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AVEVA WORLD MILAN, MAY 2026

ENEL Green Power

Sustainability Gains from Predictive Remote Diagnostics

Andrea Pica, ENEL Green Power

ENEL Green Power: Sustainability Gains from Predictive Remote Diagnostics

Enel Speaker

Eng. Andrea Pica
Head of Global TS Cross Remote Diagnostic Area
Enel Green Power and Thermal Generation

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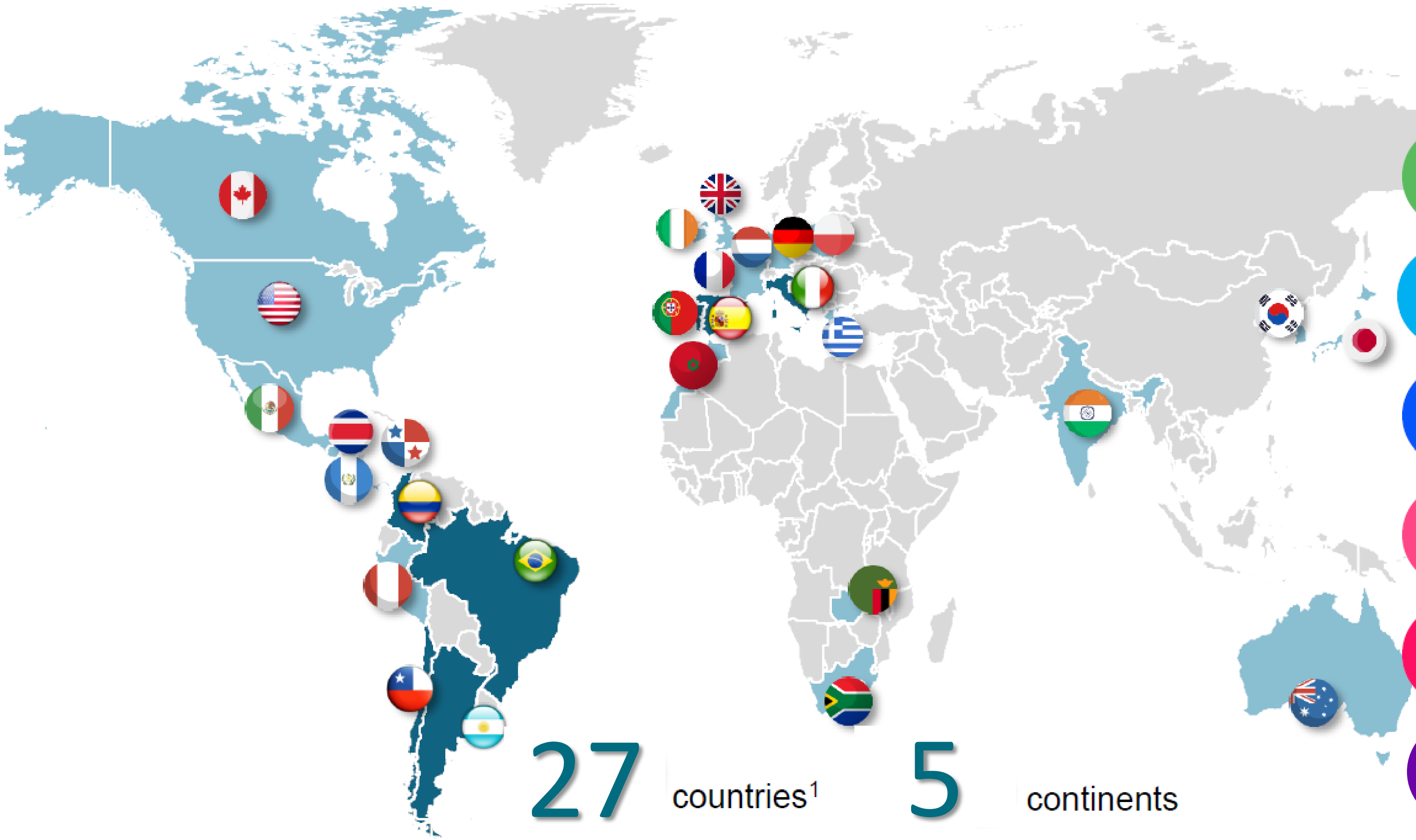
Enel at a glance



27 countries[1]

5 continents

2025

92.8 GW	Total installed capacity[2]
200.3 TWh	Group production
54.0 mn	End customers
10.2 GW	Demand response
33 k	Public charging points
97 gCO_2eq/kWh	CO_2 footprint

Enel Green Power Predictive Monitoring Area overview

MAIN ACTIVITIES

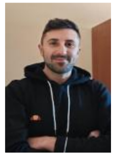
- Dedicated Global team for Near Real-Time monitoring and first level diagnostic
- Data Driven Approach to support Country O&M decision making process
- Flexibility and scalability of process and tools on other technologies of the fleet
- On-demand in-depth analysis and creation of new models in existing assets previously not deployed
- Performance reports and quarterly meetings with Country O&M on the global fleet status
- Development of new solutions and initiatives (i.e., smart sensors, pilot project on predictive diagnosis, robotics and metering tools

ORGANIZATION & FOOTPRINT

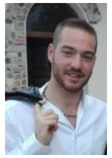
A. Pica

S. Renzi

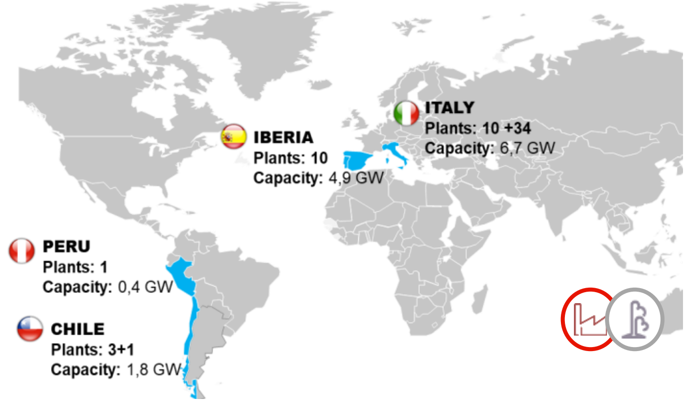
M. Leoncini



P. Serpente

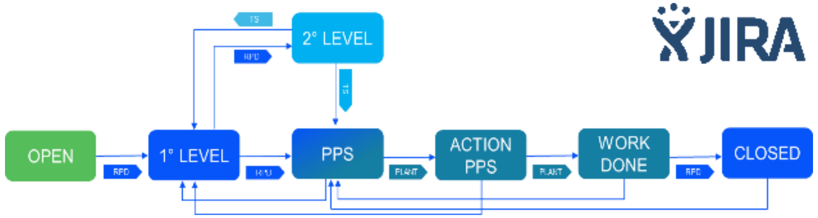


F. Galassi



2 Technologies in 4 Countries
86 Power Generation Units
≈14,6 GW Installed Capacity
>1100 Assets 37k PI TAGs ≈ 3000 Analytics

PROCESS & KPI



Unique global end-to-end process with direct communication with power plants

KPI Closing '24

328	119	≈2000 h
Tickets opened	Real cases catched	Est downtime avoided

KPI Closing '25

245	127	≈1300 h
Tickets opened	Real cases catched	Est downtime avoided

Sustainability improvement through data driven diagnostic

Challenge

- Evaluate sustainability benefits of applying a monitoring and diagnostics process in EGP Thermal & Geothermal fleet allowing a reduction in the unplanned unavailability of power plants

Solution

- Set up of a methodology together with AVEVA BVC Team using a bottom-up or a top-down approach and calculation of the results derived from real cases identified in a 48 months period using Predictive Analytics

Benefits

- A more efficient resource utilization, fewer energy losses and a decrease in direct/indirect emissions. Predictive maintenance also helps extend asset life, supporting long-term operational sustainability and reinforcing the company’s ESG commitments with measurable result

Benefits of predictive diagnostic

O&M Resource Optimization

Targeted Maintenance Savings

Predictive diagnostics enable focused maintenance, reducing costs for spare parts, labor, and emergency repairs.

Minimized Production Losses

Anticipating equipment failures prevents unplanned outages, minimizing costly production losses.

Extended Component Lifespan

Timely maintenance extends the lifespan of critical components, lowering replacement frequency and capital expenses.

Efficient Resource Allocation

Maintenance efforts focus on truly needed areas, boosting operational efficiency and financial performance.

Enhancing Reliability and Efficiency

Early Anomaly Detection

Predictive diagnostics enable early identification of equipment anomalies, preventing major failures in critical components.

Minimized Unplanned Downtime

This approach reduces unplanned downtime, ensuring continuous and stable energy production in power plants.

Optimized Maintenance Scheduling

Maintenance is scheduled based on real equipment conditions, improving resource management and reducing unnecessary tasks.

Enhanced Asset Reliability

Overall asset reliability and availability are improved, leading to more efficient and smoother plant operations.

Benefits of predictive diagnostic

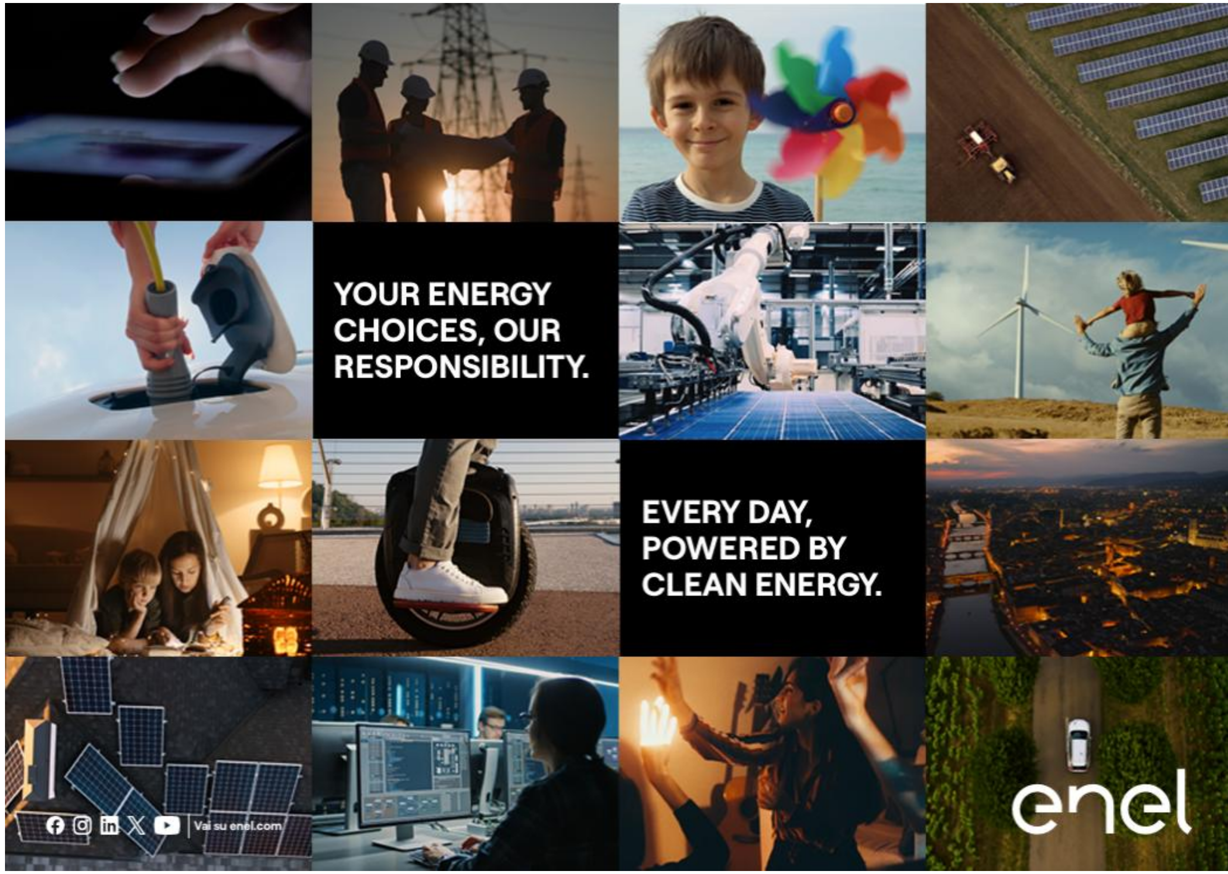
Supporting Sustainable Operations

Energy Efficiency Improvement
Predictive diagnostics optimize equipment efficiency in power plants, reducing energy waste and enhancing sustainability.

Emission Reduction
Timely maintenance prevents malfunctions that cause higher fuel consumption and harmful emissions in power generation.

Minimized Environmental Footprint
Reducing emergency repairs and unplanned shutdowns lowers the environmental impact of maintenance operations.

Alignment with Global Sustainability Targets
Predictive diagnostics support cleaner energy production and global carbon emission reduction efforts.



Sustainability impact assessment

How to measure the impact of predictive diagnostic other than O&M reliability/efficiency

IDENTIFY A PROPER METHODOLOGY AS A GUIDE MAP

EPRI Guideline on Proactive Maintenance contains a well detailed cost benefit calculation section, guideline was developed in collaboration with several US and European companies' best practices and evaluated how they could be incorporated into a PAM program

EPRI

Guideline on Proactive Maintenance

Technical Report

B

COST BENEFIT CALCULATION

Occurrence Assumption Worksheet				
Plant Name:	Waukegan Sta. 16	Unit Number:	7	
Definition of detected fault:	#7 Main Transformer, B phase bushing significantly hotter than adjacent phases			
Occurrence No.:	WAK-008	Max. Rated Load:	353	
Occurence Assumption:	**(a)Catastr.**	**(b)Moderate**	**(c)Loss of Perf.**	**(d)Actual**
Occurrence Description	Transformer destroyed, forced	Bushing failure, transformer		Bushing replaced.
Loss of Generating Revenue				
Power Reduction (MW)	353	353	0	353
Hours	3456	100	0	48
Capacity Factor (%)	60	60	0	
Forced Outage (Yes =1 No =0)	1	1	0	0
Maintenance Costs				
Cost of Parts ($)	$1,250,000	$20,000	0	2000
Labor Hours (Hrs)	2160	1008	0	72
Percent Probability of Fault Occurrence	10	90		

Definitions:

OCCURRENCE - any detected or diagnosed fault which the station takes action, whether the action was proactive or reactive.

When the station schedules repairs or modifies plant operation to minimize the fault's impact, a cost benefit analysis will be conducted.

If maintenance is deferred based on a PDM technology, the CBA, based on the deferral, will be calculated on the time-value of $$$ saved.

CATASTROPHIC - Total equipment failure requiring full repalcement.

MODERATE - System failure resulting in some repairable equipment damage.

LOSS OF PERFORMANCE - Reduction of operating capacity due to fault.

ACTUAL - Actual cost of outage.

			Input Data
	Calculated Values		
Total Cost Benefit - This Occurrence	$855,637	Average Replacement Power Costs ($/MWH)=	9
Maintenance Costs Savings ($):	$177,792		
Impact on EFOR (%):	4.97		
		Average Labor Rate ($/HR) =	35

Figure B-1
Cost benefit calculation example

CONVERTING EPRI COST CALCULATION TO SUSTAINABILITY KPIs

Leveraging on the approach of the guideline is possible to identify at least 4 main areas impacted by the process

- **GHG Emissions**

Scope 1 GHG emissions = core process + by-process direct GHG emissions

Scope 2 GHG emissions = energy related emission = energy consumption x energy CO_2 footprint

Scope 3 upstream GHG emissions = quantity of feedstock x feedstock upstream CO_2 footprint

- **Energy**

Utilities direct consumption reduction in core process (electricity…) + by-process utility consumption reduction.

- **Materials**

Reduced scrap amount per unit produced x number of units produced + reduced amount of not qualified units.

- **Water**

Water consumption reduction in core process + water consumption reduction in by-process

Sustainability impact assessment - ENEL Case

PROCESS DESCRIPTION

- Scope of impact analysis process include EGP Thermal & Geothermal Fleet under monitoring with PA
- AVEVA Predictive Analytics and PI Systems were deployed to monitor critical power generation assets for combined cycle thermal power generation and geothermal power generation.

MAIN HYPOTHESIS

- **Unplanned shutdown** for power generation unit will lead to replacement power **generated from less efficient assets**, or more emission-intensive assets.
- **Early mitigation** of low-criticality incident consumes less time for maintenance and less amount of replacement power, compared to high-criticality incident.
- **Two possible ways to assess the impact:**
    - **Bottom-up approach** useful to breakdown each contributor
    - **Top-down approach** where avoided impact per incident, based on **CO_2 emission factors** for replacement power, is estimated as:
        - 310 $kgCO_2e/MWh$ for geothermal power generation asset
        - 20 $kgCO_2e/MWh$[1] for thermal power generation asset

DATA SOURCE

- DB containing EGP real cases identified in 2022 - 2025 divided per plant, technology and asset involved
- External Research: CO_2 emission factors of industrial power plants in Spain
- Italy Grid Power Emission Factor: CO_2 emissions per kWh in Italy – Nowtricity
- McKinsey & World Steel Association – Steel scrap emission factors
- WINT- water intelligence – Flush water emission factors

1 Delta value between Avg CCGT emission factor and Avg ENEL fleet values

Sustainability Impact Assessment - ENEL Case

BOTTOM-UP APPROACH MODEL

Case description, data and assumption

Illustration of ENEL Sustainability Benefit Calculation	27/08/2024

Case Description
Predictive Analytics detected anomaly at GT-2 cooling temperature and corrected actions identified a wedge delamination, improved cold air temperature, avoided a generator failure.
Base case: Run to failure that would lead to LL-level downtime with longer maintenance and more energy, material and water consumption for the case without early detection.
Improved case: Using predictive analytics leads to early warning and early inspections to take corrective actions in time and lower the damage, shorten the maintenance and avoid downtime.

GT-2 Data		
Power Gen Rate	60	MW
LL Time	7,61	hr
Restoring Time	152,97	hr

GT-2 Assumption		
Assumption: the scrap and replacement parts are made of steel, and flushing uses water.		
Energy Consumption for Repairing Work without early detection	1	MW
Energy Consumption for Repairing Work with early detection	0,5	MW
Steel Scrap without early detection	100	kg
Steel Scrap with early detection	10	kg
Steel Spare part for repair work without early detection	100	kg
Steel Spare part for repair work with early detection	10	kg
Flush Water Consumption for repaire without early detection	10	m3
Flush Water Consumption for repaire with early detection	5	m3
Repair Time Consumption with early detection	48	hr

Case data, emission factors and KPI calculation

Case Data		Without Early Detection & Action	With Early Detection
Operation Cost			
Normal Time	hr	0	7,61
Normal Power Gen	MWh	0	456,6
Downtime	hr	7,61	0
Replacement Power Gen	MWh	456,6	0
Maintenance Energy Cost			
Machine Power	MW	1	0,5
Machine Time	hr	152,97	48
Machine Energy	MWh	152,97	24
Maintenance Material Cost			
Steel Scrap	kg	100	10
Steel Spare Part	kg	100	10
Flush Water	m3	10	5

Emission Factors			
Replacement Power Gen Emission Factor	kgCO2e/MWh	390	Note 1
Normal Power Gen Emission Factor	kgCO2e/MWh	370	Note 2
Maintenance Machine Power Emission Factor	kgCO2e/MWh	310	Note 3
Steel Scrap Emission Factor	kgCO2e/kg	1,85	Note 4
Steel Spare Part Emission Factor	kgCO2e/kg	1,85	Note 5
Flush Water Emission Factor	kgCO2e/m3	3,7	Note 6

Sustainability KPI Calculation		Without Early Detection & Action	With Early Detection
Total Emission Footprint	kgCO2e	225902	176438
	tCO2e	226	176
Emission Saving	tCO2e		**49**
Emission Saving%			**22%**
Total Energy Consumption	MWh	610	481
Energy Saving	MWh		**129**
Energy Saving%			**21%**
Total Material (Steel) Consumption	kg	200	20
Material (Steel) Saving	kg		**180**
Material (Steel) Saving%			**90%**
Total Water Consumption	m3	10	5
Water Saving	m3		**5**
Water Saving%			**50%**

ENEL Sustainability Impact Assessment

ACTIVITY WRAP-UP

- Data-driven approach also support **sustainable operation** due to lower impact in terms of GHG emission of low-criticality incidents

- Define the **strategy** of the analysis is crucial for the embedding of the calculation in the company's process

- **Bottom-up analysis** is feasible to show **direct and indirect GHG emissions** mitigating failure in early stage and avoid unplanned down time and low-efficiency replacement power and from reducing process waste, equipment scrap and on-site maintenance activities.

- **Top-down approach** is easier to be applied to the managed fleet and for large utilities can be sufficient to highlight the GHG impact that usually is the main contributor

Next step – Catalytic converters asset monitoring

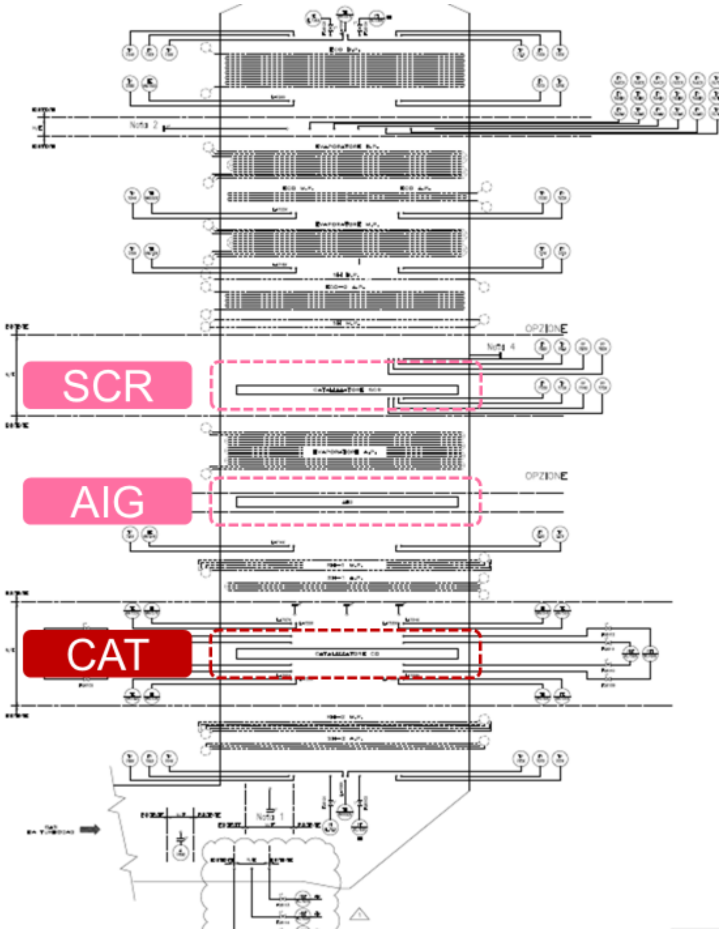
Use predictive diagnostic models for monitoring of flue gas treatment systems

A NEW ASSET TO REDUCE ENVIRONMENTAL IMPACT

- In 2024 some CCGT power plants in Italy have been equipped with an SCR system in order to reduce NO_X emissions and with a Catalyst in order to reduce CO emissions
- SCR System in particular is a complex plant involving a chemical process and some ancillaries assets that have to work properly in order to let the system works
- CO Catalyst is slightly simpler but also in this case working parameters affect the efficiency of the system

A NEW FAMILY OF ASSET TO PUT UNDER MONITORING

- Leveraging on the same approach used for conventional assets RPD Team started the development of monitoring models in Predictive Analytics with the aim to setup parameters and measuring points that affect the efficiency of these system like
    - Differential Pressure
    - In/out flue gases temperature
    - In/out emissions concentration



ENEL Green Power drives measurable sustainability gains through predictive diagnostics

Challenge

- Unplanned outages across 86 generation units in four countries disrupted reliability and operational continuity
- Anomalies went undetected, allowing minor issues to escalate into high-impact failures
- Sustainability impacts of maintenance activities were unclear, limiting visibility into avoided emissions and resource savings

Solution

- ENEL Green Power integrated AVEVA™ PI System™ and AVEVA™ Predictive Analytics to enable early anomaly detection across thermal and geothermal fleets, BVC Team helped to quantify sustainability impact over a consolidated approach

Results

- **Improved process reliability, reduced waste and maintenance activity, and lowered overall environmental footprint**
- **Strengthened a sustainability-first, data-driven culture by giving plants support to make earlier, lower-impact decisions**

409 cases

Real cases identified 2022-2025

3 TWh

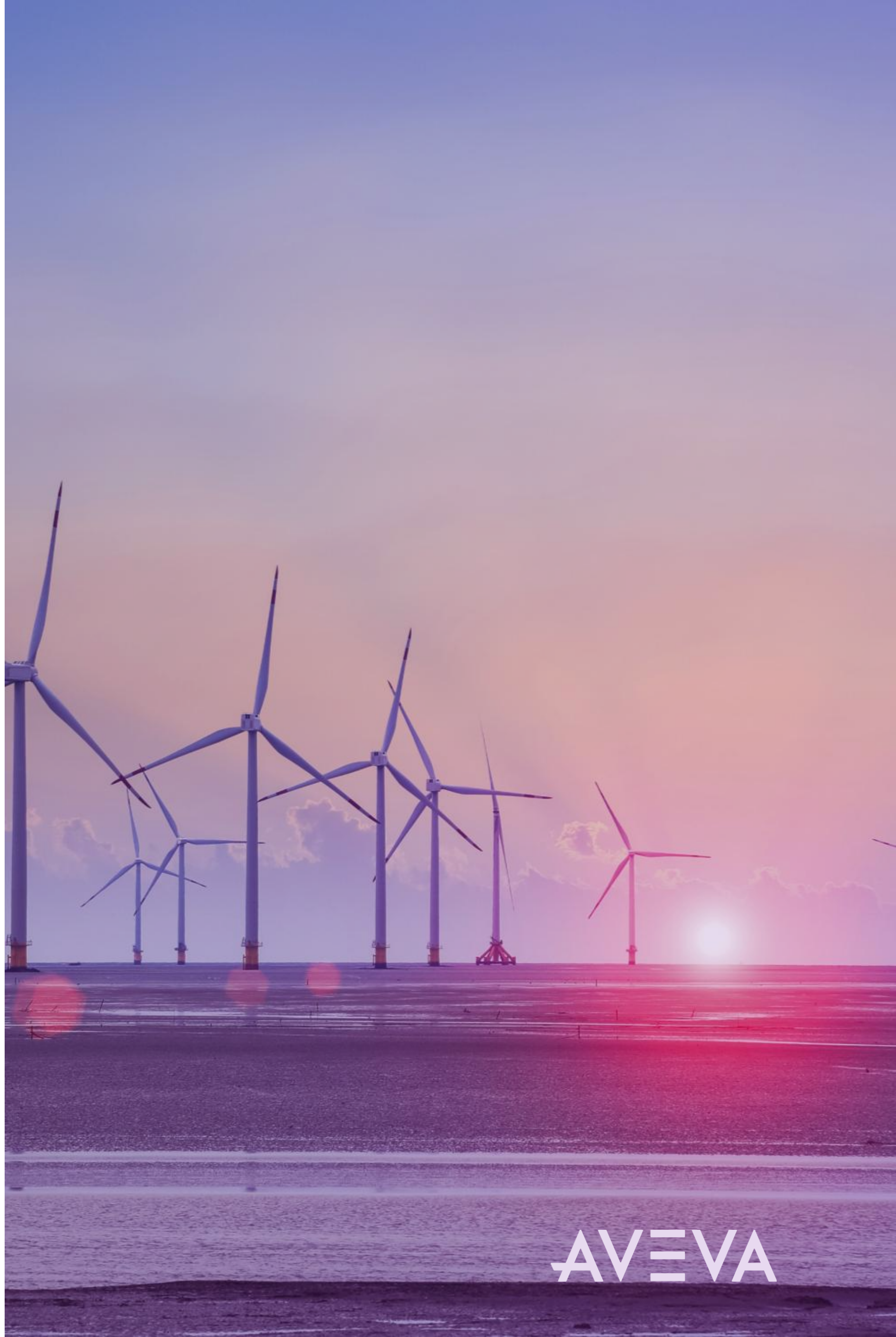
Energy saved through early detection and mitigation

61 $ktCO_2e$

GHG Avoided Emission from Avoided thermal Replacement Power

3.1 $ktCO_2e$

GHG emission saved from additional green power generation



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