted CO emission for VL5 GT – hourly average limit of 20 mg/Ncm @ normal operation – is represented in the following chart by the green line:

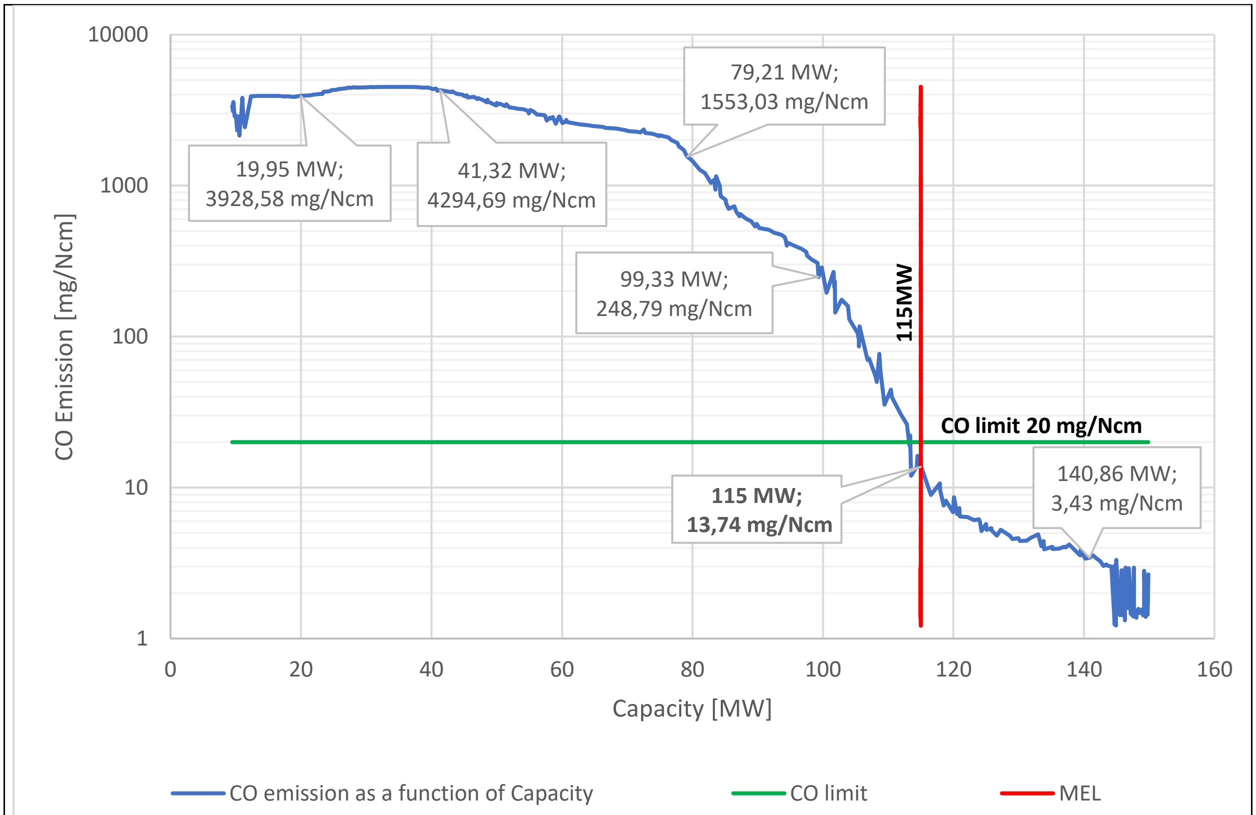

Figure 8 - CO emission from start-up to normal operation

VL5 "normal operation" is when the combustion is stable. It happens when the GT achieves or overcomes 115MW (corresponding to 190MW in 1+1 CCGT configuration or 400MW in 2+1 CCGT configuration). Up to these capacity value emissions are not guaranteed, for this Tirreno Power VL5 must reduce as more as possible the start-up period. There is a procedure - agreed with the National Environmental Body - regarding the compliance of the start-up time in 1+1 configuration or 2+1 configuration.

The oxidation of carbon in CO2 happens at high temperature in the combustion zone but once the flue gas cool down some CO is still unreacted and it cannot be oxidized spontaneously by the oxygen due to the reduced gas temperature.

In addition to the combustion control, operated by the control system of the burners, it is possible to reduce additionally the CO emission using a CO catalyzer.
It is a static element that operates on exhaust gases capturing the residual CO through oxidation.

In the CO catalyzer, the GT flue gas passes through the carbon monoxide catalytic oxidation system where the carbon monoxide is oxidized. The oxidation reaction between oxygen and carbon monoxide, which is enhanced by the catalyst, starts at 250 °C to form carbon dioxide.
Typically, the catalyst is based on Platinum (Pt) impregnated over a special metallic substrate based on FeCr alloy. The CO is absorbed by the Pt active sites, while the presence of Fe facilitates the reactiveness of the O2, leading to the final oxidation in a temperature range from +250 °C to +550 °C. The higher the temperature the higher the catalyst efficiency.
This reaction doesn't require any additional reagent in fact CO and O2 are already present in the flue gas in enough concentration.

The CO catalyzer layer is typically installed in the proper zone of the HRSG – in terms of temperature – that can foster the reaction.

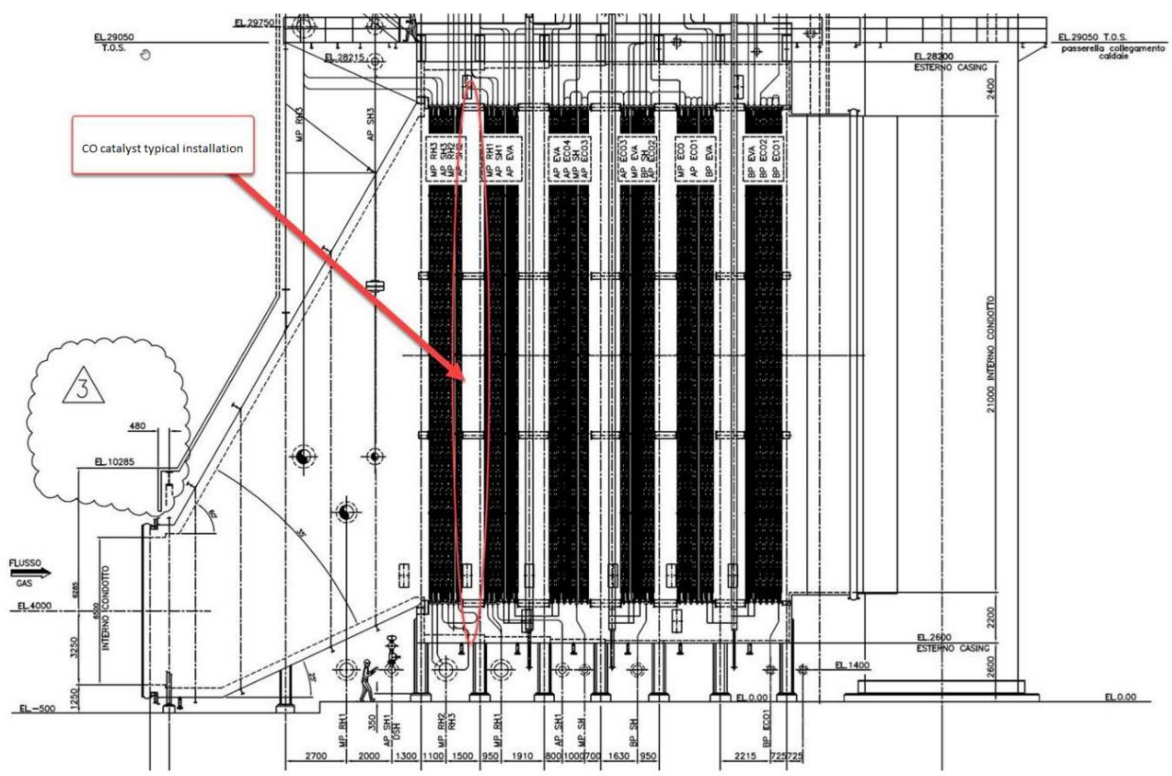

Figure 9 - HRSG sectional drawing – CO catalyzer installation area

The best operating temperature to achieve a compound reaction above 95% are 450°C ÷ 500°C. These values are met in a zone between HRSG's SH2 HP section and RH1 IP section.

The expected catalyst performance – applied on VL5 TGs – can reduce MEL to 80MW correspond to a CO absorption from 1,550 mg/Ncm to 20 mg/Ncm (considering a 15%O2 at GT inlet).
Therefore, the CO catalyzer is expected to reduce the minimum environmental load reduction from 115MW to 80MW with a influence of -30% on the current value.

The system has the potentiality to achieve lower MEL values, but in general terms, the CO catalyst design is fitted considering tech-economical pros and cons and layout constrains.

CO catalyzer layer has an expected lifetime that is near to 16,000 operating hours, after that is necessary to replace all the modules with new ones.

Below the SWOT analysis to focus on the CO catalyzer technology:

Table 5: CO catalyzer SWOT analysis

Strengths	Weaknesses
• Minimum Environmental Load reduction (higher TSO service attractiveness) • Emissions reduction (CO) • Easier GT tuning management • Management of CM	• Maintenance complexity • CCGT maintenance cost increase • Catalyst poison: iodine and ash
Opportunities	**Threats**
• Lower start-ups: less cycling stress • Lower start-ups: less NG consumption • Lower start-ups: less CCGT failures • MSD Market bandwidth increase	• Heat rate increase at MEL • Negative influence on GT maximum load due to exhaust gas pressure drop increase • Reliability reduction

Strengths

MEL reduction. CO emissions, typical at low loads, limit the possibility to stay in operation. On the other hand, TSO rewards those Operators that can help the management of RES maintaining CCGTs in the grid with prices higher than usual, in order to have the enough amount of rotating reserve. It means other opportunities like less starts, less cycling, less NG consumption for start-up as well.
More renewables are interconnected in the energy grid, more TSO needs to ask for operation of power units that can control frequency and support fast leakage of power. A CCGT working at low load has the faster response in ramp-rate than any another one available to start, but out of the grid.

From the environmental point of view, the CO reduction is a strength to easily have future Environmental Authorizations that, periodically, the National Environmental Body issues. It can be a plus because every next Environmental Authorization (AIA) will have always lower emission limits.

Operate a GT with CO catalyzer can help an easier management of the GT itself in case of environmental tuning necessities. CO Catalyst can minimize short period of burners' deviations from the standard combustion. It would enable to operate the GT waiting the tuning action by the OEM.
The possibility to manage burners inefficiency can carry advantages to the pursuit of the CM targets.

Opportunities

CO reduction means a lower MEL. With a lower MEL could be possible to reduce the yearly number of start-ups. This new operational mode (with less start-ups) can carry the following opportunities:

1. reducing cycling stresses and extend the GT and CCGT lifetime
2. saving of NG consumption from GT start to MEL
3. reducing of GT and CCGT failures linked to transient conditions
4. MSD Market bandwidth increase

Being the period between 2 main overhauls (MI and HGPI) equal to 33,000 EOH, considering an average number of 125 start-ups per year and an average of 5,300 EOH per year, is possible to define the MEL reduction expected benefit.
Installing a CO catalyzer, the VL5 GT's MEL will move from 115MW to 80 MW. Table 6 shows that is possible to put in relation start-ups saved with cubic meters of NG saved and EOH saved.

Start-ups reduction includes a saving in NG cost to carry the GT from zero rpm to MEL. Currently, with 115MW MEL, a hot start-up needs 30,000 Nm3 of NG (with an average LHV_{NG} of 37 MJ/Nm3), each one "costs" 310 MWh_t. With an 80MW MEL, the start-up will need 20,000 Nm3 with a cost of 205 MWh_t.

The following Table 6 refers start-ups saved to NG consumption saved and EOH saved. Anyway, it is highly unpredictable to foresee the effect of the MEL reduction on CCGT operation; it strongly depends on a lot of uncontrollable factors: NG cost, MSD necessity (it varied strongly from year to year according to electrical grid evolution), climate events (drought periods, for example) mainly.

Table 6: Start-up influence on CCGT

% Start-ups saved	# saved start-ups/year	NG Nm3 saved *	saved EOH/year	% saved EOH on yearly average	Years between a MI and HGPI
0%	0,0	0	0	0%	6,2
10%	12,5	437.500	125	2%	6,4
20%	25,0	875.000	250	5%	6,5
30%	37,5	1.312.500	375	7%	6,7
40%	50,0	1.750.000	500	9%	6,9
50%	62,5	2.187.500	625	12%	7,1
60%	75,0	2.625.000	750	14%	7,3
70%	87,5	3.062.500	875	17%	7,5
80%	100,0	3.500.000	1000	19%	7,7
90%	112,5	3.937.500	1125	21%	7,9

* Considering hot start up only (35,000 Ncm of NG consumption)

To relate the failures reduction reducing start-ups is harder, but it is clear that anomalies are most likely to occur during start-up because more equipment operates in off-design condition and the thermal and pressure excursions are higher. Similarly, to Fogging system, CO Catalyzer helps to increase the MSD down bandwidth. If fogging - in specific weather condition - can increase the maximum load, CO catalyst - reducing the MEL - increases the MSD down band selling area. It is a clear opportunity especially in summer when the maximum load is nearer to MEL.

Figure 10 - MSD bandwidth increase

Weaknesses

The need to replace the elements of the catalyst every 16,000 EOH - the expected lifetime - introduces a further complexity on plant management. This can represent a weakness especially for the achievement of the plant availability targets (mostly considering the CM).
It introduces a constraint to manage the maintenance periods of GT and ST which are not always compatible.

It is simple to understand that to introduce a new equipment means to have more maintenance Operating Expense and Capital Expenditure.

CO elements are subject to poisoning. Catalyst poisons are: heavy and base metals, such as lead, mercury, arsenic, antimony, sodium, potassium, lithium, zinc, copper, iron, nickel and chrome, sulphur, silicon, and phosphorous and chlorine, fluorine, bromine, iodine and ash.
In case of plant near the sea, iodine could be an issue. The same weakness is for those cogeneration plants that are near industrial site.

Threats

A MEL reduction corresponds to an increase in the CCGT Heat Rate. It is not easy to predict whether the minimum load operation cost is attractive to the TSO and therefore there is no certainty that the investment will bring an actual benefit.

Against a reduction of the technical minimum, even at maximum loads there would be a pressure drop on the flue gas side (approximately 5 mbar).
The increase in back pressure at the GT exhaust results in a reduction in machine performance of about 0.5% in capacity for every 10mbar increase in pressure drop.

The impacts on flame stability, increase in combustion chamber T are negligible.
It is important to pay attention to the possible impact on the flatter of the GT turbine discharge blade, which, even if protected by the shutdown/trip logic, could be a cause of possible unscheduled unavailability.

4.3.2. NOx Selective Catalytic Reduction

VL5 GT has a NOx hourly average limit of 30mg/Ncm at normal operation, an annual average limit of 25 mg/Ncm and a mass emission limit of 400t/year as a sum of TG51 and TG52.

During star up period as well – under the MEL – the NOx production is over the emission limit, anyway they reach the requested value before the CO.
VL5 "normal operation" is when the combustion is stable and the environmental limits accomplished. The normal NOx emissions are met at lower load then CO emissions, but they must be managed if the MEL is reduced by a CO catalyst.

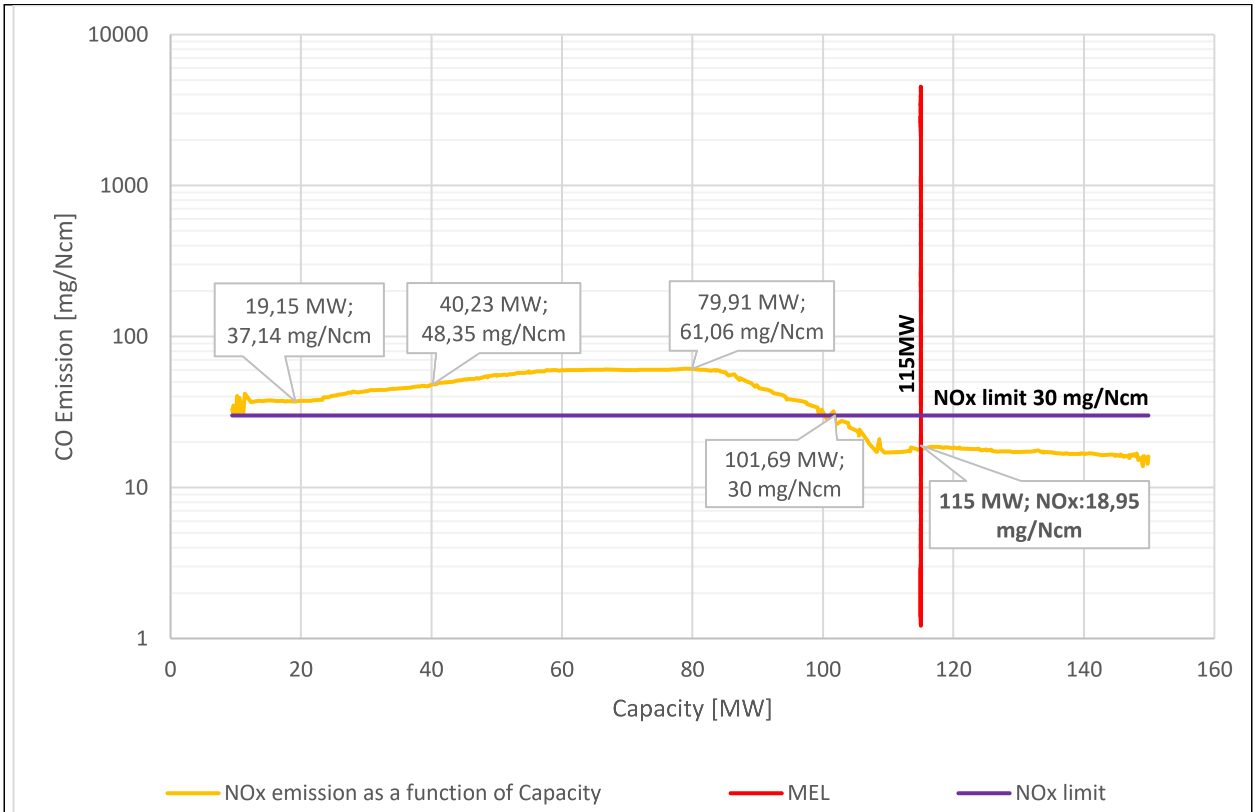

Figure 11 - NOx emission from start-up to normal operation

In addition to the combustion control, operated by the control system of the burners, it is possible to reduce additionally the NOx emission using a NOx Selective Catalytic Reduction system (SCR).
It is a static element, a reactor, that operates on exhaust gases capturing the residual NOx.

In a combined cycle it is possible to use the HRSG itself as catalyst seat of the reactor. The reactor is installed in the position where the flue gas, passing through the HRSG duct, has the proper temperature (between 350°C and 420°C) in the complete range of operation.

The catalyst receives the exhaust gas from the upstream tube banks, mixed with the gaseous ammonia coming from the evaporation system. SCR technology is composed by a ceramic honeycomb structure, mainly consisting of titanium dioxide (TiO_2), containing smaller quantities of active catalytic compounds, mainly vanadium pentoxide (V_2O_5) and tungsten trioxide (WO_3).

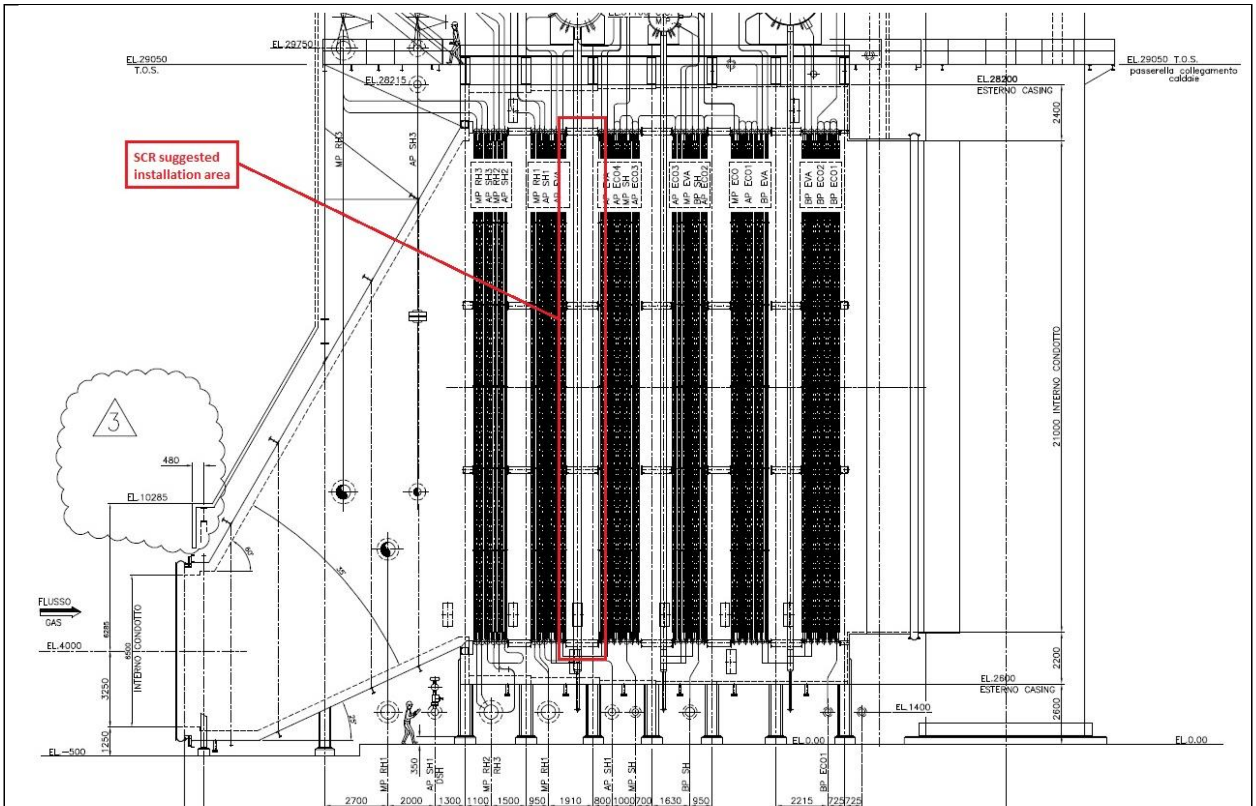

Figure 12 - HRSG sectional drawing – SCR installation area

In the SCR process the nitrogen oxides (NO_x) are reduced to molecular nitrogen (N_2) and water (H_2O) by a reductant agent.

The reductant is always ammonia (NH_3). Ammonia can be supplied as:

- Anhydrous ammonia (pure ammonia, NH_3). It is rarely used because it is a dangerous chemical subject to strict restrictions.
- Ammonia aqueous solution, the concentration varies between 19% and 25%. It is commonly used and probably the easiest reagent to adopt for SCR system.
- Urea ($CO(NH_2)_2$) available in water solution with concentration between 32,5% and 50%. Urea must be decomposed before the contact with the catalyst, so that free ammonia is available at the catalyst. Urea is not a dangerous chemical but is more complex to use and to transform in NH_3.

The ammonia flowrate is adjusted by measuring the gas flow (or the unit load) and by the difference between NO_x concentration upstream of the SCR and NO_x concentration at stack. Through a dedicated control loop, it is possible to inject the ammonia quantity strictly necessary to obtain the desired emissions, without exceeding the ammonia slip.

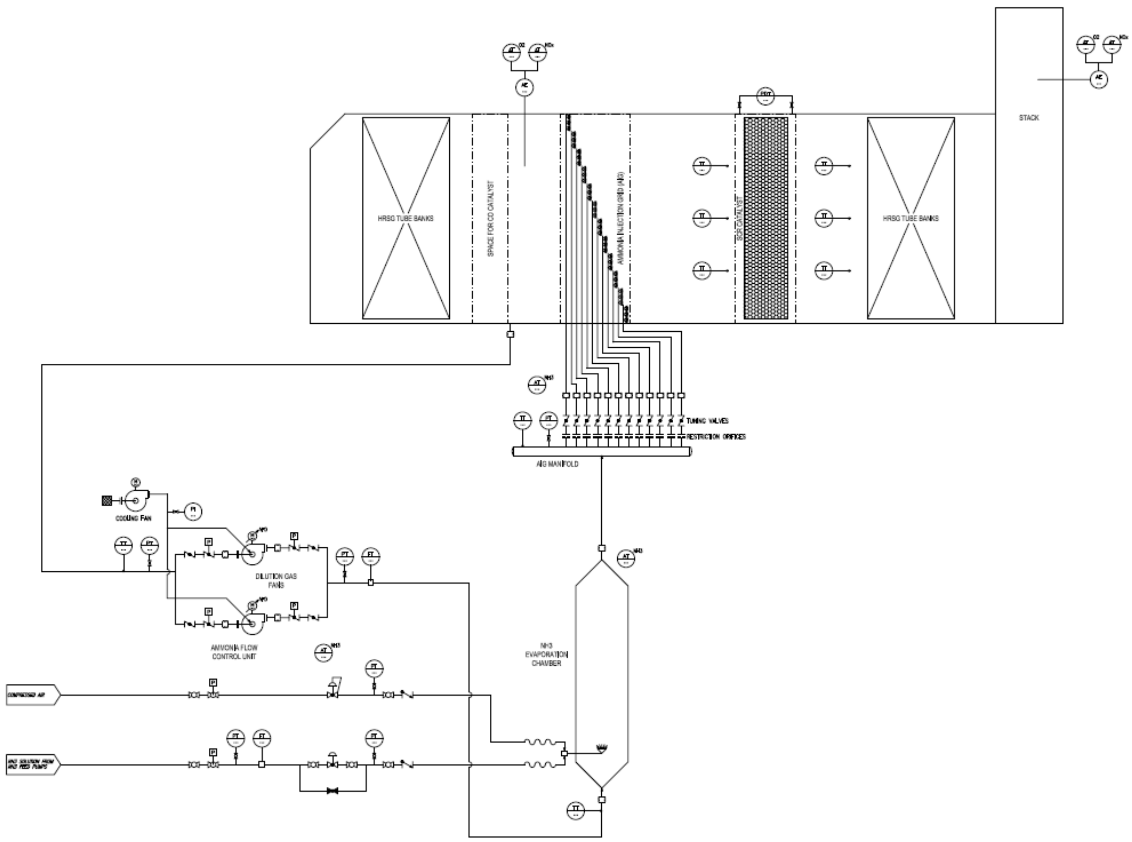

Figure 13 - SCR typical arrangement

The ammonia necessary for NOx reduction is obtained by converting an aqueous solution of ammonia, which is injected in a stream of hot air or gas. The injection of diluted gaseous ammonia upstream of the SCR takes place through a special ammonia injection grid. An optimal distribution of the reagent is essential to achieve the overall performance of the SCR system, in terms of:

- NOx reduction
- ammonia slip containment
- ammonia consumption reduction

The SCR system normally works over the whole load range of the HRSG without limiting its operation and follows the load variation by modifying the amount of ammonia that is injected.

The ammonia solution used as reagent for the SCR is usually stored in a common area that can serve many SCRs in the same power plant.

The SCR performance (DeNOx-efficiency and NH_3-slip) will be met by the catalyst until the end of 10,000 operating hours.

Below the SWOT analysis to focus on the SCR technology:

Table 7: SCR SWOT analysis

Strengths • Emissions reduction (NOx) • Easier GT tuning management • Management of CM	Weaknesses • CCGT maintenance cost increase • Possible new emission constrains (NH3 slip)
Opportunities • CCGT lifetime extension (referred to AIA)	Threats • Negative influence on GT maximum load due to exhaust gas pressure drop increase • Reliability reduction

Strengths

The direct benefit is the emission reduction in terms of NOx.
Operate a GT with SCR can help an easier management of the GT itself in case of environmental tuning necessities. SCR can minimize short period of burners' deviations from the standard combustion. It would enable to operate the GT waiting the tuning action by the OEM.
The possibility to manage burners inefficiency, as well as CO catalyzer contribution, can carry advantages to the pursuit of the CM targets.

Opportunities

The GT maximum load is obtained with a sequence which foresees the total opening of the IGVs and the subsequent increase of the temperature in GT's combustion chamber increasing the NG flowrate at steady air flowrate; this temperature is controlled by the GT exhaust gas temperature measurement. Therefore, the maximum load is reached by increasing the exhaust gas temperature after having reached 100% IGV.
In this situation, the greater the increase in temperature, the greater the load output. This condition leads to 2 problems: NOx increase and flame instability. The increase of NOx could be managed through SCR, the flame instability instead is less controllable therefore it is preferable to give priority to reliability rather than to the maximum load obtained with the increase of T.

For this reason, the presence of the SCR would be important in the case of further restrictions on NOx emissions. Currently the burners guarantee emission limits compliance at the maximum load .

The installation of a SCR can provide more confidence on the yearly mass emissions target, according to the AIA's purposes. It will be a plus for the achievement of future Environmental Authorizations that will have likely lower limits. It would represent a condition for the lifetime extension of a CCGT.

Weaknesses

The need to replace the elements of the SCR every 10,000 operating hours - the expected lifetime - introduces another maintenance constrain on plant management. This will be a weakness especially for the achievement of the plant availability targets (mostly considering the CM).
It introduces a restriction to manage together the maintenance of GT and ST which are not always compatible.

It will increase the maintenance Operating Expense and Capital Expenditure.

Furthermore, a not correct operation of the SCR can cause possible event of ammonia slip. This new pollutant must be notified to the Environmental Body that can set new limitation on CCGT operation.

Threats

The SCR bench installed in the flue gas can introduce, as indicated for the CO Catalyzer threats, a back pressure increases at the GT exhaust that results in a reduction in machine performance.

Adding a new package can carry more possibilities of unscheduled out of service. These can be avoided if it possible to switch off the SCR's ammonia injection.
If instead, with the SCR installation, AIA imposes a stricter limit on NOx, SCR could lead more GT unavailability cases introducing a reliability reduction of the power plant.

4.3.3. FLEXnCONFU

Here it is reported only a summary of the results to what is extensively set out in the Deliverable 1.2 and an organization of them in accordance with the SWOT analysis proposed for the previous assets.

The analysis performed for the WP1 reported in D1.2 shows the performances that Flex'n'Confu solutions can achieve in terms of flexibility, in particular for Maximum Load, Heat Rate and CO_2 emissions.

The Flex'n'Confu's performances have been evaluated with 5 different fuel gas combustion simulations: 100% methane, 30% hydrogen and 70% methane, 100% hydrogen, 30% ammonia and 70% methane, 100% ammonia.

Although the mixed fuels (methane and hydrogen and methane and ammonia) didn't give significant results, on the other hand 100% hydrogen combustion and 100% ammonia combustion improves significantly CCGT performance.

The following trends have been observed for 100% H_2 combustion:

1. Heat rate improvement of 1.5%
2. Power output improvement of 3.5%
3. CO_2 reduction in flue gases by around 20% for 50% volH_2

The following trends have been observed for 100% NH_3 combustion:

1. Heat rate improvement of 3.5%
2. Power output improvement of 14%
3. CO_2 reduction in flue gases by around 30% for 50% volNH_3

Regarding the impact on materials that the use of hydrogen and ammonia can lead, the D1.2 reports how the use of hydrogen and ammonia have negative influences on the fuel supply system, the combustion system and on turbine hot gas path.

Below the SWOT analysis to focus on Flex'n'Confu:

Table 8: Flex'n'Confu SWOT analysis

Strengths • Maximum Load increase • Heat Rate increase • CO_2 specific emission reduction	Weaknesses • Incompatibility with AIA's NOx emission limit • Possible new emission constrains (NH_3 slip)
Opportunities • -	Threats • Incompatibility of the existing infrastructures with the combustion environment

Strengths

In case of full H_2 combustion the foreseen increase of Maximum Load can be +3.5% of the CCGT current value burning natural gas.
In case of full NH_3 combustion the foreseen increase of Maximum Load can be +14% of the CCGT current value burning natural gas.
While regarding the Heat Rate reduction is -1.5% and -3.5% for H_2 and NH_3 respectively.
The expected CO_2 emission reduction is expected to be in a range of -20%÷-50% considering both technologies.

Opportunities

No other advantages seem to be available implementing the use of H_2/NH_3 as fuel.

Weaknesses

As D1.2 reports, the simulations are not fully validated for NOx emissions. The trend is that NOx emissions will increase with higher hydrogen and ammonia concentrations in the fuel this is strong constrain for the CCGT's AIA environmental limits.
During the combustion of ammonia and hydrogen, larger quantities of water vapour are formed. Water vapour increase the wear and tear of certain hot gas path components, such as the thermal barrier coatings reducing the lifetime of such components.
In the case of ammonia combustion, as it is a slow burning fuel, the ammonia slip might become important. This new pollutant must be notified to the Environmental Body that can set new limitation on CCGT operation.

Threats

Hydrogen affects the existing gas turbine hardware. The assessment of hydrogen embrittlement on the base materials and protective coatings of the hot gas path should be further considered when operating the gas turbine with partial or full injection of hydrogen. For the gas turbine components downstream of the combustion section, the influence of hydrogen injection on the materials will be an indirect influence due to higher temperature, increased volumetric flow, high water vapor content.

Concerning the impact of adding ammonia to the fuel on the existing gas turbine hardware, highly corrosive atmospheres can be created. Depending on the composition of the fuel, both acid and basic atmospheres can be formed (possible presence of water vapor, NO, unburnt ammonia), which will be interacting at high temperatures with the structural materials.

5. Flexibility needs of the FLEXnCONFU concept - Conclusions

In the recent past, the Energy Market has been extremely variable, due to the influence of external factors such as: the reduction of coal-fired sources of production, the advent of the pandemic and the subsequent reduction in demand, the Ukrainian crisis, periodic regulatory updates in the electricity market.
These situations mean that when the market raises prices, the economic returns are such as to make the plant efficiency less important, but availability becomes very important instead.

The study conducted draws the pros and cons of adopting the various technologies that can always be profitable or profitable only in some conditions.
The **MEL** reduction is related to the Heat Rate. There is not enough experience of how the strategy of reducing the MEL can bring benefits in terms of reducing start-ups and therefore plant cycles. Furthermore, the sustainability of the MEL must be supported by a Heat Rate that can guarantee at least the balance between the cost of gas and the price of energy.
The occurrence of this condition benefits on the MSD market by providing a greater bandwidth of MSD. The improvement of this KPI can be achieved by adopting **Pump-Heat** or the **CO Catalyzer**.

The increase in the **Maximum Load**, on the other hand, is a feature that has no drawbacks as it acts positively on all markets: MGP, MSD, and Capacity Market
The assets that guarantee the increase of the Maximum Load are **Fogging** and **Pump-Heat**. It must be specified that power increase is possible only when the ambient T are the typical of the summer; higher than 15°C for Fogging and higher than 5°C for Pump-Heat.

Table 8 shows how the increase in the **Load Gradient** cannot be improved with the adoption of any of the assets analysed.

As for the Maximum Load, the reduction of **Heat Rate** has only positive effects. Among the assets analysed, only **Pump-Heat** allows a slight improvement of this KPI.

No asset guarantees the **CO_2 Specific Emissions Reduction** (except of Pump-Heat which, by improving the Heat Rate, reduces very slightly the production of CO_2 by virtue of a NG lower consumption under the same capacity condition).
CO Catalyzer and **SCR** introduce advantages in terms of absorption of polluting substances by containing the emission of CO and NOx respectively. However, these assets have the advantage of minimizing short period of GT burners' deviations from the standard combustion helping the CCGT availability.
They are important in case of CO/NOx restrictions for further AIA authorizations.

The **Start-ups Reduction** is a secondary effect introduced by the MEL reduction. As previously described, its effectiveness due to the flexibility assets installation cannot be foreseen because it depends on how the energy is remunerated for these loads. In the summer and in case of very high energy prices, the

possibility to remain in operation for long time, even at night, was tested. This was possible because the economic remission to keep the plant at MEL during the nighttime corresponded to the cost of the additional gas consumption to stop and restart the plant.
This outcome can be obtained by installing the **CO Catalyzer** or **Pump-Heat**.

Availability is a KPI that benefits from the **CO Catalyzer** and **SCR** installation.
These assets can help reduce the effects that an incorrect combustion brings in terms of availability. It was necessary to shut down the plant to fine-tune the combustion. For the same reason, these assets may have an effect on the CDP linked to the Capacity Market and to the future AIA environmental authorizations both in the case of complying with existing ones, and in the case of having to face new and more stringent limits of future AIA which, without these assets, would force the plant possibly even to close.

In conclusion, the final Table 9 shows the performance values in terms of flexibility with which Flex'n'Confu project will have to deal with.

Table 9: Assets vs KPIs

Assets KPIs	MEL Reduction	Maximum Load Increase	Load Gradient Increase	Heat Rate Reduction	CO_2 Specific Emissions Reduction	Start-ups Reduction	Availability	
	458 MW net	781 MW net	26 MW/min	6.299 kJ/kWh	2,09 kgCO2/NcmNG	Hot startup = 30 kNcm	4%	**SWOT Analysis Highlights**
Fogging		**+10%**						**S**. Up to +10% of Maximum Load increase in summer condition **W**. Effectiveness only in a short period of the year **W**. Need of first blades special coating **O**. MSD/MGP bandwidth increase **O**. CDP increase **T**. Risk of catastrophic event (FOD)
Heat Pump	**-16%**	**+14%**		**-1%**		**X**		**S.** Up to +14% of Maximum Load increase in summer condition **S.** Up to -16% of MEL **S.** Up to -1% of HR in GT off design operation **W.** System complexity at GT intake (coalescent filter and GTHX **O.** CDP increase **T.** CO2 emissions if performed without the TES
CO Catalyzer	**-30%**				**Only CO pollutant**	**X**	**X**	**S**. Up to -30% of MEL **S**. Easier GT tuning management **W**. CCGT maintenance cost increase **O**. Start-ups reduction **O.** MSD bandwidth increase **T**. HR increase at MEL
Selective Catalytic Reduction					**Only NOx pollutant**		**X**	**S**. Easier GT tuning management **W**. Possible new emission constrains (NH3 slip) **O.** CCGT lifetime extension (referred to AIA) **T**. Negative influence on GT maximum load due to exhaust gas pressure drop increase
FlexnConfu H2/NH3		**+3.5%/+14%**		**-1.5%/-3.5%**	**-20÷-50%**			**S.** Up to +3.5% with H2 and +14% with NH3 of Maximum Load increase **S.** -1.5% with H2 and -3.5% with NH3 of CCGT HR **S.** -20÷50% of CO2 specific emission **W.** Simulations not fully evaluated for NOx emission **T.** Incompatibility of the existing infrastructures with the combustion environment

Annex n.1: Natural gas composition 2016-2020