ESMAP
Energy Sector Management Assistance Program
MINISTERO DELL'AMBIENTE E DELLA SICUREZZA ENERGETICA
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ESMAP Knowledge Exchange & Study Tour on Grid Digitalization and Cybersecurity in Italy
May 20 - 27
Italy

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Session 1: Strategic Overview of Electricity Distribution

05/21/2026

Agenda

1 Introduction to Enel Grids

2 Sectorial trends and enabling regulatory frameworks

3 DSO opportunities and challenges

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1 Introduction to Enel Grids

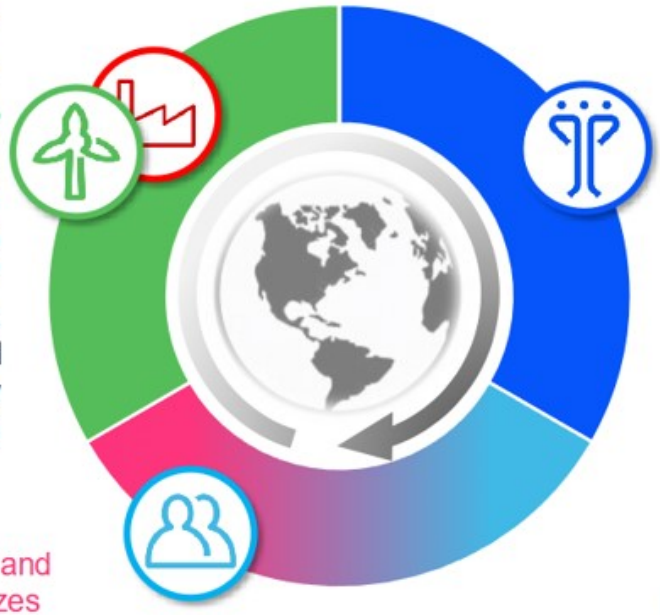
2 Sectorial trends and enabling regulatory frameworks

3 DSO opportunities and challenges

Enel's Global Business Lines Grids overview

Enel Green Power & Thermal Generation

Leads the energy transition through renewables' expansion, overseeing the development, construction, and operation of assets. Leverages Storage and pumped hydro as key solutions to balance renewables' variability, enhance grids' flexibility, and ensure reliable power supply. In addition, oversees the management of thermal assets globally, maximizing operational efficiency across regions



Enel Grids and Innovation

Develops, operates and renovates electricity networks. Ensures high standards of service quality, safety, resilience and sustainability. Maximizes operational efficiency and enables energy transition through renewables integration, electrification and fast and scalable technological innovation.

Enel Commercial

Develops customized integrated energy solutions and services driving the commercial strategies, optimizes customer value and operational efficiency, while innovating lifecycle solutions, exploring new technologies and business models, and overseeing the e-Mobility portfolio across countries to maximize growth and profitability.

Global Energy and Commodity Management

Leads the **optimization of generation** and customer supply positions in spot energy markets, drives the **valorization of asset flexibility** in ancillary services markets, **oversees gas sourcing optimization** for thermal generation and customer portfolios, and **maximizes integrated margins** through structured hedging and trading strategies.

Enel's leadership

World Presence

27 Countries

World's largest player in renewables

~ 68 GW installed capacity[1]

1st network operator

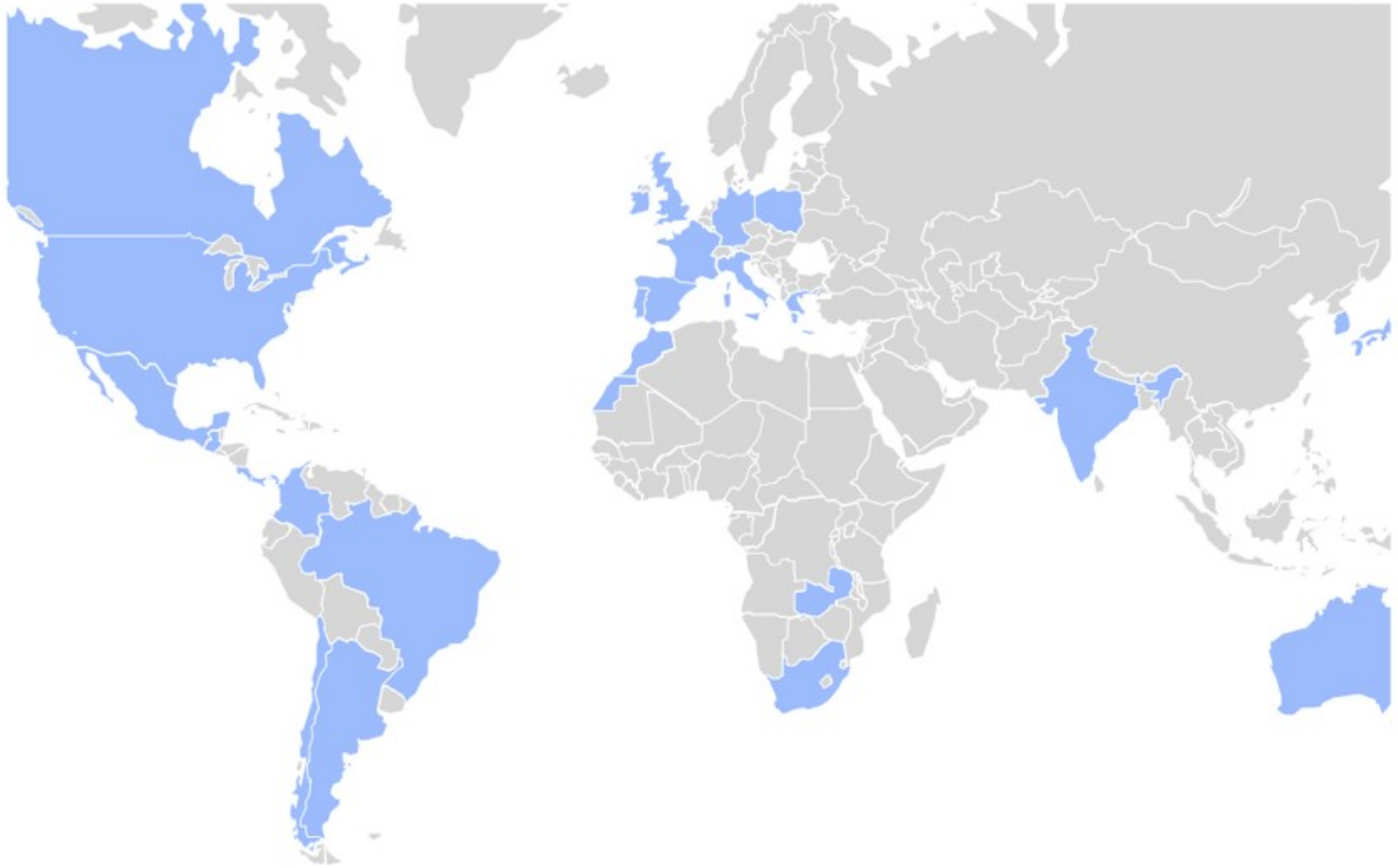
~69 mn end users

Largest retail customer base worldwide

54 mn customers[2]

EBITDA 2025

~ 22.9 €bn



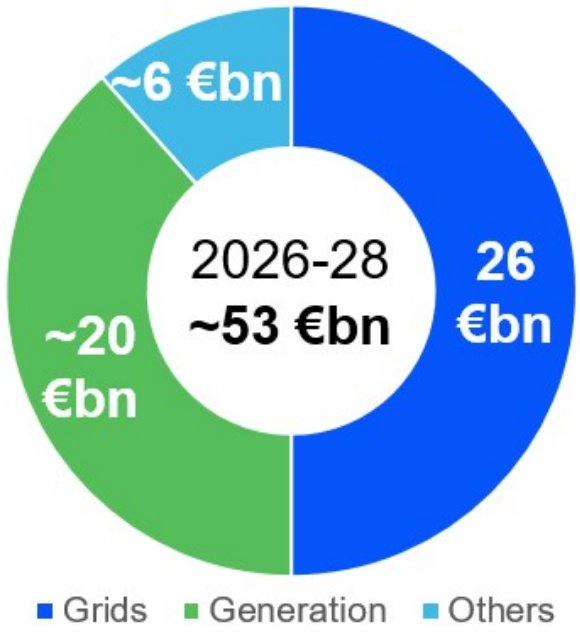
FY data; Benchmark update: data as of 31.12.2025; Enel's leadership in the different categories is defined at a Global level among listed companies, excluding companies with predominant state control.1. It includes managed capacity and BESS; 2. It includes power customers (liberalized and regulated markets) and gas customers

Enel Grids overview

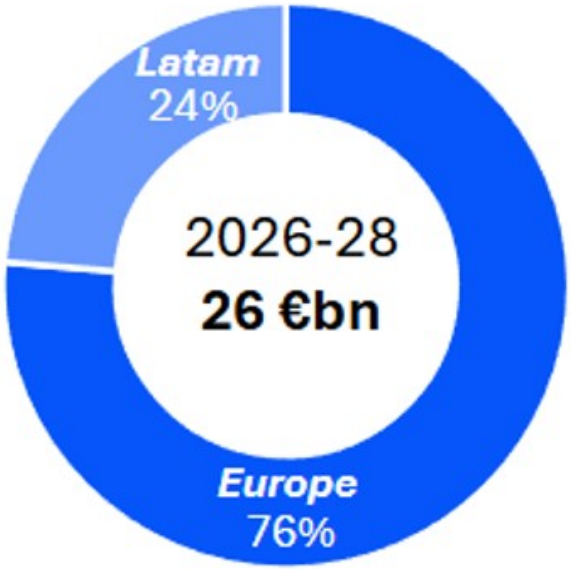
People	30 k
Lines	1,9 mln km
Primary Substations	4.200
Secondary Substations	1.160 k
Distributed Energy	481 TWh
Customers	69 mln
Smart Meters	45,2 mln
EBITDA (2024)	7,9 mld€

Enel Group allocates half of capex on grids to increase resilience and lead the transition

Capex 2026-2028



Enel Grids



- *Connections*
- *Networks' upgrade*
- *Quality improvement and resilience*
- *Asset maintenance and recurring network development*

Speakers

Mena Testa

Industrial Engineer

Head of Grids Studies and Positioning

Enel Grids and Innovation/ Network Engineering and Development/DSO Evolution and Grids Opportunities

Vito Ponzo

Energy Engineer

Grids Studies and Positioning specialist

Enel Grids and Innovation/ Network Engineering and Development/DSO Evolution and Grids Opportunities

Alessio Marcelli

Energy Engineer

Head of Grids Analysis & Network Assessment

Enel Grids and Innovation/ Network Engineering and Development/Network Assessment and Technical Plan Optimization

Agenda

1 Introduction to Enel Grids

2 Sectorial trends and enabling regulatory frameworks

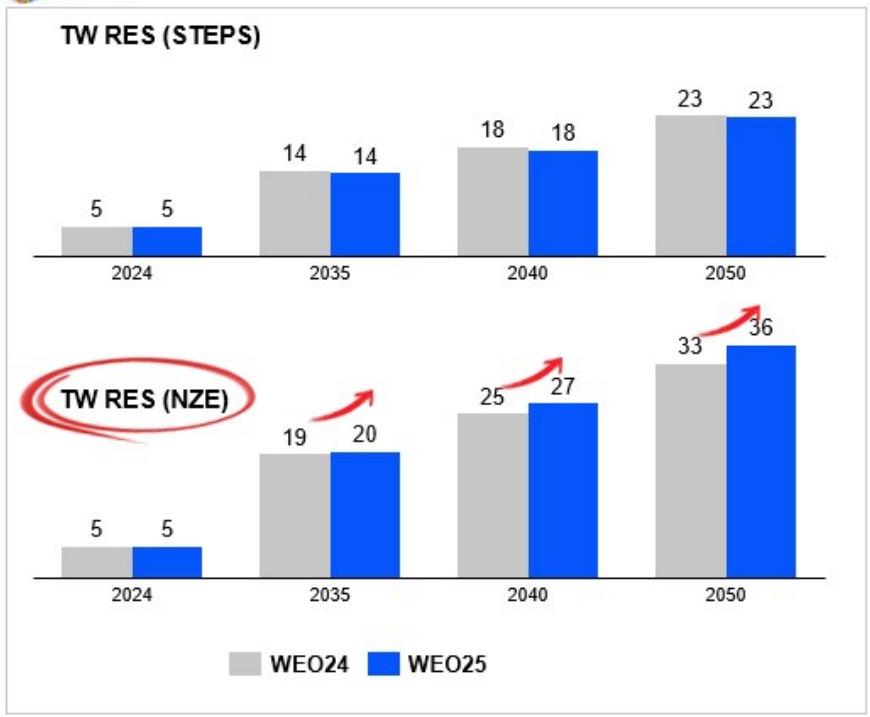
- Scenarios and grids investments
- Regulatory trends
- Focus on resilience

3 DSO opportunities and challenges

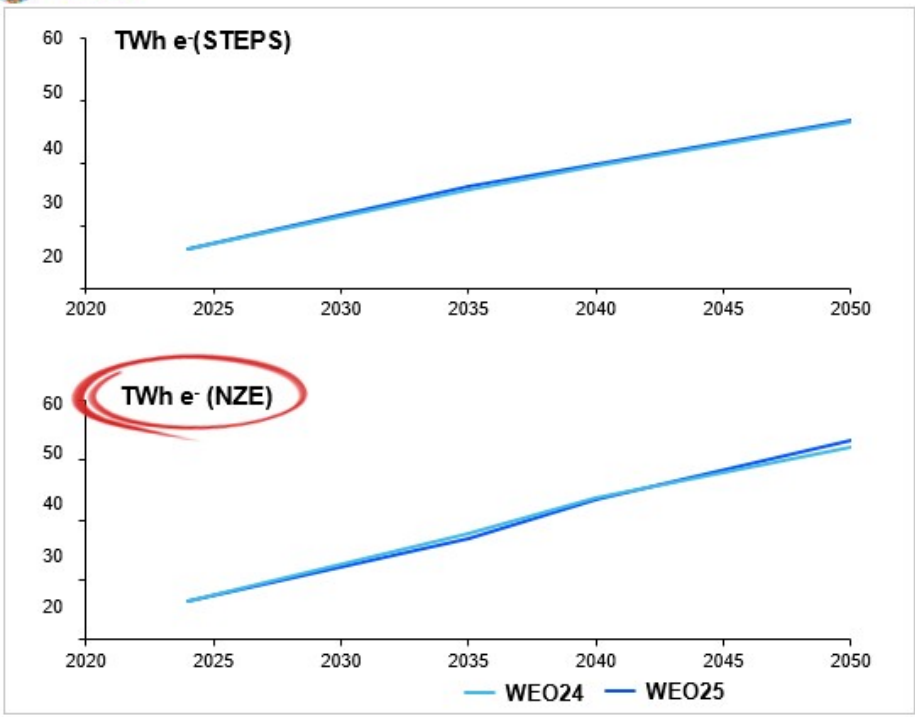
Renewable generation & Electrification trends stable

…but acceleration is needed to achieve net zero in 2050

Supply: global RES to increase x5 in baseline and x7 in Net Zero in 2050 vs 2024



Demand: electrification ~doubles in 2050 vs current values, due to more demand and efficiency

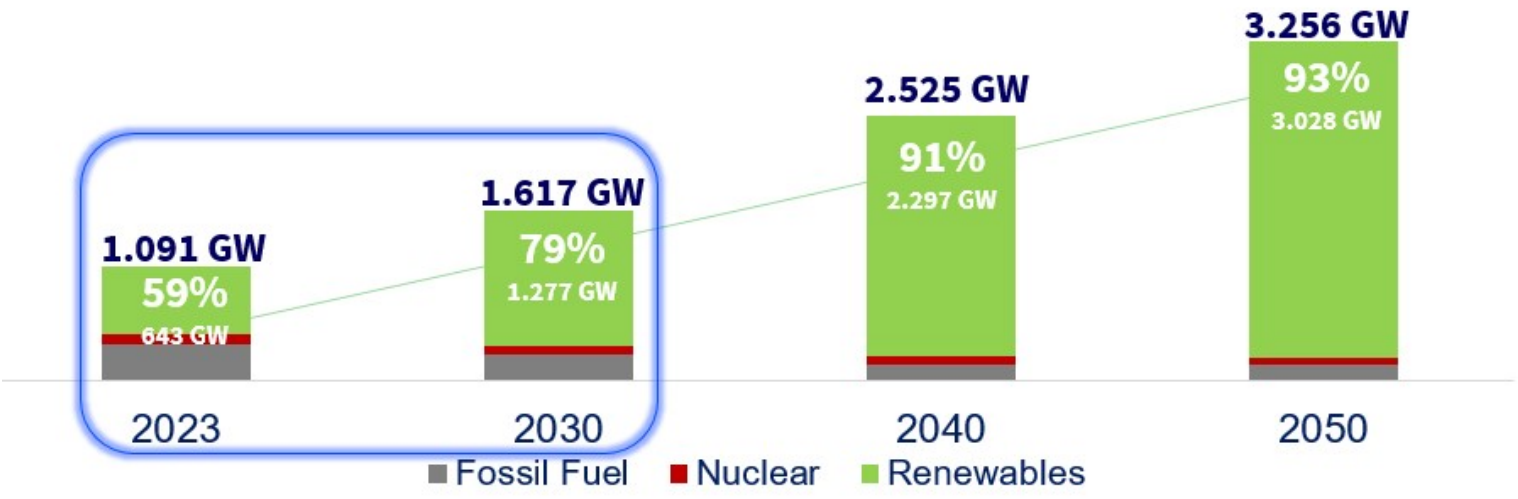


Source: IEA WEO 2024, IEA WEO 2025, STEPS: Stated Policies Scenario; NZE: Net Zero Emissions Scenario

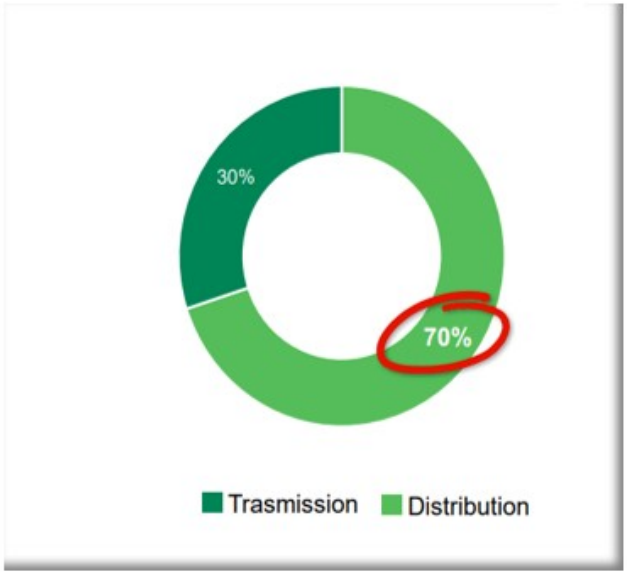
In Europe, the share of RES in installed electricity capacity by 2050 should reach 93%, up from 59% today…

…mainly connected on distribution grids

Installed electricity capacity in the EU by source and focus on RES



New RES EU connection 2023-30



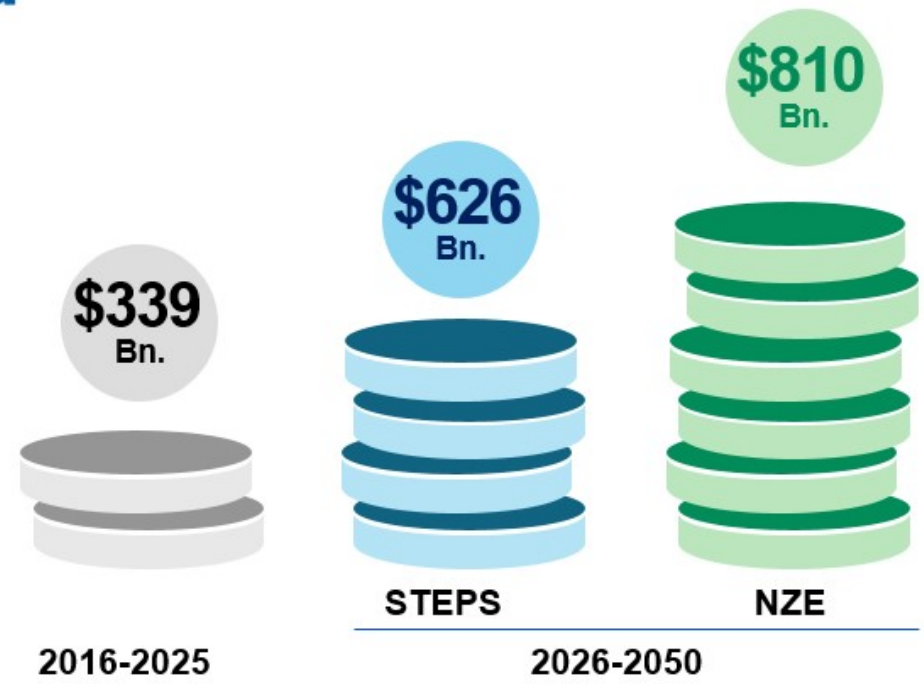
Grids remain the backbone of the transition

N.B.: targets given here take into account the Repower EU and Fit-for-55 targets. Values to 2040 are in line with a 90% reduction in net emissions-
Source: TEHA Group Studio 2024 on data from the European Commission, 2024 Europea, 2024; IEA World Energy Outlook 2025 (STEPS scenario)

Investment in grids expected at least to double

…being modernization, decarbonization & electrification and resilience major drivers

Global network investment outlook ($bn/yr)



Investment drivers in power networks

Electrification & Decarbonisation
RES **x5-7**, demand **x 2** vs current values

Modernization & renewal
EU 40% Dx grids being over 40 years old
+Digitalization

Universal Energy Access
grids & minigrids

Resilience & security
Tx & Dx lines affected in 85% of disruptions on infrastructure by climate

Source: IEA WEO 2025

Effective regulation needed to support this evolution

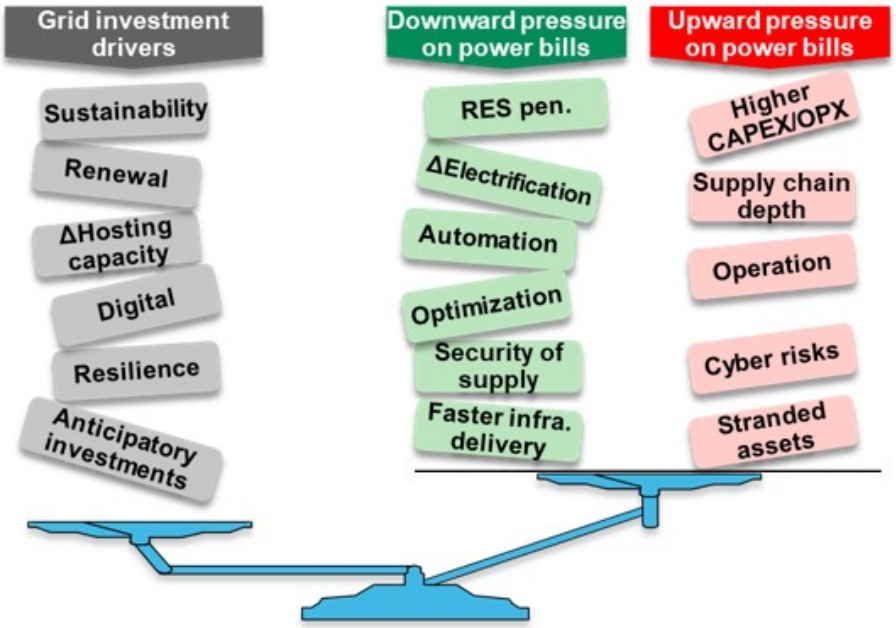
Electricity distribution is a **natural monopoly** activity

How to promote electricity distribution market effectiveness?

Regulated remuneration for Distribution System Operators (**DSOs**)

An **effective remuneration** should consider:

- **well-functioning** and **competitive/attractive** market segments
- welfare impacts on **electricity consumers** and society
- trade-off with **energy bill affordability**



Regulators seek a balance between grid development costs and its direct and indirect benefits that reduce electricity (energy) costs

Regulators and governments work on different and complementary approaches

From external challenges and political goals…

Ursula von der Leyen

Electrifying = independence

Donald Trump

Drill, baby, drill

Xi Jinping

Clean energy = economic power

…to regulation design

Grid-related

Regulatory framework	• WACC • TOTEX • Supportive regulation for investment (resilience) • …
Planning	• Anticipatory investments • Stakeholder engagement • Non-wire alternatives/flexibility • …
Tariffs	• Time & locational signals • Charges allocation (type & time) • ….
Funds	• Grants • Loans • …
Procedures	• Permitting • Connection • Capacity maps • …

Other

Markets	• Price caps • Interventions • ETS • …
Taxes	• VAT reductions • Subsidies • …
Retail	• Special tariffs • Protections • …

Focus on Resilience

External Challenges

Extreme weather events are having an **increasing impact**, particularly on distribution grids

Regulatory Response

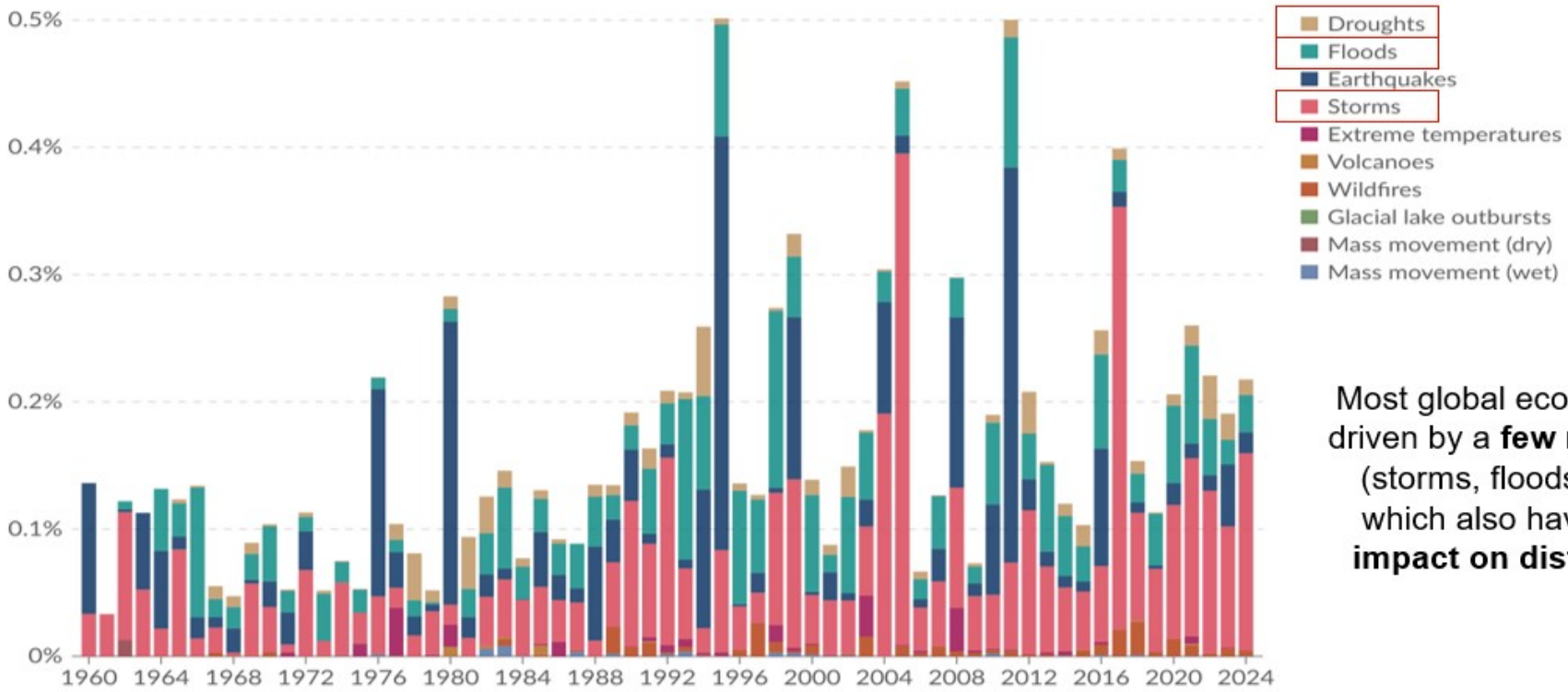
Regulation needs to **evolve** to ensure that grid development is not only efficient, but also **able to cope with new system challenges**

DSO Strategy

DSOs should put in place an **adequate *Climate Impact Assessment***, and, using innovative technology and systems, define **focused investment plans** supported by regulatory framework

Extreme weather events impact increasing

Economic damages from disasters as a share of GDP, World, 1960 to 2024



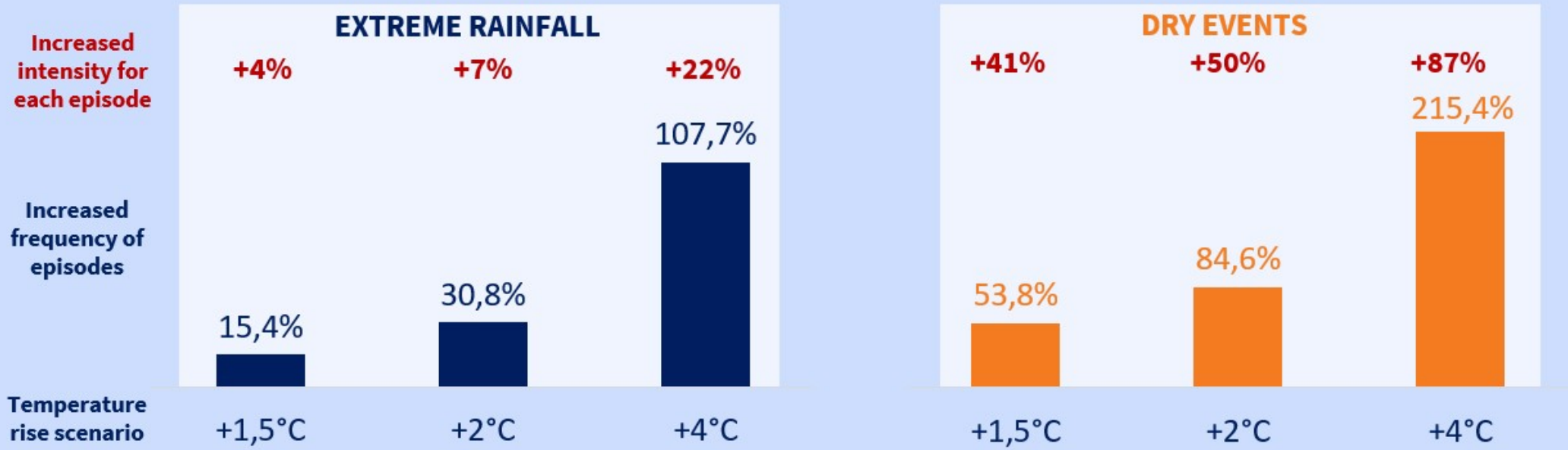
Most global economic losses are driven by a **few recurring events** (storms, floods and droughts) which also have the **greatest impact on distribution grids.**

Source: OurWorldinData.org/natural-disasters

Data source: EM-DAT, CRED / UCLouvain (2025); National statistical organizations and central banks, OECD national accounts, and World Bank staff estimates (2025)

Extreme Weather Events expected to grow in frequency and intensity

Increased frequency projections of extreme precipitation and dryness events under different IPCC(**) global warming* scenarios globally (% increase vs. today*)**



(*) Temperature increase scenarios are compared to the 1850-1900 average. (**) Intergovernmental Panel On Climate Change (***) To date, the global temperature has already increased by +1 degree Celsius compared to the 1850-1900 average. - Source: TEHA Group Studio 2024 - data IPCC elaboration, 2024

Extreme Weather Events impacting distribution grids

Heatwaves
High temperature for several days in urban areas → underground cable faults

Wet Snow - IceSleeves
Overhead lines with accumulated wet snow → collapse of the conductor. Phenomenon really complex (humidity, temperature, particular network typology and technology)

Wildfires
High temperature and low humidity for several days → green areas at risks due to network itself (e.g. California) or to linked to spontaneous fires in arid areas

Windstorm
Strong wind gust and speed can provoke directly lines fall or indirectly through tree fall

Flood and Rain
Heavy rains, intense and continuous rainstorm can provoke direct consequence on the network or indirectly (e.g. flood)

External Challenges | Regulatory Response | DSO Strategy

ARERA Regulatory response for resilience

Italian regulatory framework evolved to address new challenges

Context

The **growing incidence of extreme weather events**, particularly prolonged heat waves, has prompted **a reassessment of the resilience framework for electricity distribution networks**, requiring the **evolution of existing resilience models** to systematically incorporate extreme climate scenarios into grid planning and development criteria.

Regulatory measures

In December 2023, following the emergency in Sicily, the Authority **established an output-based incentive mechanism**, in addition to the base remuneration, for development interventions (including resilience), with initial implementation in 2024.
In November 2024, the **NRA confirmed the framework for the 2025–2027 period**:

CBA>0

List of **interventions must be approved** with the related **positive Cost-Benefit Analysis**

13% premium

Maximum incentive = 13% of the investment cost

No penalties

No incentive reduction or penalties in case of delay in implementation

Investment limit around €3,1 Billion (85/LV users), for a maximum premium of ≈ 400M€

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- Grid resilience
- Big data and planning
- Smart grids and Advances Metering Infrastructure

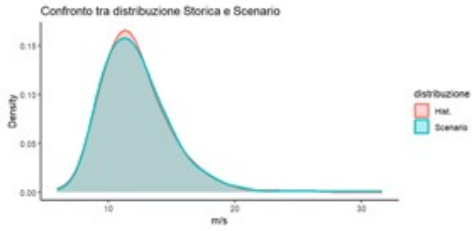
Grid resilience

Climate Adaption impact assessment

1. Identification of critical climate variable

Starting from Climate Scenario, the **most relevant climate variable** is selected and data are analysed to correct bias, obtain the right time interval and frame, select the specific area, etc

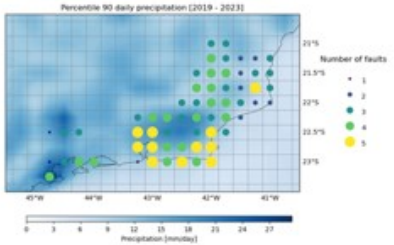
Instead of using only a critical threshold, the **whole statistical distribution** of the climate variable is analysed, so to better understand its evolution (return period, probability, etc).



2. Geo-time analysis of impact

The **historical data of faults** are collected and analysed, using the necessary filters.

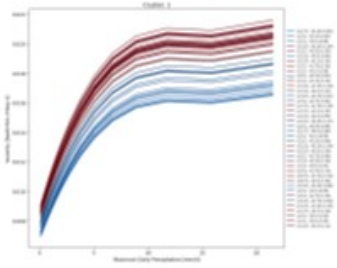
The faults are **aggregated at asset level and organized in climate cells**, then correlated with climate variables and other possible inputs (ground, vegetation, etc).
The analysis is more accurate in terms of location and asset



3. Construction of vulnerability curves

Considering the historical faults and historical climate variable for each asset or climate cell, a **relationship of vulnerability** is calculated between the intensity of climate variable and fault rate of asset element / area.

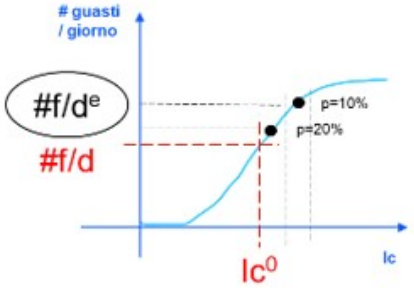
This introduces in the analysis elements like asset type, material, location and other characteristics of the grid



4. Forecast of the future impact on grid

The Climate scenario is used to predict the expected faults using the relationship found in the previous step (**Vulnerability curve**). Therefore accuracy is increased with asset focus.

Average costs of faults are applied to estimate also future economic impact



Grid resilience

CBA and investment planning

1 Asset List

List of the lines to be addressed according to priorities (lines with the highest expected failure rate of adaptation).
The list of Assets is the output of the previous process step: Scenario Input Analysis.

2 Critical asset selection

The planner identifies a critical line section and selects the solution to be applied from the catalogue. Typical resilient solutions could involve increasing network meshing through new MV lines and renewal of portions of the existing underground MV network with jointless cables.

3 Cost-Benefit Calculation

The catalogue suggests the optimal solution to improve the asset's performance and provides an estimate of the cost and technical benefits. Using the calculation models, the economic benefits are calculated, and the regulatory mapping is applied to identify which benefits are applicable to each DSO.

4 Projects with B/C > 1 selection

Calculation of the Benefit/Cost ratio and selection of projects with a ratio >1.

5 Prioritization

The priority list is sorted in descending order, starting with the intervention with the highest B/C ratio.

Big data and planning

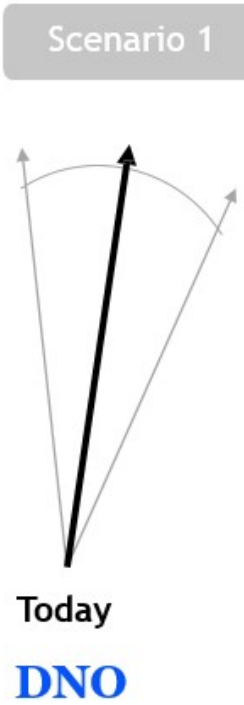
From traditional to modern planning

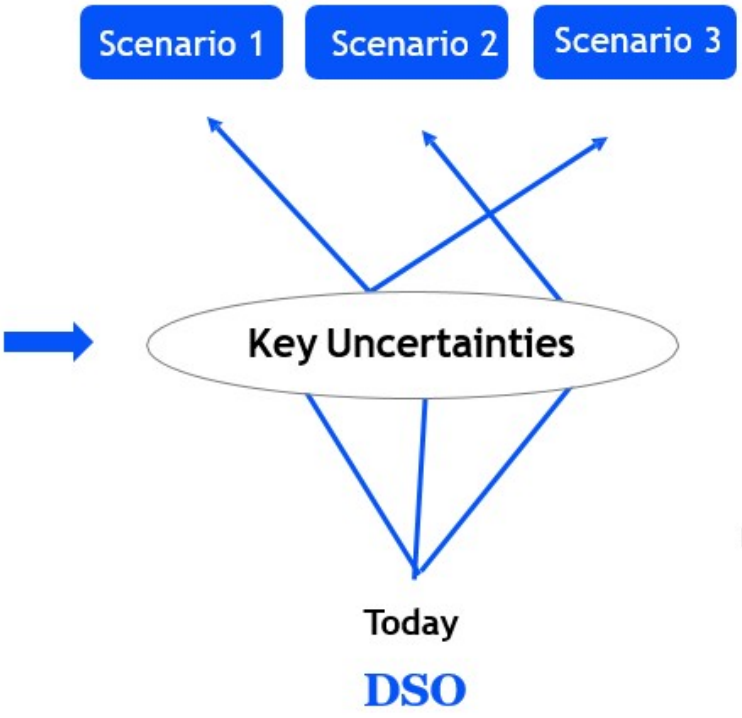
Traditional Planning

- Deterministic planning
- Single future scenario
- Worst-case conditions (i.e Max.load-No gen. & Min.load-Max gen.)
- Static snapshots of load and generation levels

↓

Inefficency and **excessive investments** justified only by very **rare** critical operating conditions





Modern Planning

- ✓ Probabilistic planning
- ✓ Multi-scenario planning
- ✓ Typical operating conditions and relative probability of occurrence
- ✓ Time-varying load and generation

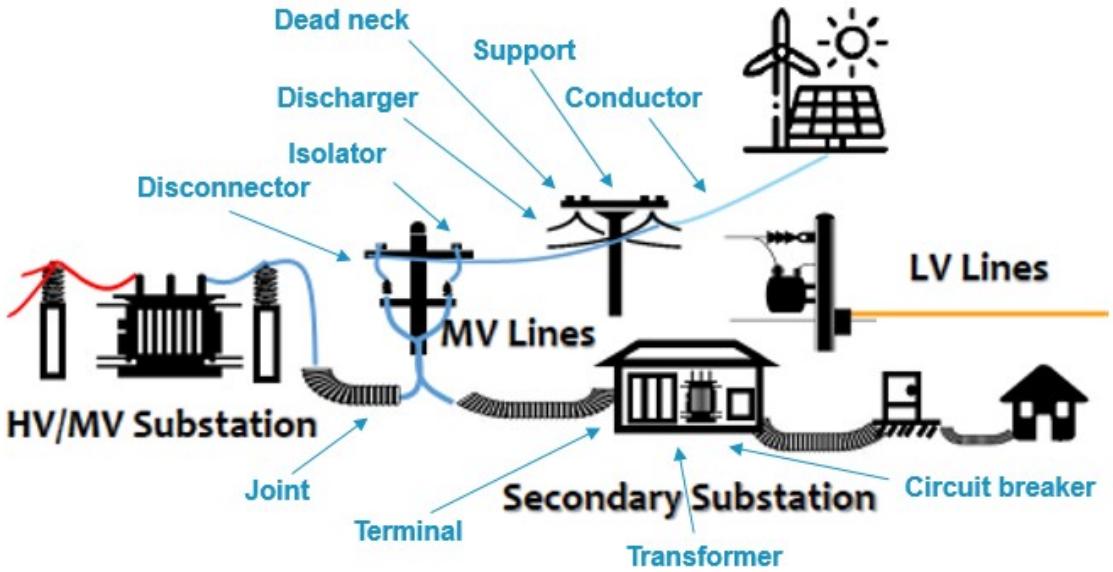
↓

Accurate planning model able to **realistically** represent the impact of **DERs**, **uncertainties** and **weather events**

Big data and planning

Fault and Impact Prediction Model

What are we predicting on the MV grid?

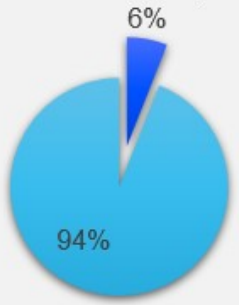


One km of overhead network has on average ~500 individual parts and a secondary substation over 50.
Each of them represents a potential point of failure.

Objective: estimate **which line segment** will fail in the next three years on the Italian Distribution Network

Key numbers:

- **1.120k** line segment in Italy
- **367k** km of MV grid
  - Type A 180k km
  - Type B 25k km
  - Type C 162k km
- **60k** failures in 3 years
- **6%** failure rate for the observation period



The fault is currently recorded at the line segment level (network section) and per substation

Big data and planning

Outage Risk – Outage probability

Distribution of outage probability and impact

Element type

SEGMENT

Outage Probability

0,85 1,00

Impact (AV20)

0,00 2.107.084,82

Org. Code & Description

Tutte

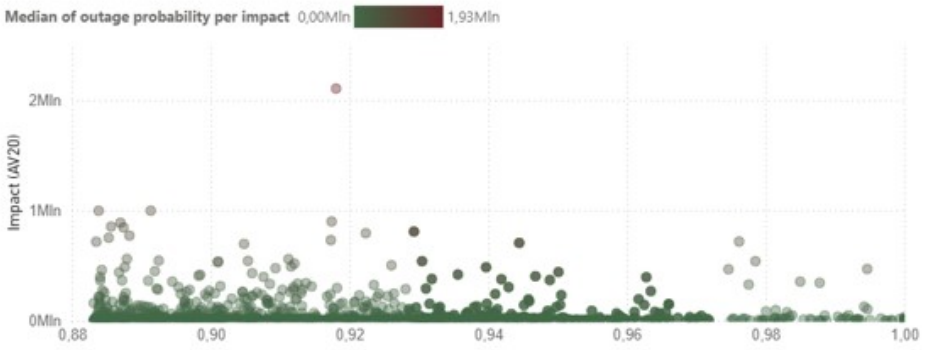
Region

Tutte

Line

Tutte

Outage prob. per impact (AV20)



Smart grids and Advances Metering Infrastructure

Critical factors and main technologies to enable the future ecosystem

WHY

- Real-time remote management
- Aging mitigation
- Energy flows prediction
- Safety improvement

WHAT

- Advanced Metering infrastructure
- Digital switchgears
- IoT sensors
- Future-proof data centres

HOW

- Data Mining
- Artificial Intelligence solutions
- Advanced TLC systems and protocols

WHAT Smart Grid Technologies

Advanced metering

- Smart meter
- Metering infrastructure
- Meter Data Mgmt Systems

Grids digitalization

- Advanced Edge Device
- Smart street box
- IoT sensors

On-field activities digitalisation

- Safety solutions
- Workforce Management
- Augmented and Virtual reality
- Drones/Robot
- Network digital twin

Innovation and digitalization for a sustainable evolution of DSO

Smart grids and Advanced Metering Infrastructure

Smart Meters: an advanced grid sensor enabling benefits for all

- Energy balance
- Grid Sensor
- Plug and Play
- Enhanced Cyber Security
- Network monitoring

- Remote reading
- Remote relays management
- Outages diagnosis
- Power Quality measurement
- Antitampering

Thank you