Conférence du Comité National Français

La Transition Energétique

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Bâtiment Gaston Berger - INSA Lyon
16 octobre 2025

CIGRE France Conference

Strategic development plan for the French transmission network by 2040

Jonathan Roulot (RTE)

Bâtiment Gaston Berger - INSA Lyon
16 octobre 2025

For power system expertise

SDDR

The strategic development plan for the French transmission network by 2040 (SDDR) aims at providing a complete and long-term overview of the industrial needs

The development of the SDDR is one of the **legal responsibilities of the public electricity transmission system operator**. Since 2019, RTE publishes an extended version of what is legally expected

- It is not only about network development but also about renewal and telecommunications for example
- It is a plan over 15 years, consistent with the investments in the infrastructure (compared to 10 years legally expected)

The French public electricity transmission network integrates **voltage levels from 63 kV to 400 kV** (a wider range than most other transmission networks in Europe).

The SDDR, a prioritized, optimized, and timed strategy for 2040 :

- Transformations needed to ensure that the electricity transmission network continues to **meet our future electricity needs**
- A document that provides consumers, producers, and storage operators with visibility on what tomorrow's public electricity transmission network will look like, and **equipment suppliers and construction companies with visibility on equipment needs, recycling strategies, and employment prospects**

The SDDR 2025 has entered its second phase with public consultation and debate

Phase 1
Consultation and development

Phase 2
Review by authorities and public debate

2023 –2025

Execution of a wide-ranging program of technical and economic studies and environmental and industrial analyses

Consultation with authorities and stakeholders

13 February 2025

Publication of the main guidelines of the SDDR

LA CNDP commission nationale du débat public – MA PAROLE A DU POUVOIR → *Organization of the public debate*

Ae → *Environmental review*

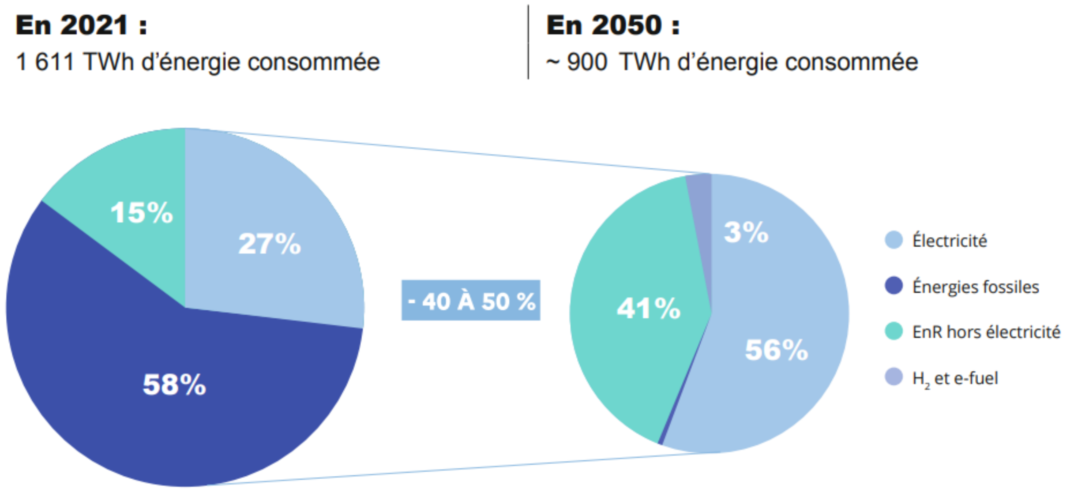
CRE → *Approval of technical and economical considerations; investment framework*

RÉPUBLIQUE FRANÇAISE → *Validates consistency with policy objectives*

Generation and consumption assumptions

Changes in the energy mix influence the design of the electrical system.

Two main objectives are pursued :
- Achieve carbon neutrality by 2050
- Reindustrialize the country



Final energy consumption in 2021 and projections for 2050 – draft French energy and climate strategy

- ↑ Increasing the share of electricity in final energy consumption in France.
- ↑ Produce more low-carbon electricity (both nuclear and renewable energies) to support this increase in electricity consumption.
- ↓ Reducing dependence on imported fossil fuels (gas and oil) for energy consumption in France.

The challenges for the electricity transmission network consist in anticipating and planning network developments to enable this new stage in the construction of the French electricity system.

Changes in the energy mix influence the design of the electrical system.

Two scenarios from the **power system's adequacy outlook 2035** have been extended by five years for SDDR studies.

Scenario A-reference is broadly consistent with the draft multiannual energy program (PPE3) for 680 TWh generated in 2035.

Scenario B-low corresponds to a five-year delay in achieving the national objectives of the draft PPE 3 and 615 TWh generated in 2035.

	Production facility operational at the end of 2024	Scénario A-ref 2040	Scénario B-bas 2040	*Network connection: contracts already signed*
Solar and onshore wind	47 GW	+ 89 GW	+ 60 GW	+ 46 GW *pour des mises en service avant 2035*
Offshore wind	1,5 GW	26 GW	18 GW	+ 18,5 GW
Nuclear	61 GW	69,5 GW	63 GW	+ 9,6 GW

Network connection contracts are very important and demonstrate the importance of adopting joint planning for the network. Otherwise, the network will be planned on a case-by-case basis in response to each request.

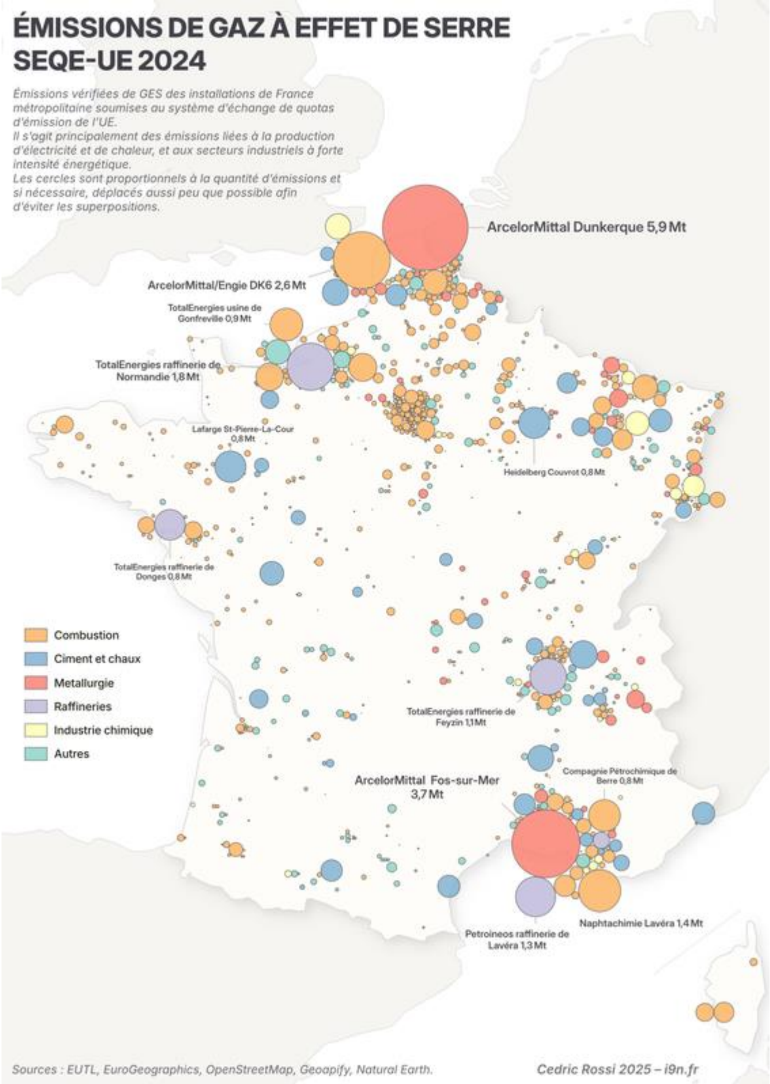
Scenarios and assumptions

Consumption assumptions are based on the needs reported by the sectors and on an extensive program of studies and consultations.

Identification of needs related to achieving decarbonization and reindustrialization objectives	**+**	**Increase in demand from consumer sectors (steel industry, metallurgy, road transport, etc.)**	**+**	**Integration of energy efficiency and conservation measures, tested in households via an independent survey**

Increasing the share of electricity in final energy consumption in France and reducing dependence on imported fossil fuels (gas and oil) for energy consumption in France implies, in part, a strong and rapid growth of **electricity consumption in large harbors and industrial areas** (consistent with the connection demands received by RTE).

- ➢ The French power system would be able to meet the growing needs of industry with a low-carbon and competitive electricity supply but **accelerating reinforcement of the transmission grid in these few large areas is a prerequisite** for connecting the new demand.



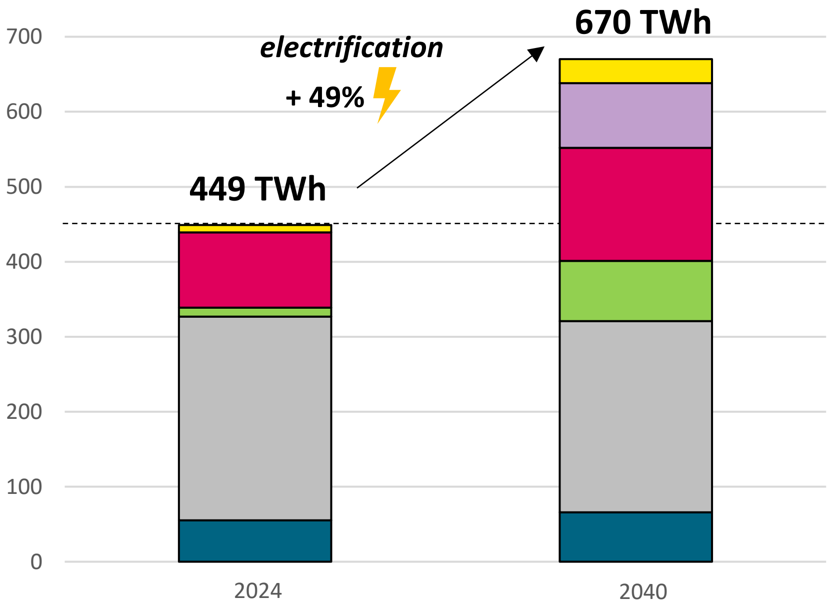
Source : Les émissions industrielles de gaz à effet de serre en France métropolitaine

Consumption scenarios and assumptions used in constructing the SDDR

Two scenarios from the **power system's adequacy outlook 2035** have been extended by five years for SDDR studies.

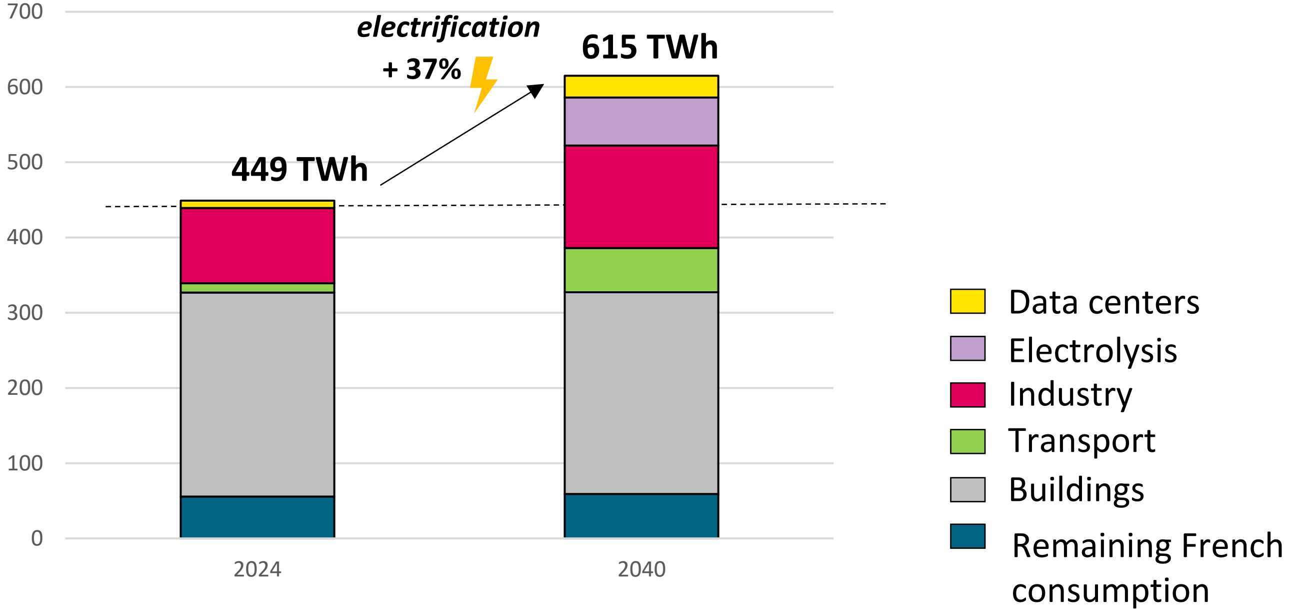
Scenario A-reference

Achievement of public objectives



Scenario B-bas

Five-year delay in achieving public objectives



Overview of the grid development plan 2025-2040 proposed by RTE

The priorities proposed by RTE are based on the results of technical and economic analyses and public consultation

Input from public consultation

+

Technical and economical studies
and environmental and industrial analyses

3 industrial priorities to develop the French electricity transmission network, broken down into technical requirements, economic requirements, and environmental impacts

Renewing the network and adapting it to climate change

Preserving the network's quality of service and the country's economic attractiveness

Connecting new low-carbon facilities

Accommodating new consumers (industry, data centers, hydrogen) and new production facilities (offshore wind, new nuclear power, onshore renewable energies, etc.).

Strengthening the network's backbone

Strengthen the structure of the network to enable it to cope with changes in the electricity system and associated changes in flows

RTE proposes an ambitious reference strategy worth around €100 billion over 15 years

- **This represents significant growth and an industrial challenge:**

40 000 km of lines to be renewed (60%), adapted or built (40%) by 2040

~ 85 000 towers to be renewed by 2040

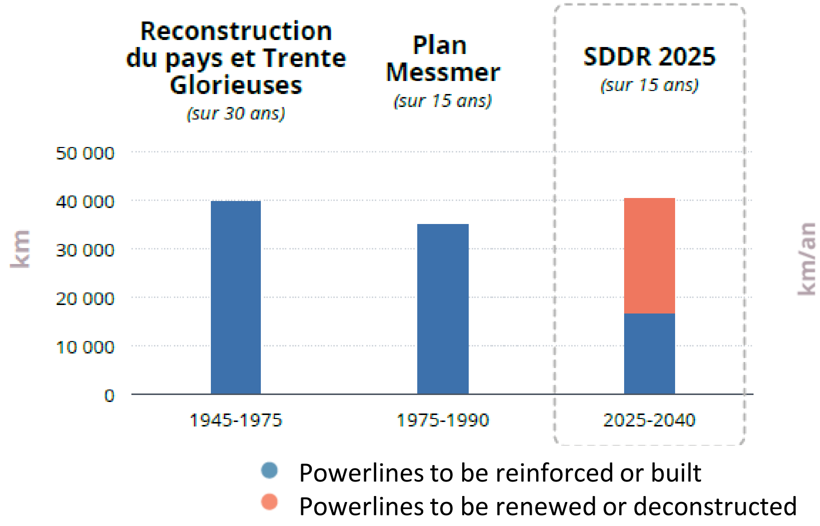
~200 km oil-filled cables to be replaced by 2030
~110 km impregnated paper cables to be replaced by 2040

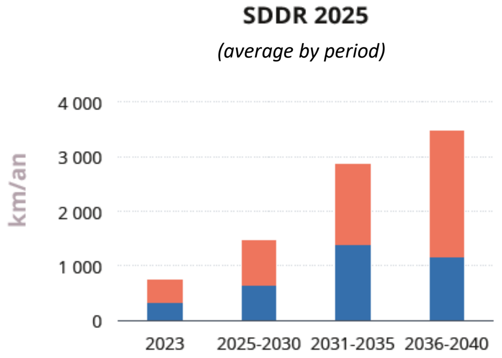
~400 power stations to be built by 2040

~50 gas insulated substation to be renewed by 2040

~ from 550 to 600 control and protection systems to be renewed per year by 2040

Industrial needs according to the reference strategy



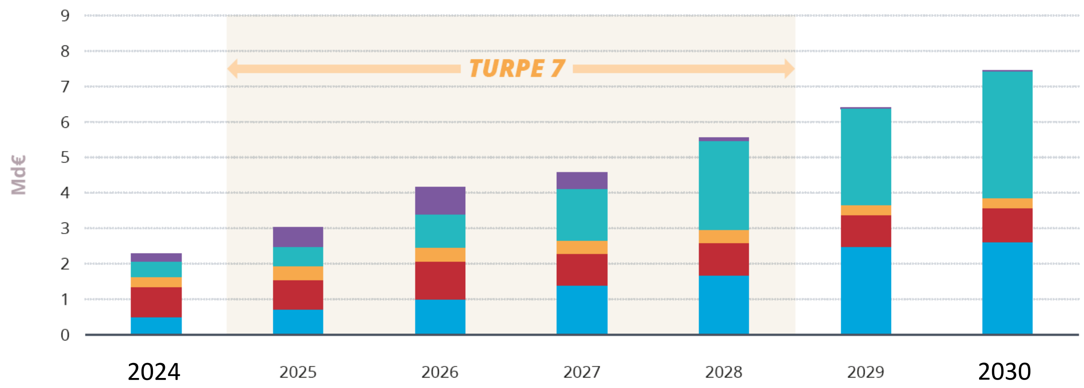


Investment trajectory

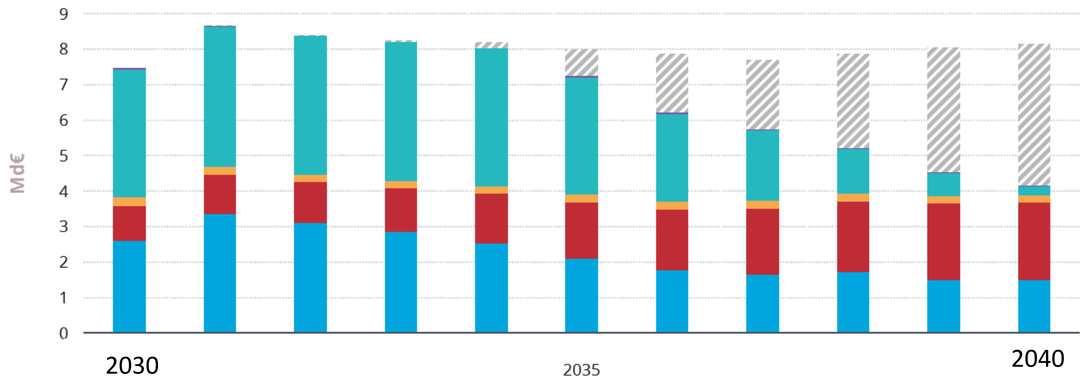
A reference strategy divided into two periods, each with different challenges

Annual investments

First period : from 2025 to 2030



Second period : from 2030 to 2040



Main indicators

First period

Interconnections : Celtic (FR - IE) and Golfe de Gascogne (FR – ES)

Offshore networks : completion of work from the 1st national multi-year energy planning PPE1, securing supplies on PPE 2 and 3, studies and work on PPE 2, start of PPE 3 projects

Digital backbone : replacement of copper local loops, network restoration plan, deployment of automated systems, consolidation of control-command renewal rhythm

Renewal : renewal of overhead lines mainly from 1920-1960’s, Laser Imaging Detection and Ranging (LIDAR) targeting strategy, renewal of underground cables with oil pressure, consolidation of the electric post equipment's renewal rhythm

Network adaptations and connections : zones P1-P2 (or even P3), 2nd generation of the regional land-based renewable energy development plan (S3REnR), very high voltage network phase 1 (start of phase 2)

Second period

Projects commissioned after 2040 : start of projects 2040-2050 (3rd phase of very high voltage level network structure strengthening, offshore windfarm from the 4th national multi-year energy planning PPE4, etc.)

Interconnections : according to the authorities

Offshore networks : studies and work on PPE 3

Digital backbone : maintaining the deployment of automated systems, accelerating the pace of control and command renewal

Renewal : renewal of overhead lines mainly from 1940-1970’s, renewal of underground cables with impregnated paper, acceleration of the electric post equipment's renewal rhythm

Network adaptations and connections : additional consumption zones possible, new planning approach on regional land-based renewable energy development (S3REnR), new nuclear generation, very high voltage network phase 2

Among several levers to implement the proposed strategy, RTE needs to accompany its industrial ecosystem and adapt its procurement strategy

- **Successive crises and growth in demand for network equipment around the world create a saturation effect on supply chains for certain grid components.** The acceleration of grid investments over the next decade requires a shared industrial roadmap. Strengthening the commitments of network operators is a prerequisite for manufacturers and technology providers so they take actions to be able to deliver on time.

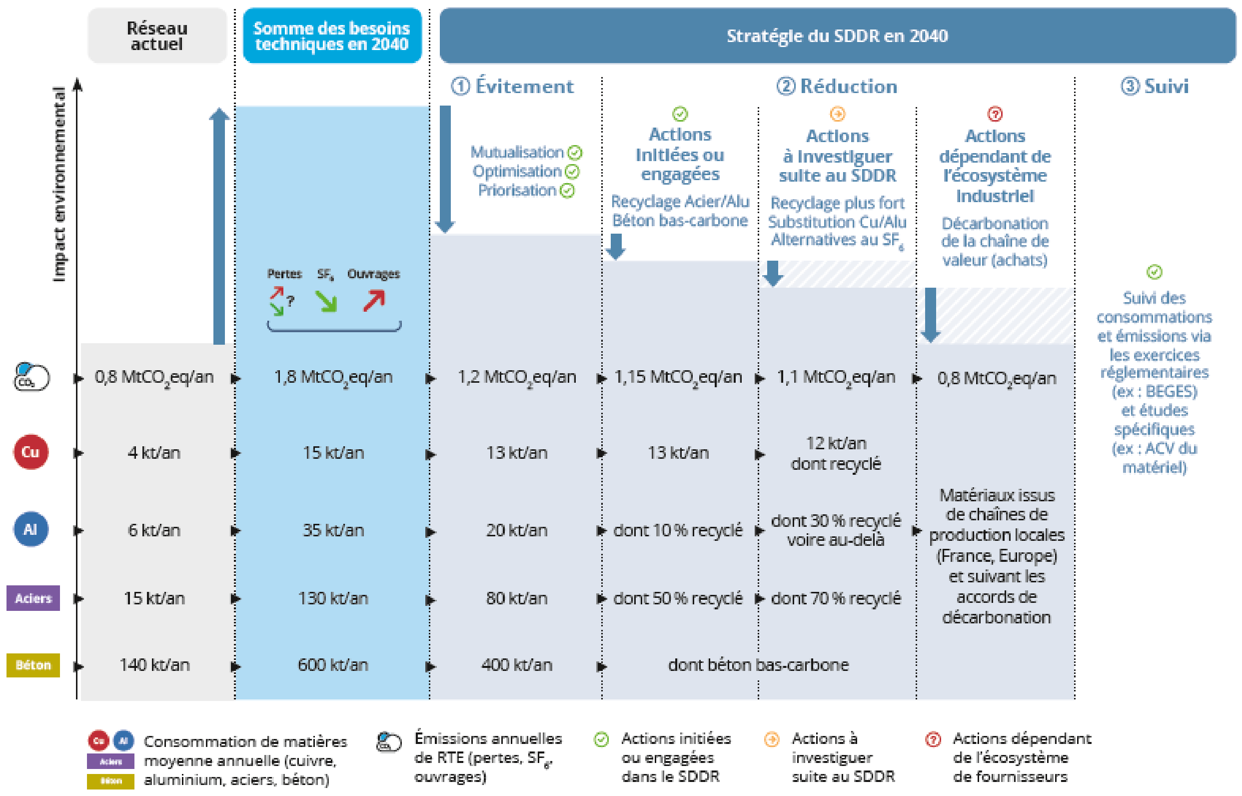
- **In this context, RTE supports the transformation of its industrial ecosystem and develops its procurement strategy**

by planning, consolidating, and **standardizing requirements**
- from 45 to 14 references for overhead cables
- from 34 to 10 reference for underground cables
- from 13 000 to 1 500 reference for pylons

by having **greater contractual commitments** (70% compared to 30% today) and **longer contract terms** (up to 8 to 10 years, compared to 3 to 5 years generally today)

- The reference strategy **addresses all the challenges the network and its ecosystem are facing** (not just those dependent on technical and economic studies) :
  - **protecting the network infrastructure** and **strengthening the country's sovereignty**
  - **providing more visibility to the network users** on infrastructure developments
  - **planning** network development at the right time to **optimize costs**
  - providing visibility to **European and French supply chains**

A reference strategy that integrates circular economy and recycling issues : a key challenge in developing dedicated industries



Reduce the carbon footprint by increasing the consideration of environmental factors in purchasing (10% compared to 3% today).

Levers implemented in the reference strategy

1. Controlling the **needs in mineral resources and the network's carbon footprint**
2. **Further reducing SF6 leaks**
3. Increasing **environmental requirements in equipment procurement**
4. Moving from experimentation to scaling up **the use of recycled materials** in the various equipment used for the electricity network
5. Explore further possibilities for **substituting copper with aluminum** in new high-power submarine cables

Skills

Even if RTE relies on a high technical expertise, investments growth in the electricity networks entails significant needs in terms of jobs and skills.

A recruitment volume comparable to the nuclear and rail sectors

106,000 jobs in 2030 across the sector (system operators, suppliers, service providers), representing an increase of 40,000 jobs compared to 2023

Considering a growth of the headcount and the need to replace departures, this represents approximately :

58,000 new hires by 2030 for the sector, or 8,000 to 12,000 new hires per year

4,300 new hires at RTE by 2030 (including 1,600 for new jobs, with the rest to replace departures)

Initiate a process to enhance the attractiveness of the sector and the training system

1. Facilitating **career transitions**
2. Enriching the **initial training offering**
3. Increasing the **attractiveness of careers** in the sector

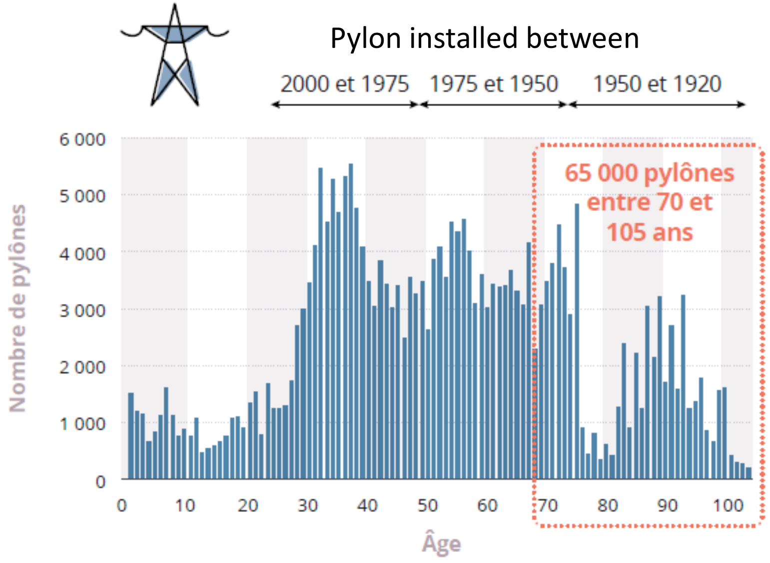
In addition to the partnership launched in March 2023 (the Network Schools for Energy Transition), the French system operators and other industrial associations created on the 4th June 2025 the **French industrial sector for electric grid companies** (FIERE) which aims at supporting skills development among other objectives like :

- Supporting the electrification of uses and reindustrialization
- Strengthening industrial capacity at national and European level
- Securing critical supplies of metals and materials

Renewing the network and adapting it to climate change

The strategy for renewal and adaptation to climate change presented in the SDDR 2025 is based on three key principles

Dilapidation (SDDR 2019 priority)



Climate change (SDDR 2025 novelty)

Flood risk for electrical substations

Risk of high temperatures for overhead lines

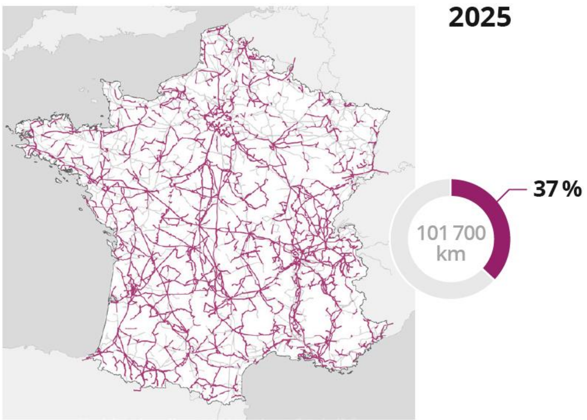
The guiding principles of the strategy:

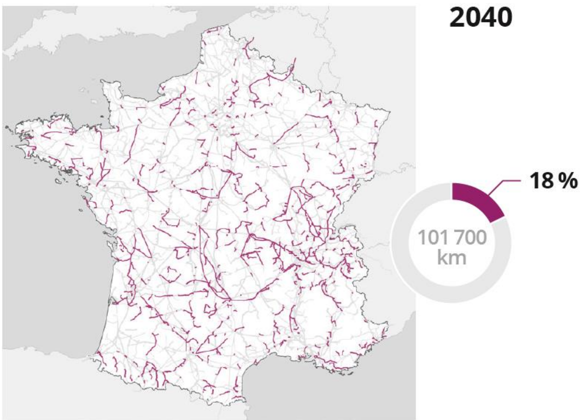
- <u>Principle n°1:</u> pooling of renewal and climate change adaptation works (**two-in-one** strategy)
- <u>Principle n°2:</u> within the renewal program defined following the 2019 SDDR, **prioritizing infrastructure** most exposed to climate risk and in areas subject to local connection dynamics.

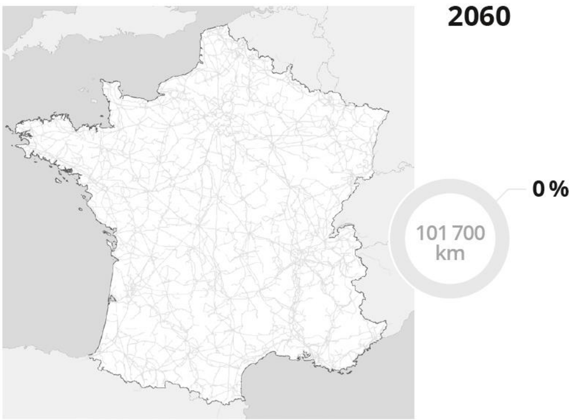
Renewal

The proposed strategy aims to make 100% of the network resilient to climate change by 2060 (80% of the network by 2040).

Heatwave risk on overhead lines

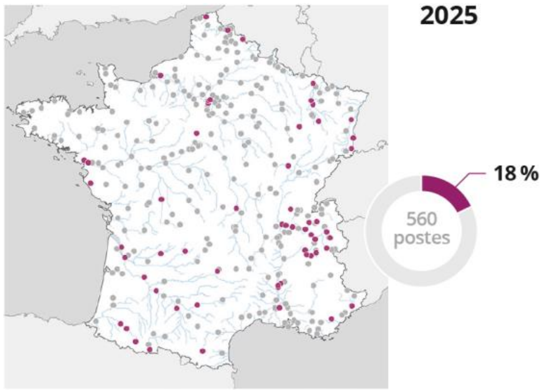


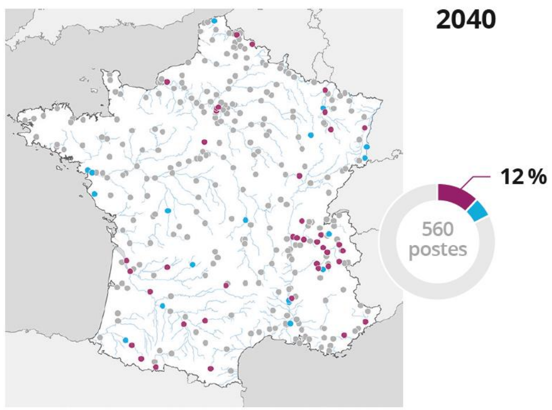


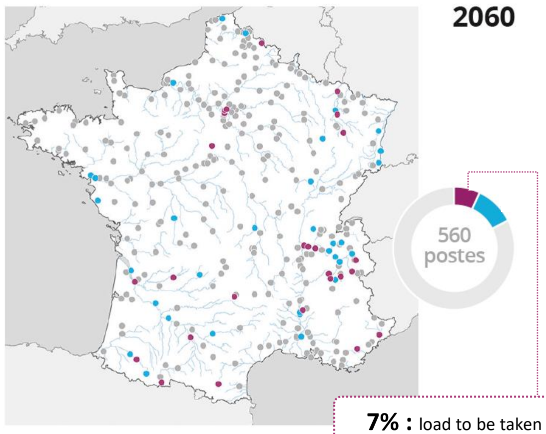


- Lines exposed to heat risk
- Non-exposed lines

Risk of 100-year flood at stations







7% : load to be taken over by neighboring stations (operational system plan)

- Flood-prone areas with risk to power supply
- Flood-proof without risk to the power supply
- Non floodable

Two challenges for climate change adaptation: (1) the design of new infrastructure and (2) the gradual adaptation of existing infrastructure

Climate change adaptation strategy

New asset

Adaptation of technical requirements from the design stage onwards

✓ **Agreed in the preparation phase of the SDDR**

Existing asset

Structure presenting several risks (dilapidation, obsolescence, climate, etc.)?

Yes

5 investment scenarios proposed in <u>the « renewal » section of the SDDR, including a baseline scenario</u>
+
Adaptation of operating and maintenance rules as a supplement

<u>Proposed in 2025 for a total of €20 billion over 15 years</u>

No

No action needed

Connecting new low-carbon facilities

Launch a major industrial program to ensure the connection of the facilities needed to decarbonize the country

Planning the connection of new low-carbon facilities

Consumption

- New industries
- Existing industries that are decarbonizing and electrifying

Generation

- New nuclear
- Offshore wind power
- Onshore renewable energies and batteries

Given their power, most of these facilities will be directly connected to the transmission grid and will influence its size.

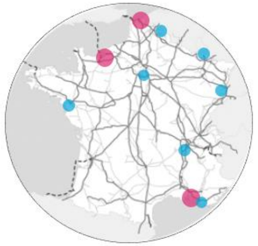
Three principles apply to each sector: **identification of favorable areas + transparent prioritization of investments + evolution of the contractual framework.**

The reference strategy is based on a new “network offering” approach

1 Provide information on favorable areas

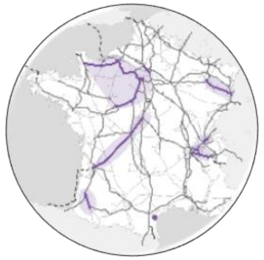
Publication of maps for each type of user, to encourage the proper location of projects in areas allowing for rapid connection.

2 Plan investment prioritization zones



P1 zones (Dunkerque, Le Havre, Fos-sur-Mer)

P2 zones (Valenciennes, St Avold, Sud Alsace, Vallée de la chimie, Plan-de-campagne, Loire-Estuaire, Sud Ile-de-France)



P3 zones with potential for accelerated development of the 400 kV network

Commissioning by 2029

- Investment triggered as soon as administrative authorizations have been obtained

Commissioning around 2030

- Administrative procedures ongoing, but works are contingent upon the progress of industrial projects

Acceleration of investments possible

- Subject to approval by authorities and investor interest

3 Developing the regulatory framework for connection to prevent speculation

Moving from a “first come, first served” principle to a “first ready, first served” principle

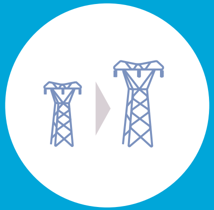
Exploring the benefits of “AMI” devices (call for expressions of interest)

Changing the ways in which customers make financial contributions

Encourage connection to available 63 to 225 kV networks

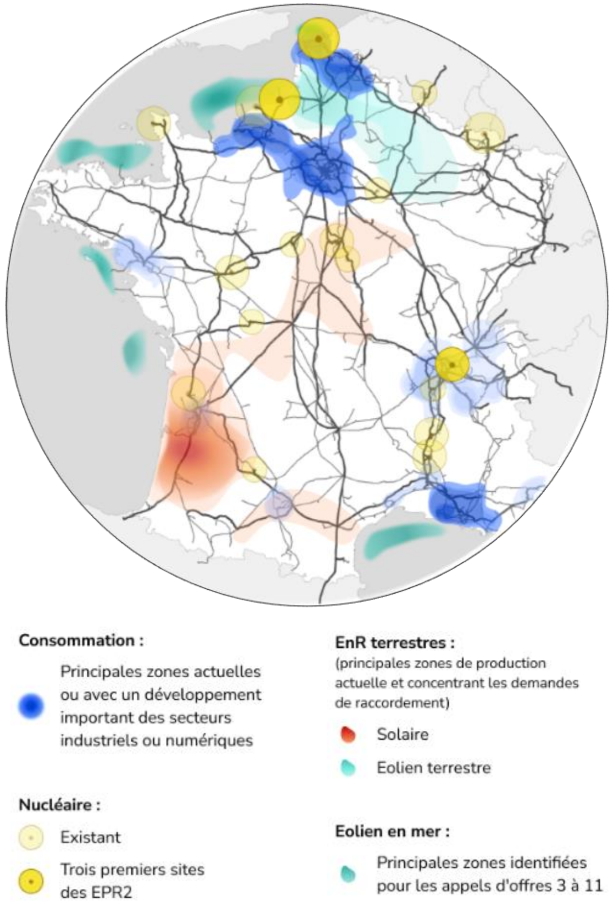
Define a specific connection framework for batteries

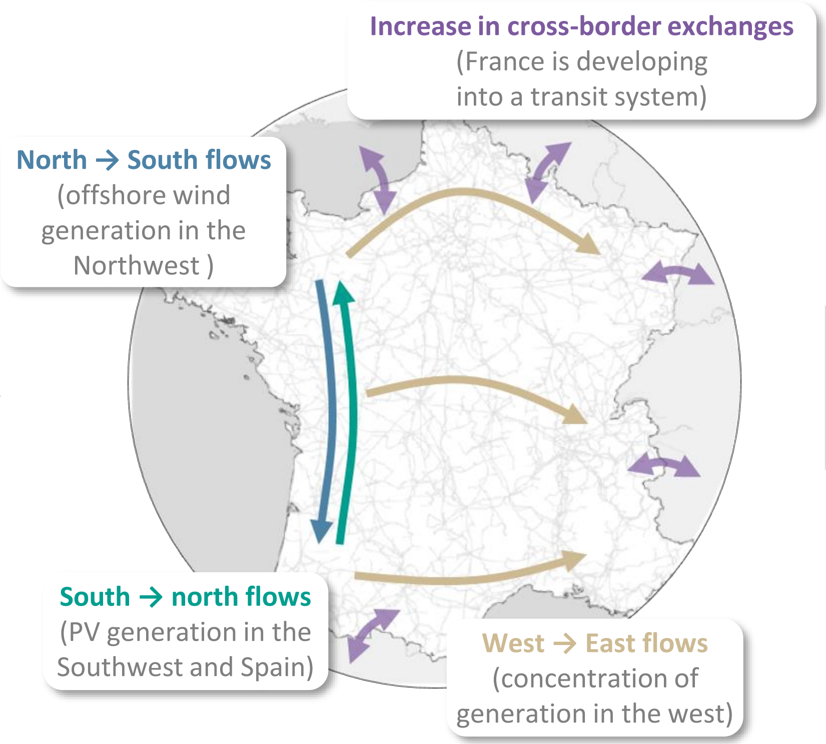
Strengthening the network’s backbone



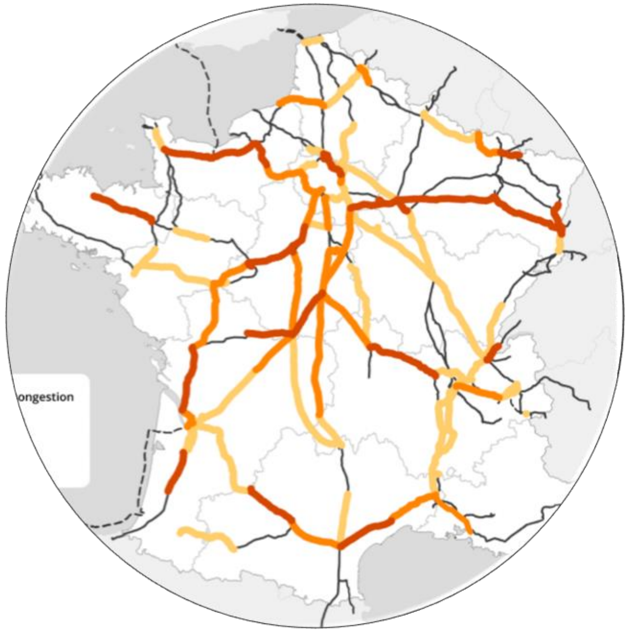
The network structure will need to be strengthened to support the evolution of flows

Localization of current and future main centers of generation and consumption





Congestion on the very high voltage network in 2040 (if no reinforcement)

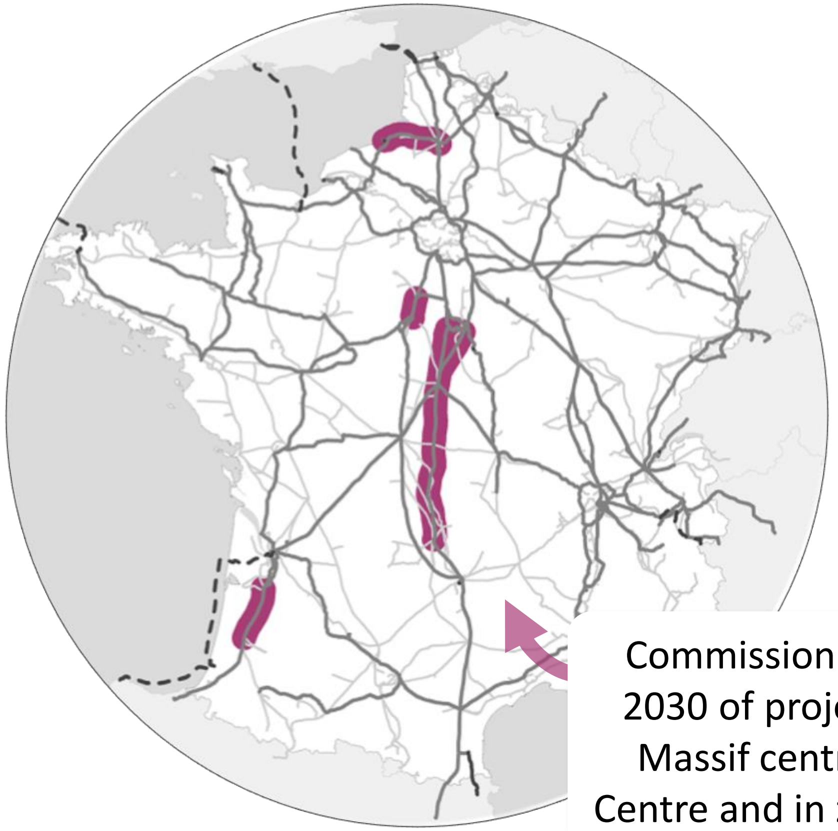


Congestion costs without reinforcement

~ €100 M/year in 2024	up to €3 B/year in 2035

The reference strategy is based on a sequenced reinforcement approach

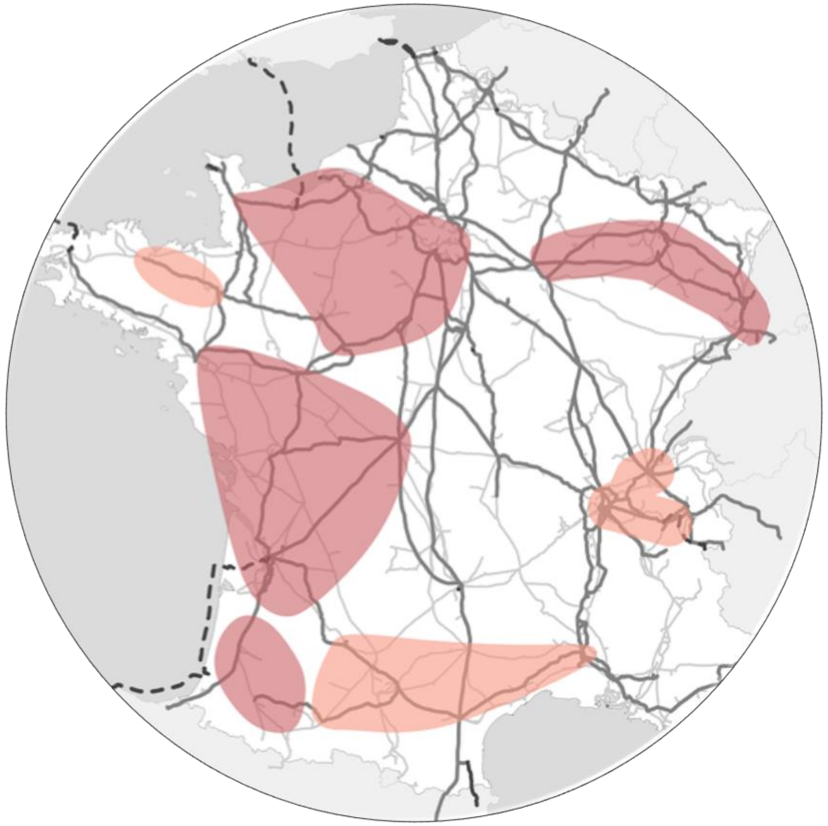
Reinforcement projects to 2030
Consultation or works planning in progress



Commissioning before 2030 of projects in the Massif central, in the Centre and in zones 1 et 2

+

Areas of reinforcement between 2030 – 2040
Identification of technical solutions ongoing



The reference strategy balances the development of interconnections and the need to reinforce the internal network

Reference strategy

By 2030, complete the commissioning of projects resulting from the last SDDR

→ two HVDC projects with Spain and Ireland + work to increase interchange capacity at the Spanish, Belgian and German borders

By 2030, France's cross-border capacity will have grown considerably:

Compared to 2020 capacities

+ 11 GW export

+ 9 GW import

After 2030, new interconnection projects are conditional on prior reinforcement of the internal network

Otherwise, either these new interconnections will not be fully exploited, or their use by the market will generate costs for French consumers without corresponding social welfare benefits

Thanks !

CIGRE France Conference

THE ITALIAN ENERGY TRANSITION: PRIORITIES AND CHALLENGES FOR THE POWER SYSTEM

Panel: The Italian Energy Transition: Priorities and Challenges for the Power System - Conference CIGRE France

ENRICO MARIA CARLINI

Chair, CIGRE Italy National Committee

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For power system expertise

LYON – OCTOBER 16, 2025

Agenda

- The Italian National Energy and Climate Plan
- Energy Scenarios
- Evolution of electrical demand in the energy transition
- Impacts of energy transition on the power system
- Enablers of the Energy Transition: NDP 2025 and the Hypergrid Project
- Advanced technology to enable large integration of RES
- Conclusions

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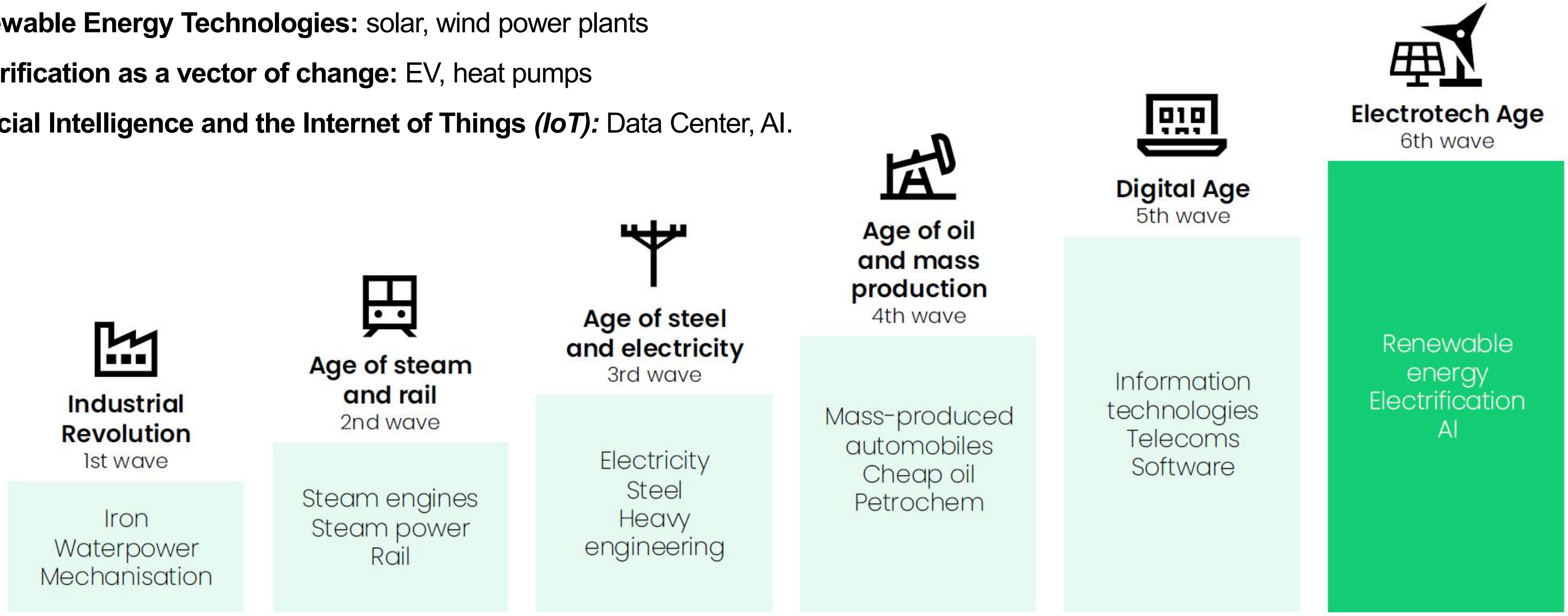
The Italian National Energy and Climate Plan

Pathways to 2030 and 2035 climate goals

A New Perspective: The Electrotech Revolution

Electricity is now the engine of change: ***Electrotech*** describes the radical transformation in the fields of electronics and electrical engineering, with the introduction of new technologies that improve the way we produce, transfer, distribute and consume energy. Some examples of innovations in this area include:

- **Advanced power electronics:** HVDC VSC converter substation
- **Renewable Energy Technologies:** solar, wind power plants
- **Electrification as a vector of change:** EV, heat pumps
- **Artificial Intelligence and the Internet of Things *(IoT):*** Data Center, AI.



Source: EMBER – The Electrotech Revolution 2025

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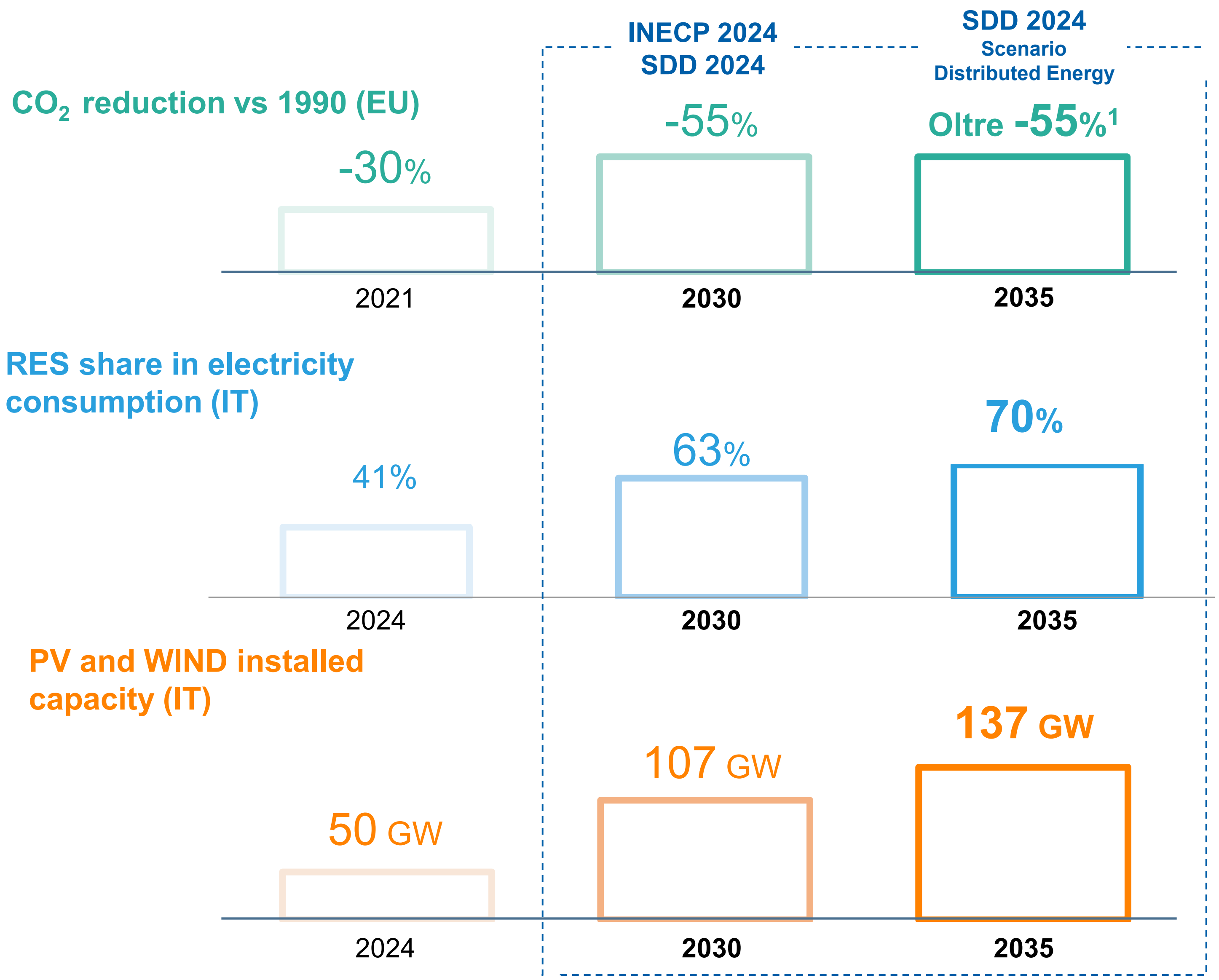
Italian Energy Framework

Decarbonization targets beyond 2030

- The **2025 National Development Plan** plays a fundamental role in achieving **European** and **national targets** for the **energy transition**, as well as for the independence and efficiency of the Electric Transmission System, through investments in strategic infrastructure.
- The Plan is consistent with the **objectives of the 2024 Integrated National Energy and Climate Plan** (INECP), as incorporated into the **energy scenarios developed by Terna and Snam** (2024 Scenario Description Document), which are aligned with the European "Fit-for-55" directives.
- The **2024 Scenario Description Document** (SDD) follows a **continuity** path with respect to the **2022 SDD** and is aligned with the 2024 INECP.



Energy Scenarios

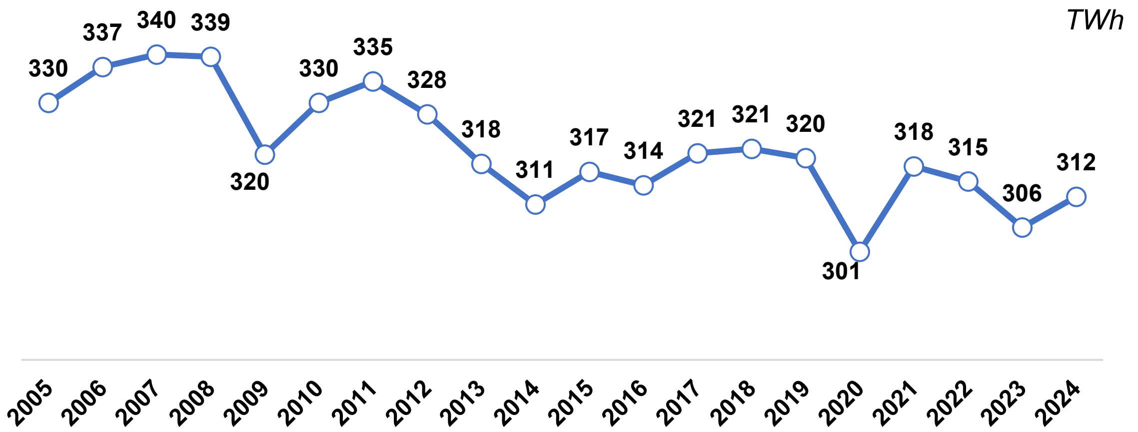
RES and storage outlook: capacity trends and connection requests

For power system expertise

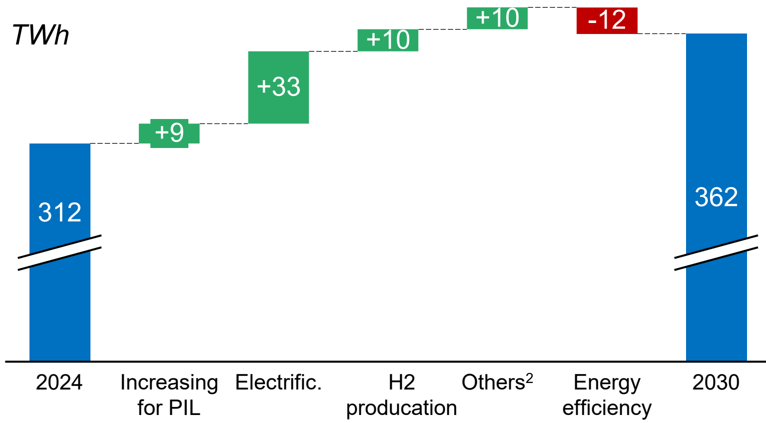
Decarbonization targets

Description of Energy Scenarios 2024

Electricity demand
(History)



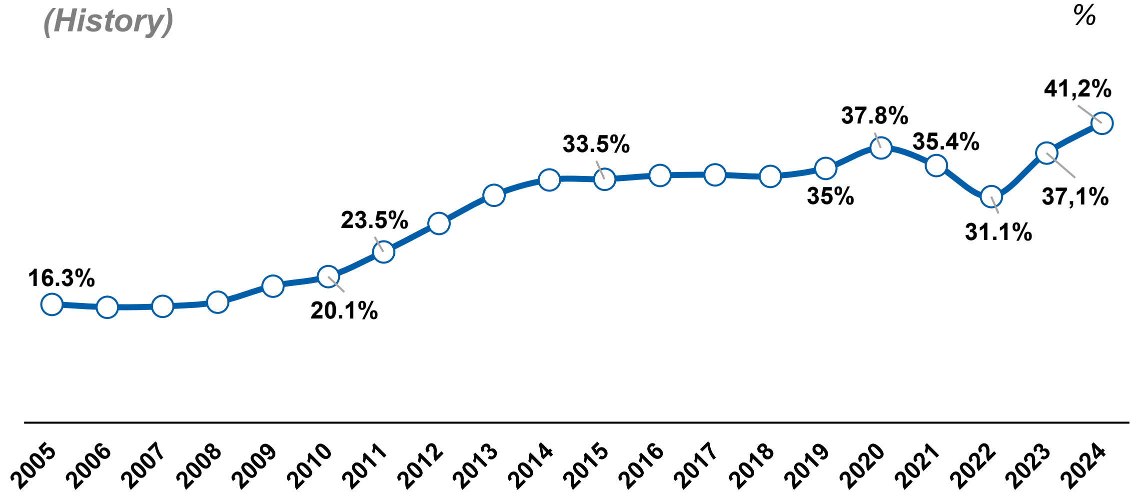
Electricity demand
(Scenario)



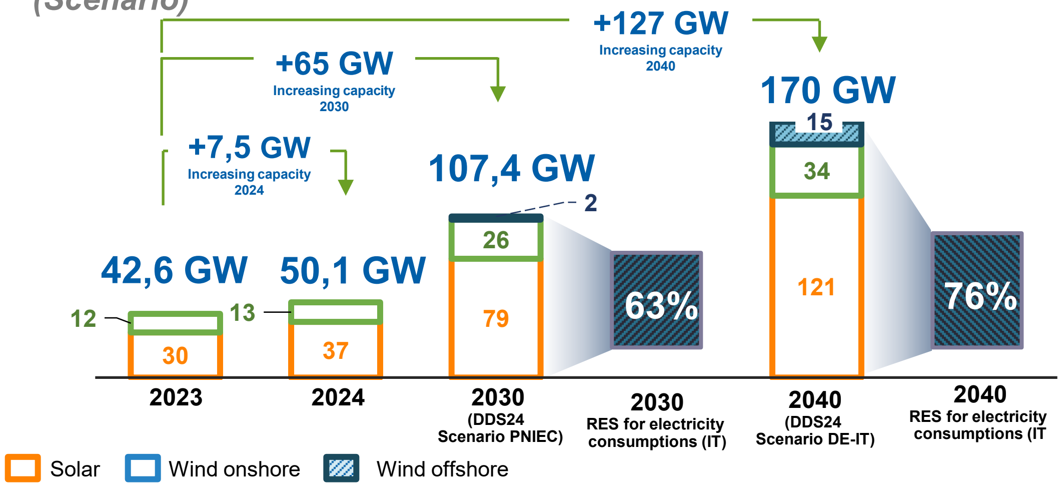
	2030
Electric vehicles [Mln]	6,6
Electric bus [k]	17,0
Electric trucks [k]	30,0
Residentials HP [Mln]	4,6

Increase in electricity demand driven mainly by the growth of electric vehicles and heat pumps.

FER
(History)



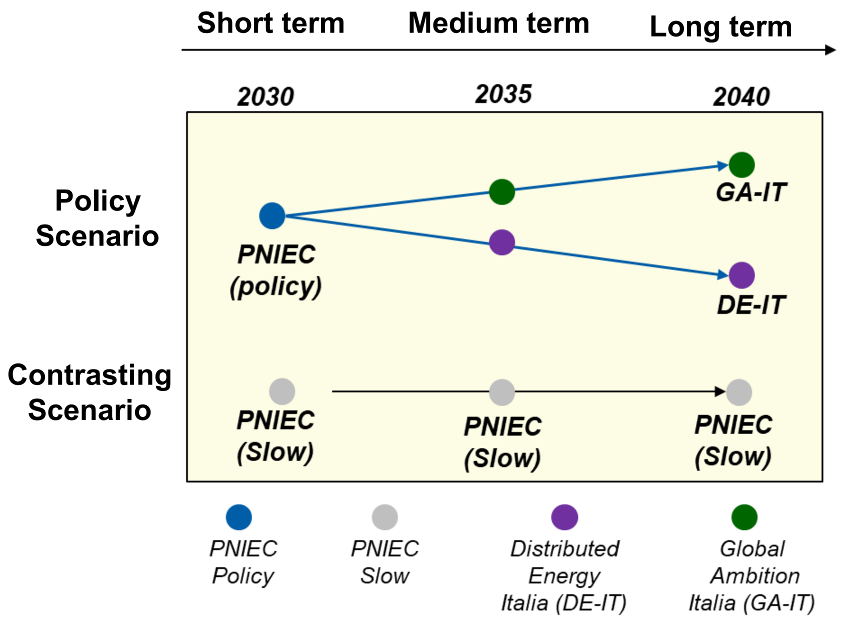
Increasing capacity RES at 2030 and 2040
(Scenario)



Energy Scenarios

The **PNIEC Policy 2030** scenario aligns with the objectives of the **PNIEC**; the long-term scenarios **DE-IT**[1] and **GA-IT**[2] explore different pathways toward carbon neutrality by 2050; the **PNIEC Slow**[3] scenario anticipates a slower transition.

Scenario and Target Years



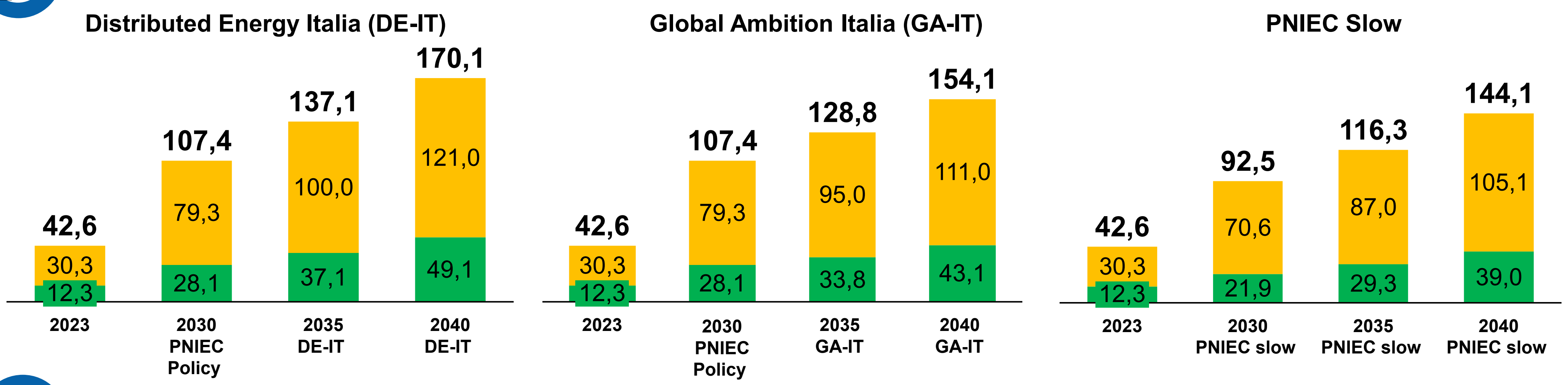
Summary of 2035 – 2040 Scenarios

	Distributed Energy Italy (DE-IT)	Global Ambition Italy (GA-IT)	PNIEC Slow
Summary Scenario	Maximization fo RES power plants. Deep penetration of electric vector in demand consumption. Residual use of green gas.	Relevant contribution from both RES power plants and green gas in demand consumption. Deep penetration of electric	2-3 years od delay respect to Policy scenario with a moderate electrification and lower RES and green gas integration.
Topology Scenario	Aligned with «Net Zero» by 2050	Aligned with «Net Zero» by 2050	Aligned with «Net Zero» by 2050
Electricity Demand	●●●●○	●●●○○	●●○○○
Industry	●●●●○	●●●○○	●●○○○
Civil	●●●●●	●●●●○	●●●○○
Transport	●●●●○	●●●○○	●●○○○
Renewables Sources	●●●●○	●●●○○	●●○○○
Green Gas Demand	●●○○○	●●●○○	●○○○○
Industry	●●○○○	●●●○○	●○○○○
Civil	●○○○○	●●○○○	○○○○○
Transport	●○○○○	●●●○○	●○○○○

1. ***Distributed Energy Italia (DE-IT)**: It foresees a strong penetration of the electric vector across all sectors (residential, transport, and industry), maximizing the use of renewables.*
2. ***Global Ambition Italia (GA-IT)**: It foresees greater development of green gas-powered technologies, used not only as feedstock but also in the transport sector.*
3. ***PNIEC Slow**: Formal request by ARERA (Italian Regulator) from Cost-Benefit Analyses (CBA)..*

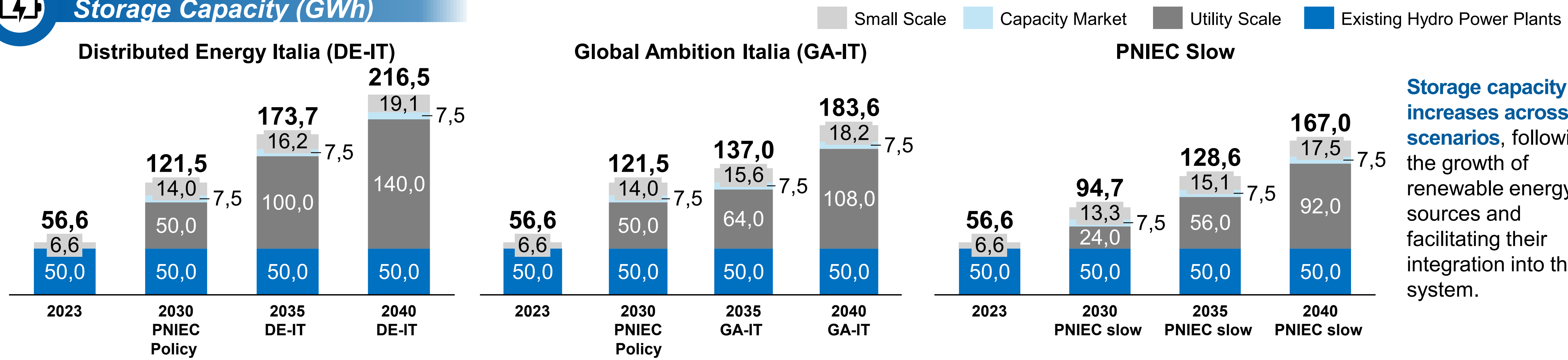
Energy Scenario – RES and Storage

RES Capacity (GW)



In line with decarbonization targets, **renewable capacity** in Italy is set to **increase** significantly **across all scenarios.**

Storage Capacity (GWh)



Storage capacity increases across all scenarios, following the growth of renewable energy sources and facilitating their integration into the system.

Energy Framework

Connection Requests: RES and Storage Power Plants

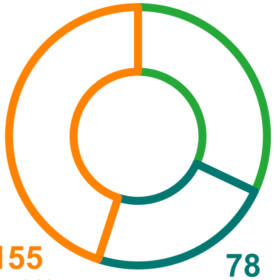
Values in GW
Update: July 31th 2025

The management of **connection requests** received on the High Voltage (HV) grid allows Terna to gain a systemic view of potential future developments of **Renewable Energy Power Plants** and **storage systems**. This enables the identification of key areas of focus to support a **coordinated and efficient expansion of grid infrastructure**, ensuring maximum efficiency in the implementation of grid projects.

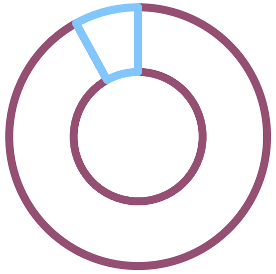
The 2025 Development Plan takes into account the share of Renewable Energy Sources (RES) and storage systems to be integrated into the HV grid, estimated based on scenario analyses, in terms of the infrastructure projects required to enable their connection.

Connection requests, both for renewable plants and storage systems, are primarily concentrated in **southern regions** and on the **islands**.

Connection requests on UHV/HV Network[1]



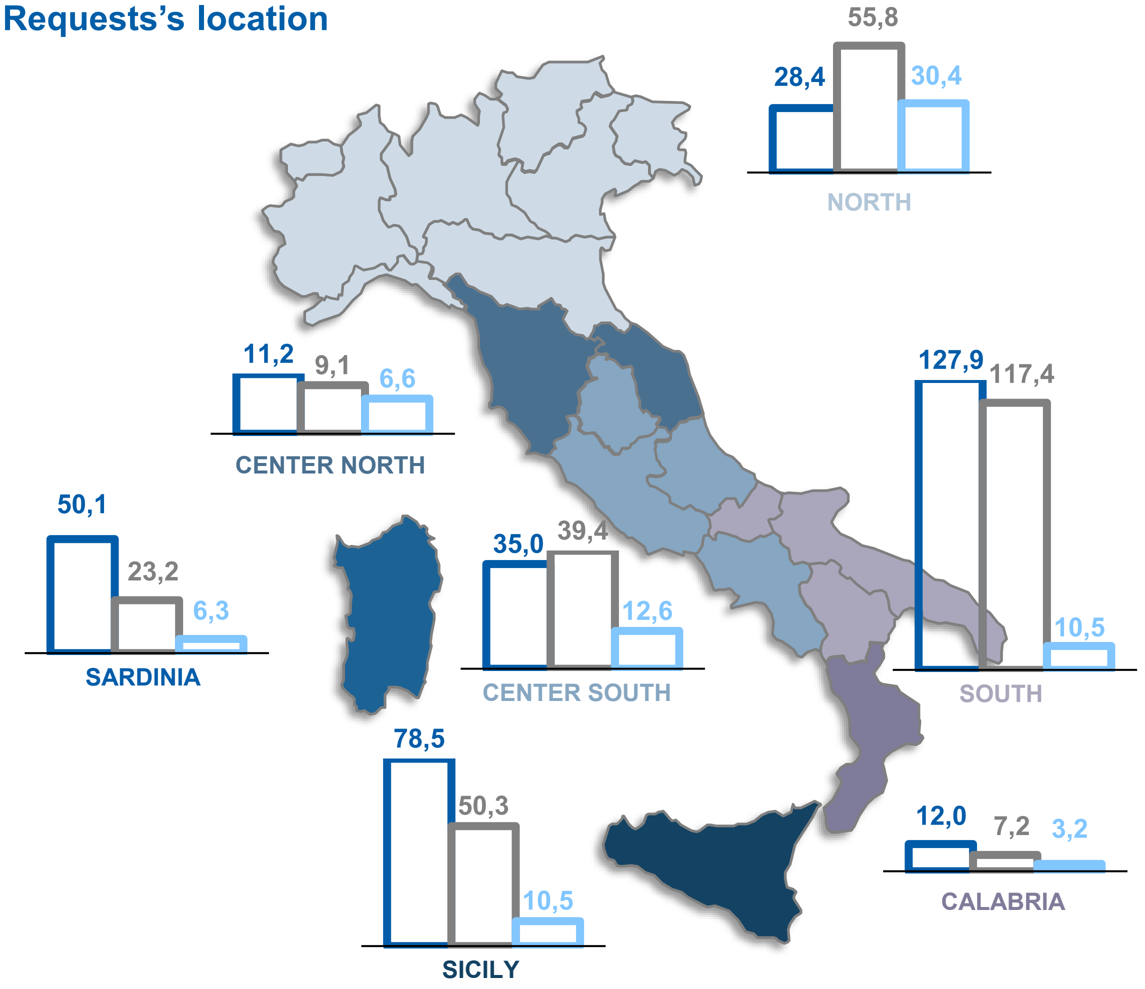
343 GW
Renewables power plant



302 GW
Storage

WIND on-shore | WIND off-shore | Solar | Stand-alone | Integrated

Requests's location



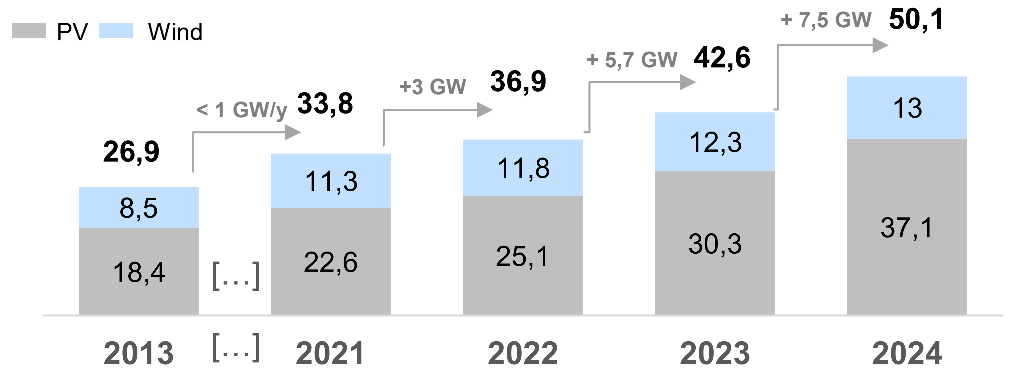
*HV connection requests by **RES*** | *HV connection requests by **Storage*** | ***Burden Sharing** energy scenario[2]*

1. *Updated data on 31/07/2025.*
2. *Solar and wind by 2030 (respect to 2022)*

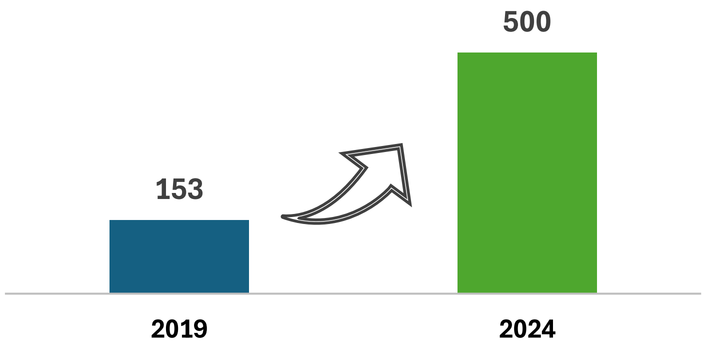
Power System Evolution

RES Installation trend

RES evolution - 2024 [GW]



*hours with RES share over > 50%**



Higher RES installation rate starting from 2022 respect to the previus average decade (≈ 1 GW/y)

Number of hours with more than 50% of the load consumption supplied by RES generation

(*) From January to April 2019 and 2024

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Evolution of electrical demand in the energy transition

RES integration and implications for the power system

The Italian Energy Transition: Priorities and Challenges for the Power System

Enrico Maria Carlini – 16 October 2025

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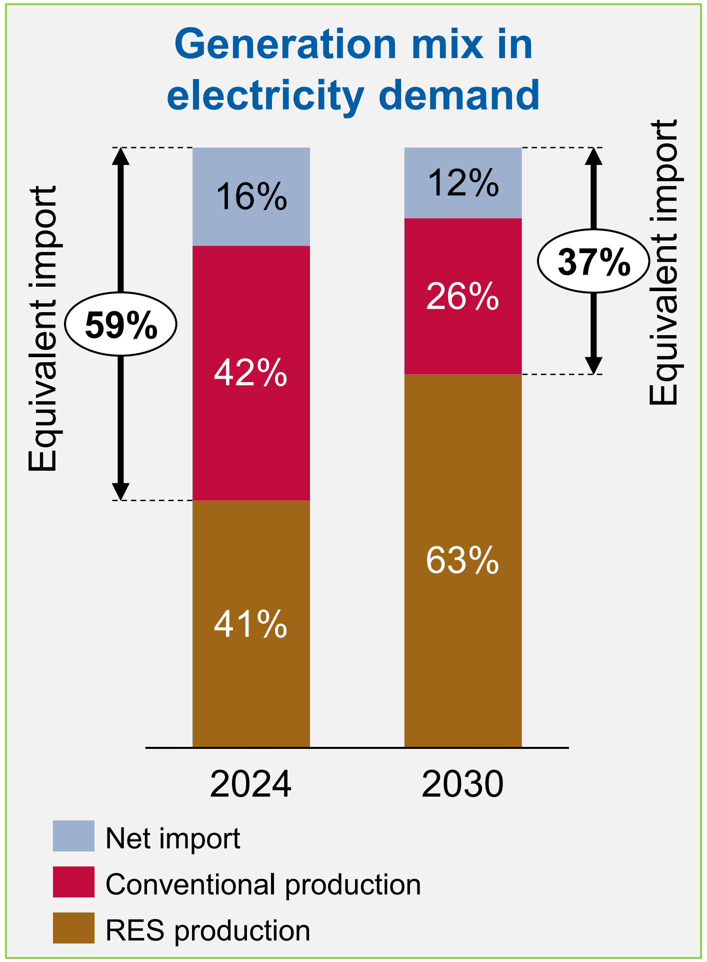
Electricity Balance 2024 vs 2030



Electricity Balance(TWh)	2024[1]	2030[2]
Total electricity demand	**312**	**362**
Traditional electricity consumption	312	352
Electricity demand for H2 production	-	10
Total electricity production	**261**	**322**
Total RES Production	129	227
Hydro	52	46
Solar	36	105
Wind	22	64
Other RES	19	17
Overgeneration	~0,3	-5
Total conventional production	133	95
of which Natural Gas	*121*	*88*
Import/Export (net import)	**51**	**43**
Storage losses	-1	-4
Storage production	*1*	18
Storage consumption	*2*	22
RES share on demand (%)	**41%**	**63%**

Solar first source by 2030

Increasing demand driven by electriification (Evs, heat pumps, Data Center)

RES production doubles, driven by solar generation

OG is aligned with the scenarious in the other EU countries

Increasing role of storage technologies

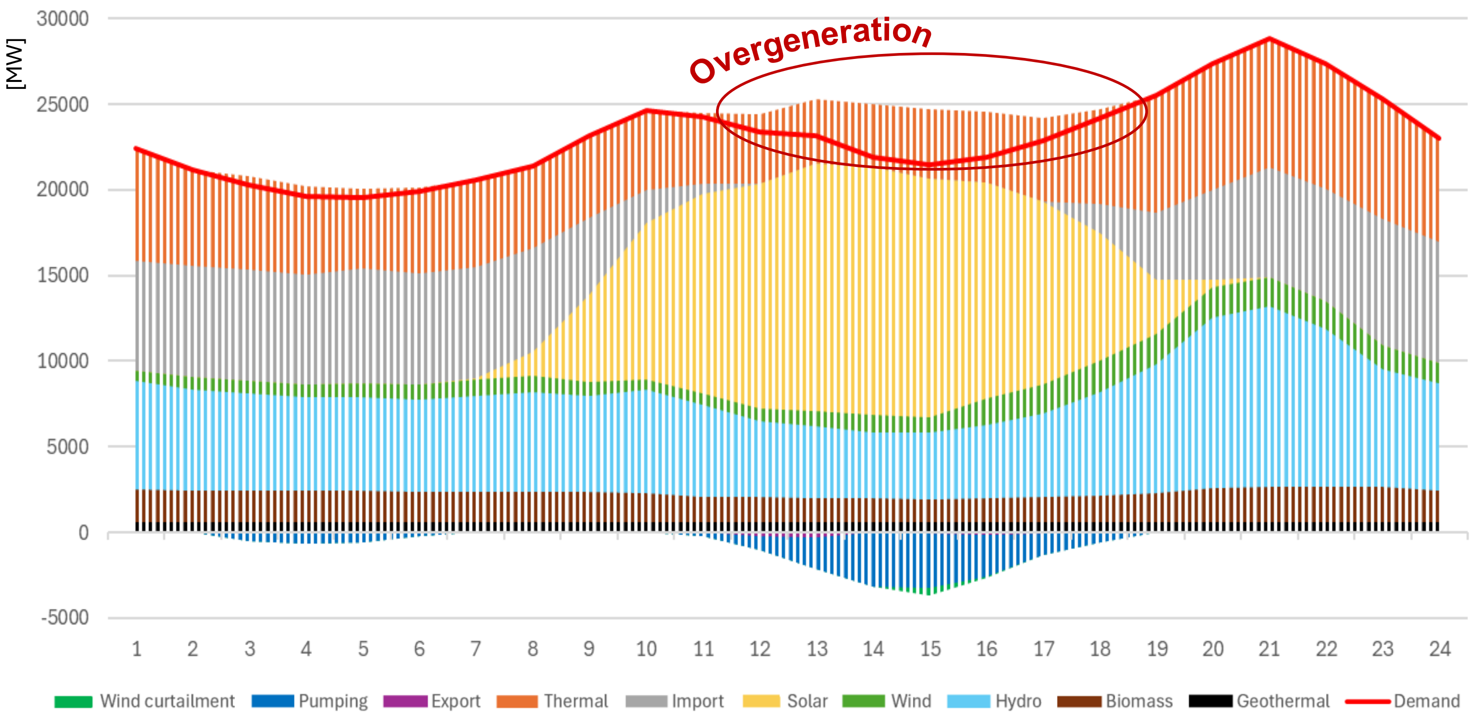
Italy's NECP foresees RES production nearly doubling by 2030, with solar as the leading technology, reducing both conventional generation and imports compared to 2024.

1) *Source: Terna. Provisional data*
2) *Source: Terna, Documento di Descrizione degli Scenari 2024, Scenario PNIEC Policy*

Electricity demand and generation on Easter Holiday

Real case study from Sunday 7th in April 2024 during springtime

Electricity demand and residual load



Solar production record, storage utilization and wind curtailment

- **Photovoltaic generation** reached a record high of **14.5 GW**, an unprecedented level, already net of self-consumption.
- **Pumped storage** contributed 13.6 GWh of system flexibility.
- Total **wind curtailment** amounted to approximately 0.5 GWh

High RES penetration in electricity demand

- **Renewable generation** covered **74%** of the daily electricity demand.
- The **peak share of RES**, recorded at 1:00 PM, reached **97% of demand**, despite the modest contribution from wind power.

Changes in generation mix

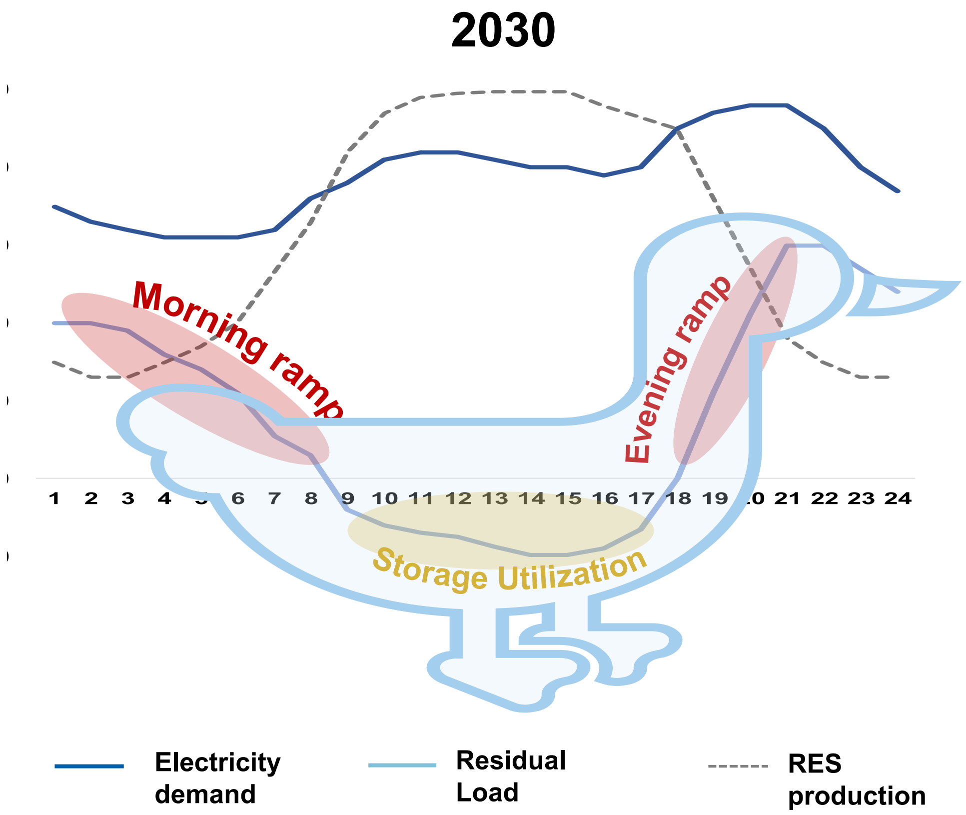
Main aspects and effects on electricity demand

Main Impacts

- **Reduced capability** for voltage and frequency regulation, as well as upward reserve provision, due to the decreasing share of **thermal power plants** in the generation mix.
- Transmission **network congestion** resulting from the geographically unbalanced deployment of **renewable energy sources**, with critical constraints particularly in **Southern Italy**.
- **Increased reliance on thermal generation** during evening peak hours to offset the decline in **photovoltaic output**.

The simultaneous RES increase and the decline of thermal capacity within the generation mix are fundamentally reshaping the configuration and operational management of the power system.

*Electricity demand and residual load**



** Residual demand not covered by RES power plant*

Impacts of energy transition on the power system

Ensuring grid stability in the era of renewable integration

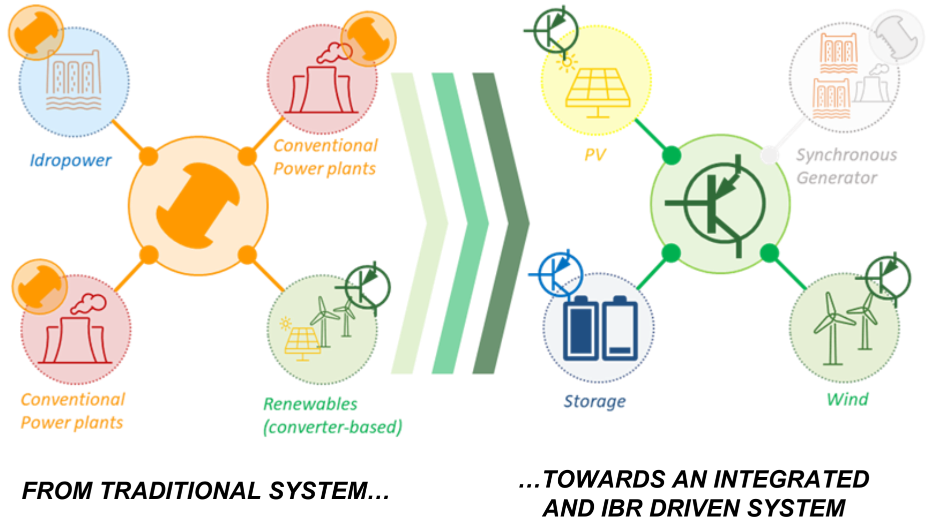
The Italian Energy Transition: Priorities and Challenges for the Power System

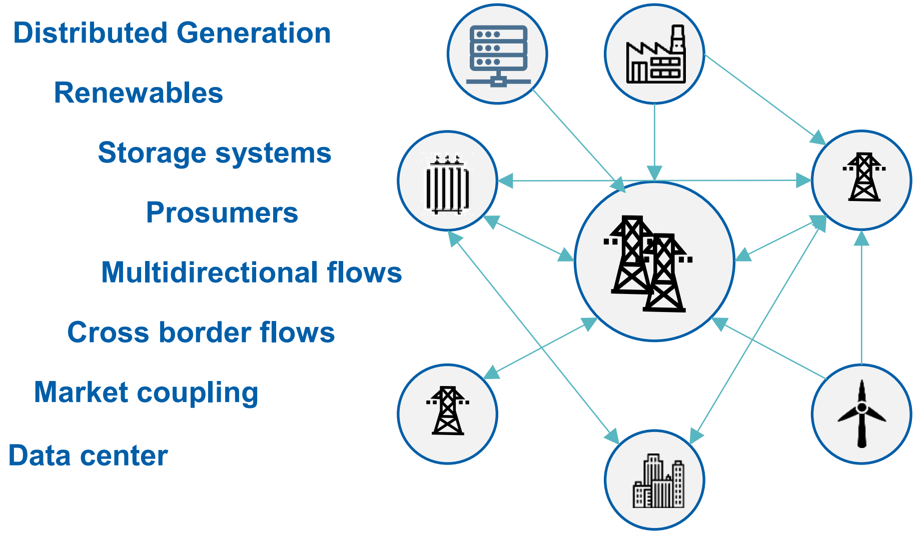
Enrico Maria Carlini – 16 October 2025

For power system expertise

How the energy transition impacts on the electrical power system

The electrical power system is facing significant transformation from generation to consumption perspective. As RES integration increases, along with thermal generation reduction, TSOs will face new challenges operating the power system.





IMPACTS ON ELECTRICAL POWER SYSTEM

RES integration and decommissioning of thermal power units	Daily/weekly variation in RES production	RES location
▪ Inertia reduction ▪ Reduction of voltage and frequency regulation capabilities	▪ Reduction in adequacy range ▪ **over-generation** during the day ▪ Increase in slope evening load ramp	▪ Increase in internal congestion based on generation and load location ▪ Distributed generation

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Evolution of the electrical power system

Cluster

Technical characteristics of RES

Intermittency of RES

Location of RES

Climate change

Impacts on electricity system management

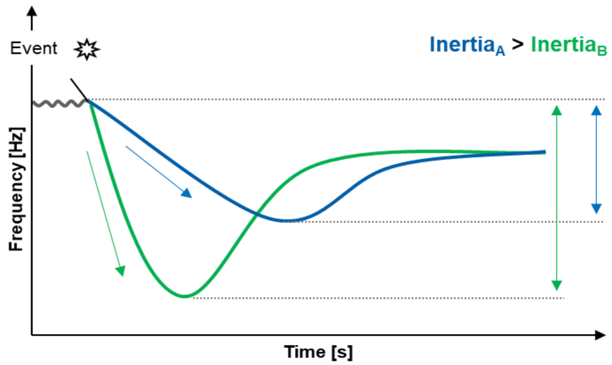
- Reduction of **system inertia**
- Reduction of resources for **frequency and voltage regulation**

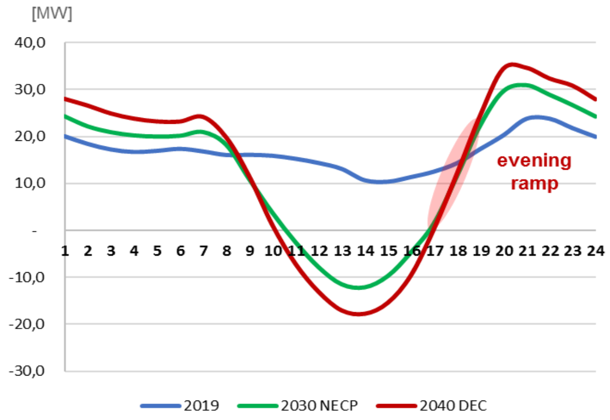
- Reduction of the **adequacy margin**
- Increasing periods of **over-generation**
- Increase in **residual load during the evening ramp**

- Increased **network congestion** due to the geographical distance between RES supply and consumption centers
- Growing **challenges** to system operation due to increased distributed generation

- Growing risk on service quality

Inertia Reduction, Overgeneration





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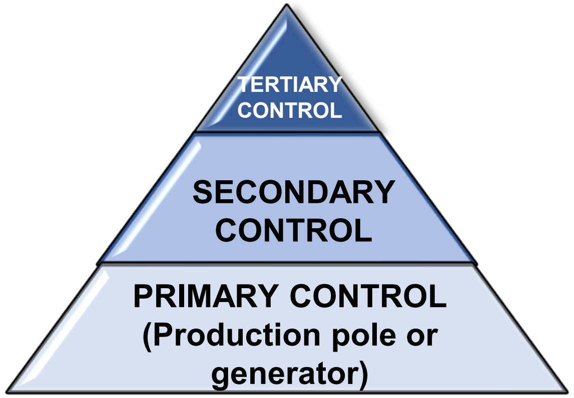
Voltage regulation and system stability

VOLTAGE REGULATION

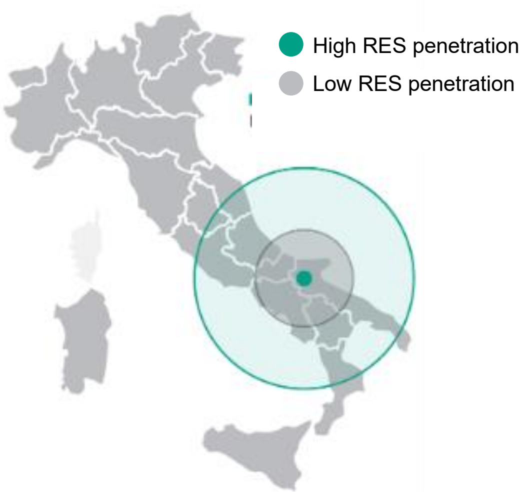
Voltage control, implemented across three hierarchical levels, keeps the grid within tight limits around the nominal value, ensuring both security and power quality.

- **Primary control**: fast and local
- **Secondary control**: regional level
- **Tertiary control**: system-wide, aimed at optimizing reactive power flows



SHORTCIRCUIT POWER AND SYSTEM STRENGTH

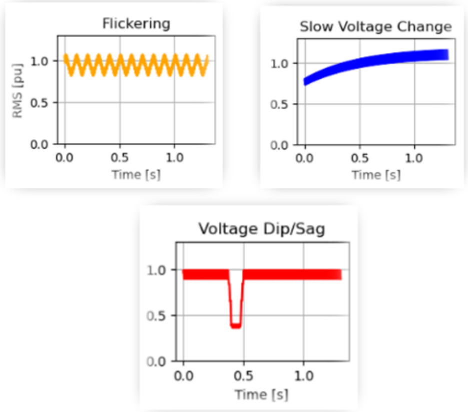
Short-circuit power is an indicator of grid strength with respect to voltage disturbances: higher values reduce the impact of perturbations on the affected area.



RES IMPACT ON GRID EVOLUTION

High penetration of RES leads to:

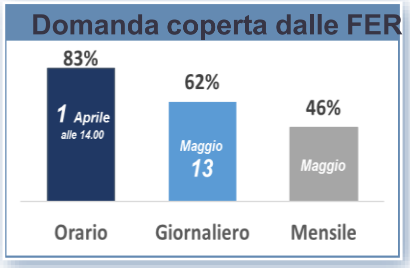
- Reduced short-circuit power due to limited contribution from inverter-based resources (IBRs)
- Increased requirements for voltage regulation systems
- A **redefined concept of grid strength**, with IBR controls becoming essential for system stability



Frequency Oscillations Issues

1 Decarbonisation

- Inverter based generation increase

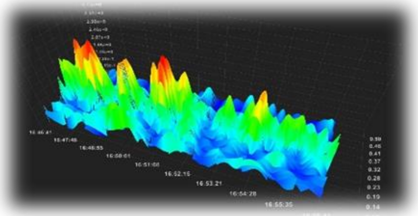


2 Impacts

- **INERTIA** reduction (substitution of existing conventional generation)
- **POWER FLOWS** increase between market bidding zones
- Facilitation of the generation of **OSCILLATIONS** propagating along the entire length of the electrical network
- **SHORT CIRCUIT POWER** reduction jeopardising the quality of supply (protection system and fault selectivity)

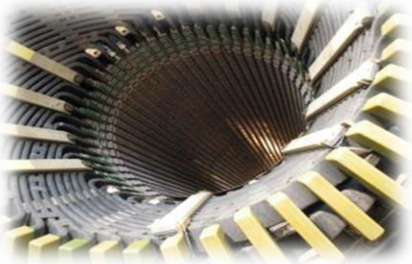
3 Critical Phenomenon

- The grid is increasingly sensitive to disturbances, subject to greater uncertainty, and reduced **STABILITY**. The grid may enter alert situations[1], potentially escalating to critical conditions.



4 Action Plan

- STATCOM, Synchronous, Condenser, Reactors, active power stabilyzer
- **REAL TIME** monitoring system of short circuit power and inertia levels



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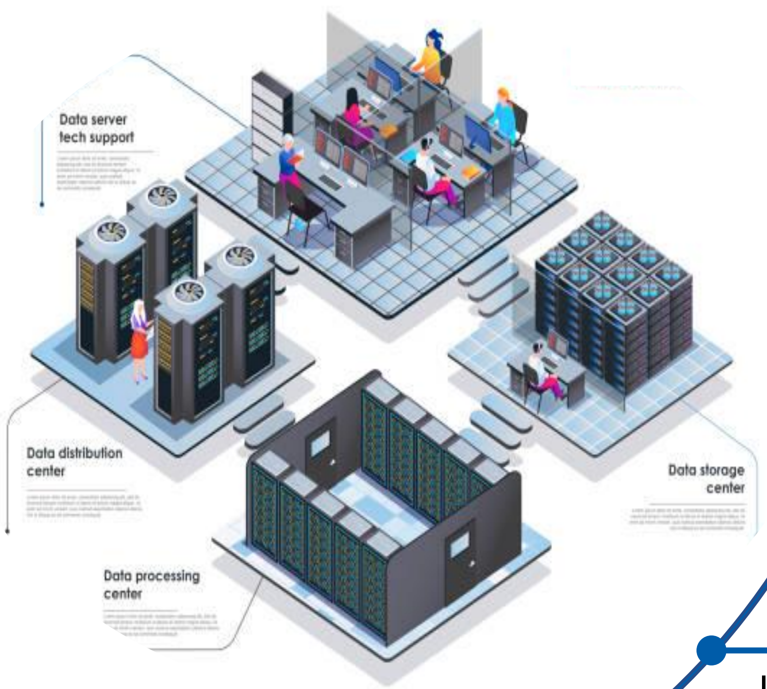
1. "According to the System Operation Regulation, the Alert State is reached when the frequency deviation is below ±200 mHz and greater than ±100 mHz for more than 5 minutes, or greater than ±50 mHz for more than 15 minutes.

New sensible and emerging loads - Data Center (DC)

Challenges and new way of planning for TSO



Data Center Impact

In **Italy**, Terna has received over **300 applications** for **55 GW**, with forecasted demand of **11 TWh by 2030 (≈3% of total)**. In the **US**, data centers could reach up to **12%** of total demand by **2028**, growing **~4% per year**.

Electric Characteristic

Inverter-based resources characterized by **fast ramping** and high **variability.**

System Stability Risks

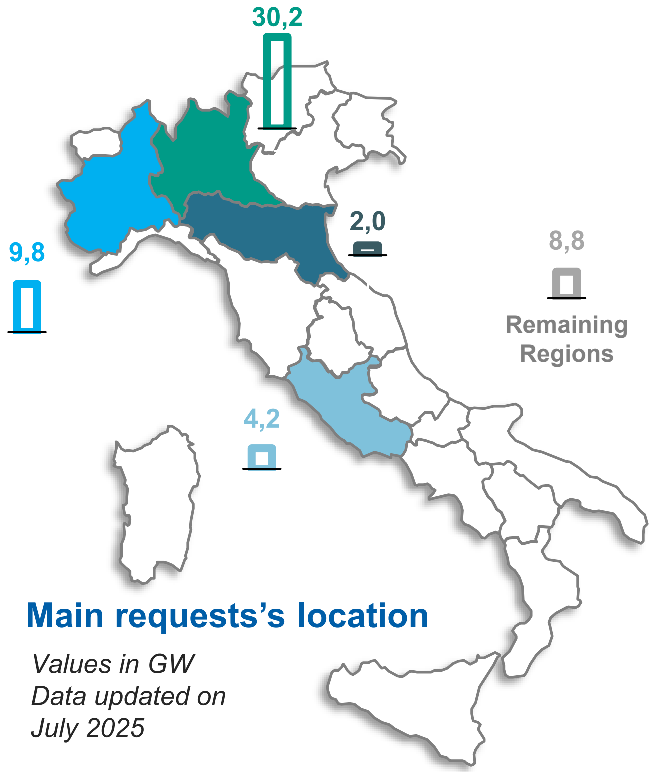
Frequency and voltage instability may arise in response to active and reactive power absorption causing **sub-synchronous oscillations**. Insufficient ride-through capability.

Planning and Forecasting Challenges

Impact on **long-term planning** and **operational reserve management**. Lack of accurate dynamic models complicate demand forecasting and **infrastructure design**.

Impact on Load-Shedding and Blackstart

It is essential to integrate data centers into **load-shedding** and **blackstart programs**, considering their internal segmentation and demand variability.



Main requests's location

Values in GW
Data updated on July 2025

Developing specific load models, updating connection and planning procedures, equip with storage to deal with peak consumption and provide stability services can help data center integration[1,2]

1. *«Whitepaper Characteristics and Risks of Emerging Large Loads, NERC (North American Electric Reliability Corporation), July 2025.*
2. *«Power Stabilization for AI Training Datacenters", Microsoft, OpenAI, NVIDIA, August 2025*

Enablers of the Energy Transition

National Development Plan 2025 and the Hypergrid Project

Enrico Maria Carlini – 16 October 2025

2025 National Development Plan

NDP in numbers

INVESTMENT PLAN

Over €23 billion

in the 2025–2034 decade and over €40 billion considering the full lifetime value of the projects

(+10% vs 2023 Development Plan)

GREATER RENEWABLE INTEGRATION

at least **+65 GW by 2030**

+94 GW by 2035[1]

(In line with the PNIEC and the 2024 Scenario Description Document)

CO_2 EMISSIONS REDUCTION

up to approximately **2,000 kt/year** by **2030**

and nearly **12,100 kt/year** by **2040** *(+2.5% vs 2023 Development Plan))*

INCREASE IN TRANSMISSION CAPACITY

from the current 16 GW

to approximately **39 GW**

(+22% vs 2023 Development Plan)

INCREASE IN CROSS-BORDER CAPACITY

by around **40%**

compared to current levels[2]

AVOIDED LOSSES

of approximately

0.4–1 TWh/year

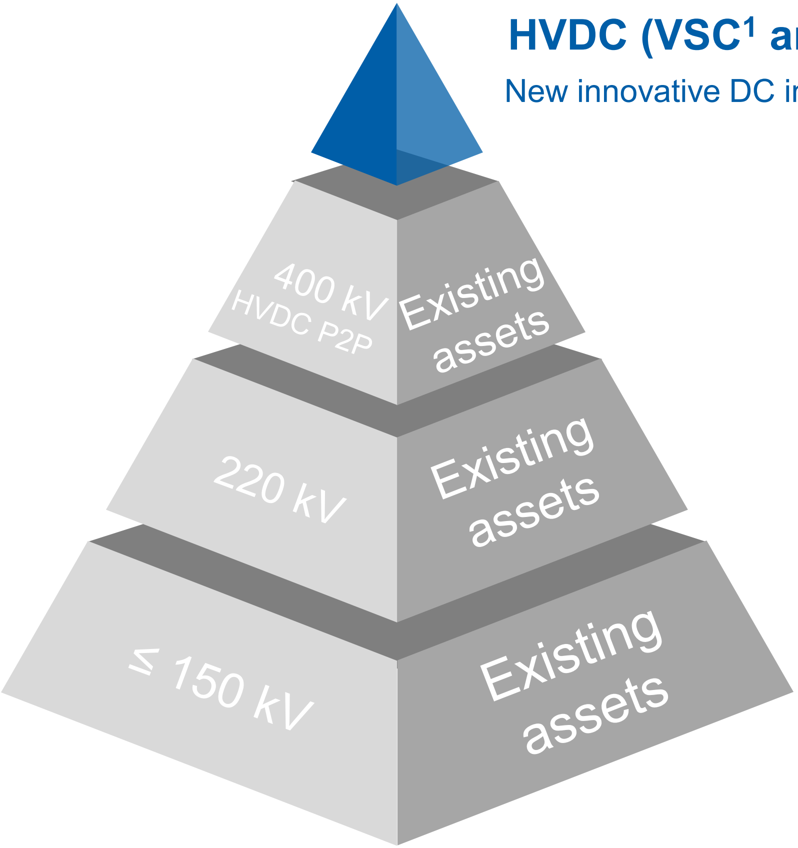
For power system expertise

1. *Of which +43 GW to be connected to the high-voltage grid*
2. *Considering all projects included in the Development Plan, including those beyond the ten-year horizon*

2025 National Development Plan

Guidelines in the planning process: Hypergrid and HVDC projects

Technological Solutions



HVDC (VSC[1] and MTDC[2])

New innovative DC infrastructures

Choice and motivation

WHY HVDC PROJECTS?

1. Greater transport capacity
2. Reduction in terms of EM field
3. Decoupling of AC and DC networks
4. Greater flexibility and flow management
5. Reliability with bipolar configuration in terms of N-1 conditions
6. System Strength services as voltage regulation and system stability
7. Technologies better integrated in an Inverter-based power system.

Development and integration **of Innovative Grid Infrastructures** able to increase **Net Transfer Capacity** among bidding zones and support the **energy transition** process towards an inverter-based dominated system.

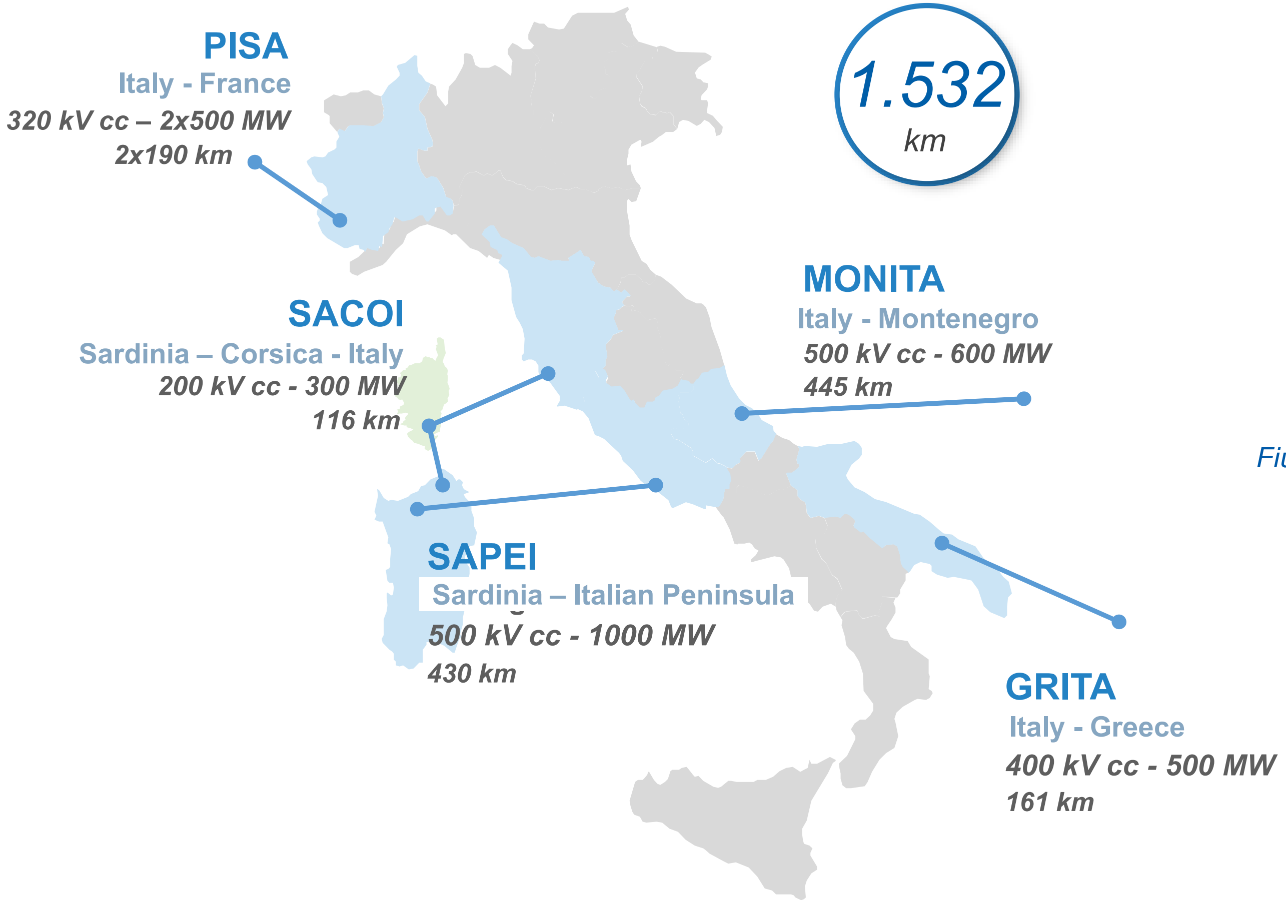
For power system expertise

1. *Voltage Source Converters*
2. *Multi-terminal Direct Current*

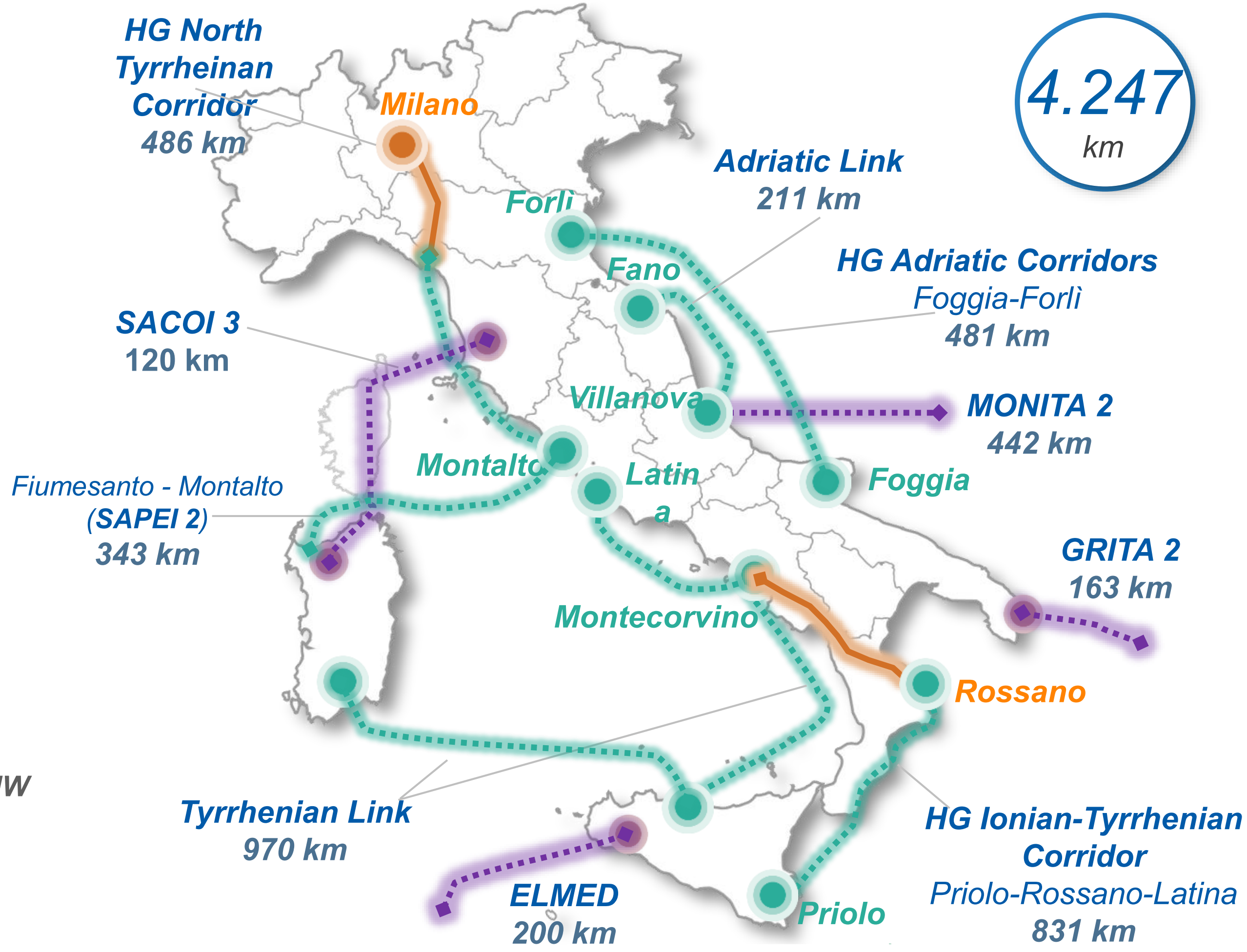
Grid developments towards the energy transition

HVDC links in Italy

HVDC links in operation



Planned HVDC links



5 HVDC links are in operation. Other **5 links** (including the so called **Hypergrid Projects**) **are in permitting or under construction**

Interconnections | Submarine HVDC | AC/DC refurbishment | AC upgrade

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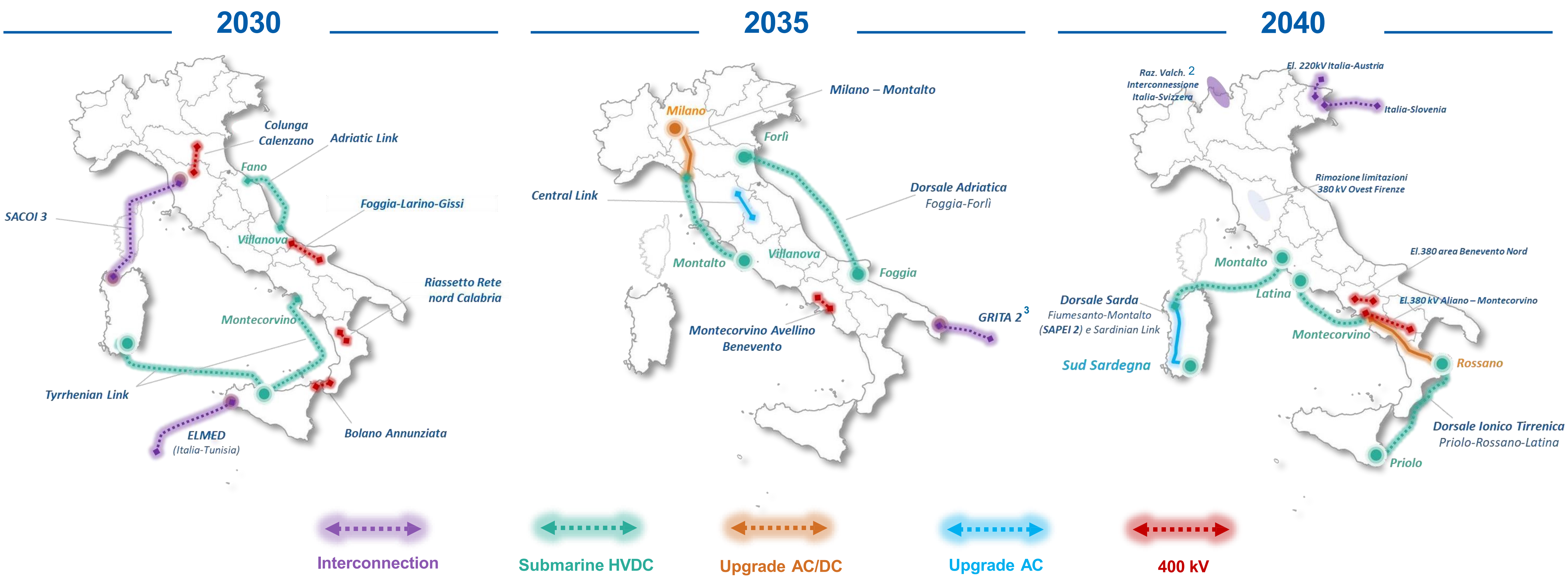
Developing the infrastructure of the future

Main interzonal projects and interconnections with foreign countries



1. Possibility of bringing forward the complete project within the 2025-2034 planning horizon is under evaluation.
2. The network scheme of the project is under further analysis with the TSO counterpart Swissgrid to identify the most suitable solutions to implement
3. GR.ITA.2 First pole: +500 MW by 2033 GR.ITA.2 Second pole: +500 MW by 2035

System needs and key features of NDP 2025

Main technological innovations for HVDC and Hypergrid projects

The realization of the Hypergrid project led to engineer new innovative solutions. Various studies and technological insights were conducted, especially in the field of towers to be used for the new overhead power lines.

› **± 525 kV HVDC VSC Converter Stations**

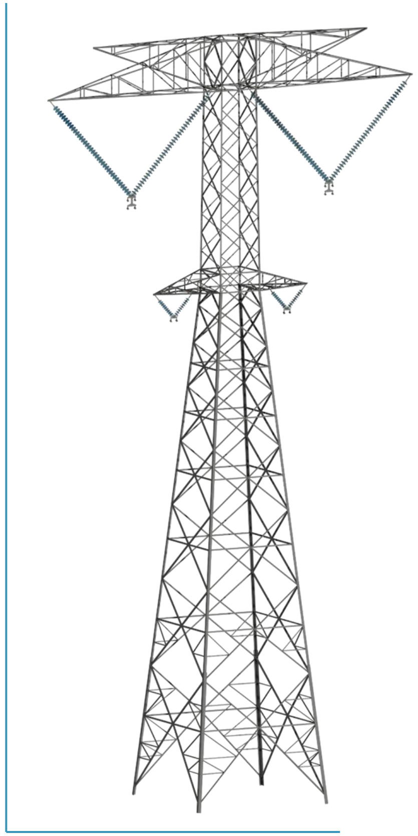
New **VSC Converter Stations** planned by Terna increase **system stability** and **flexibility** managing power flows thanks to **active-reactive decoupling** control and **STATCOM** behaviour to enhance voltage control and system strength.

Rendering VSC Converter Station

› **±525 kV HVDC Towers**

Newly planned interventions in the NDP include the **upgrade of AC backbones** (220 or 380 kV) with DC overhead lines with a voltage of up to ±525 kV, characterized by a high transport capacity over long distances.

This required the engineering of a new family of towers, whose design and engineering are based on **sustainability, minimization of visual interaction, static fields and acoustic noise**.



HVDC towers up to ±525 kV

Advanced technology to enable large integration of RES

Inverter-based and synchronous compensators

Mapping of reactive power damping devises

Terna’s investment plan

CONSTRAINTS

- Voltage damping during last 5 years has led ecoomic outcomes, particularly during low load hours
- Most expensive cluster in terms of Ancillary Services are **Brindisi, Foggia, Campania, Calabria e Lazio**

REGULATION DEVICES

Starting from 2017 Security Plan, a compensation plan has been identified and is being progressively strengthened:

- **Reactors**: static devices for reactive power compensation
- **Synchronous condensers**: rotating machines used to regulate the voltage on a grid node through absorption/delivery of reactive power and provide frequency regulation with inertia
- **STATCOM:** Static devices that, by modulating the amplitude of the internal voltage source, regulate the voltage on a grid node through the absorption or supply of reactive power
- **Damping Resistor System:** Damping resistor are devices that provide dynamic stability and damping of grid oscillations and can be used in restart strategies, allowing the mitigation of disturbances from renewable sources

MARKET BENEFITS

> Ancillary Services Costs reduction due to less Power Units committed

ELECTRIC BENEFITS

> Inertia, Rate of Change of Frequency (RoCoF)
> Short-circuit Power
> Voltage regulationd and reactive reserve
> Power System Stabilizer

Synchronous condensers

27

- 16 in operation
- 7 between ’24-’28
- 4 post ‘28

Reactors

26

- 11 in operation
- 15 between ’24-’28

STATCOM

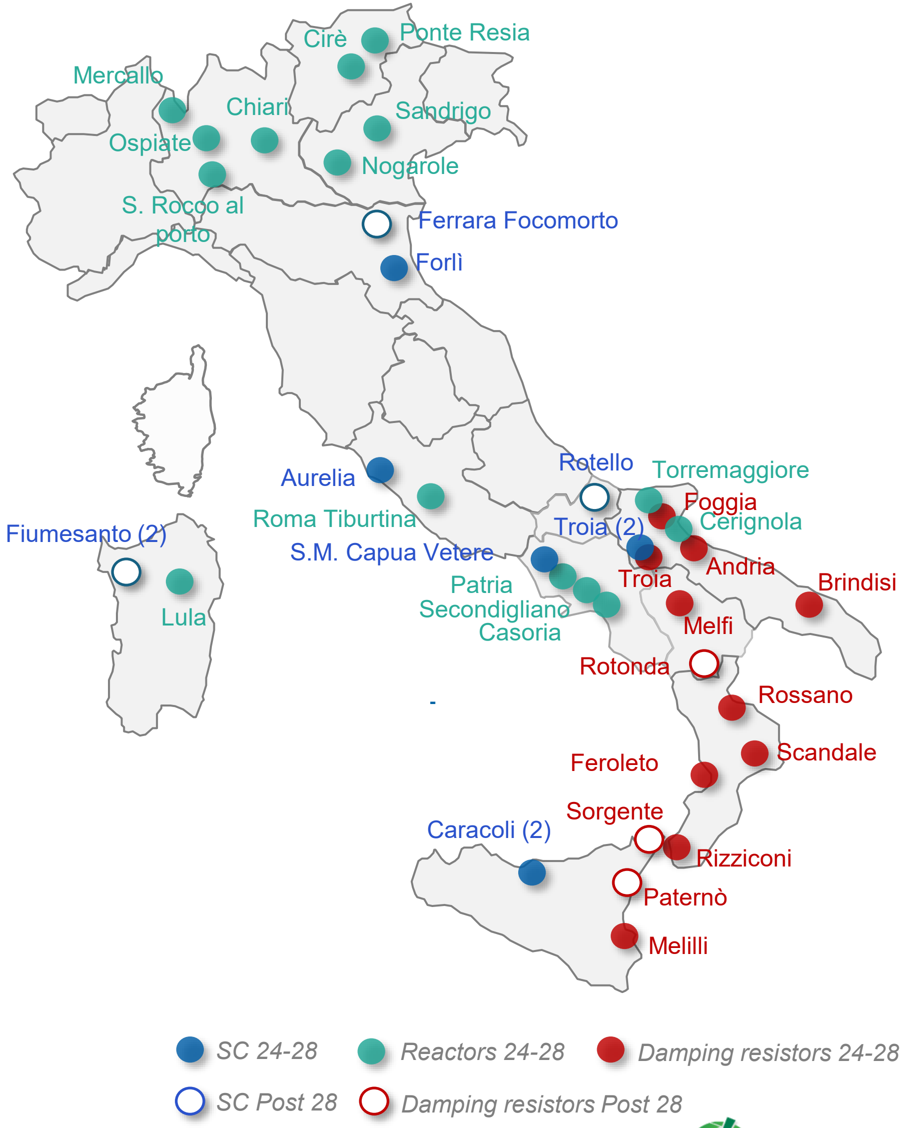
5

- 5 in operation

Damping Resistor

25

- 10 between il ’24-’28
- 15 post ‘28



Energy Framework

Synchronous condensers for grid services

01 Voltage Regulation

Synchronous condenser (or rotating condensers) are rotating machines that allow voltage regulation at a grid node by absorbing or supplying reactive power, which is controlled through the excitation system current

02 Frequency regulation

With the addition of a mechanical flywheel, synchronous compensators are able to dump frequency variations, providing increased inertia and system stability (reducing both the amplitude of oscillations and their rate of change — RoCoF).

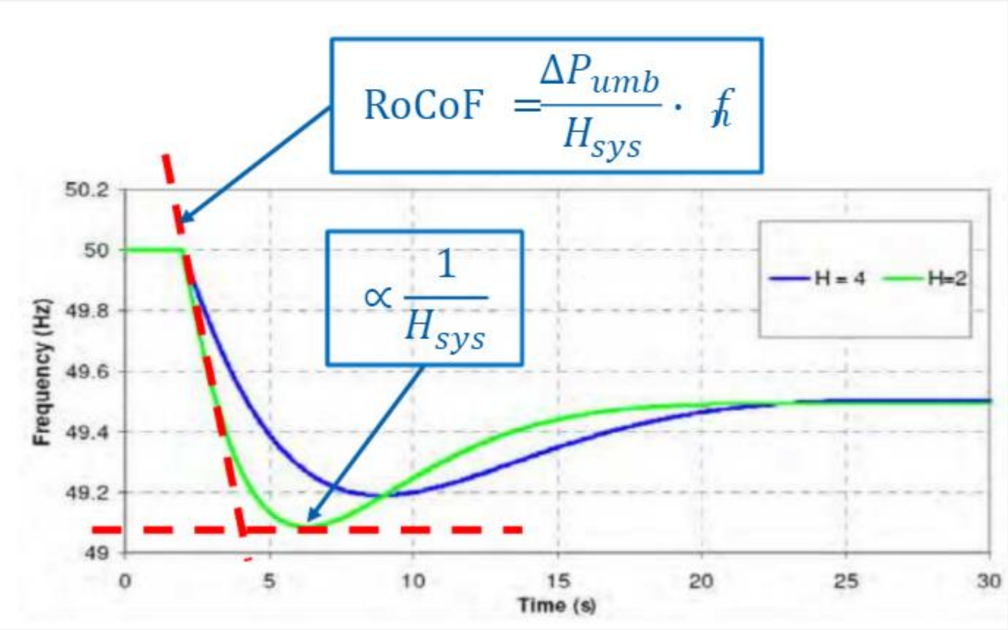
03 Short circuit power

Synchronous compensators deliver a short-circuit power level comparable to that of a conventional thermal power plant, ensuring proper operation of protection systems and improved power quality.

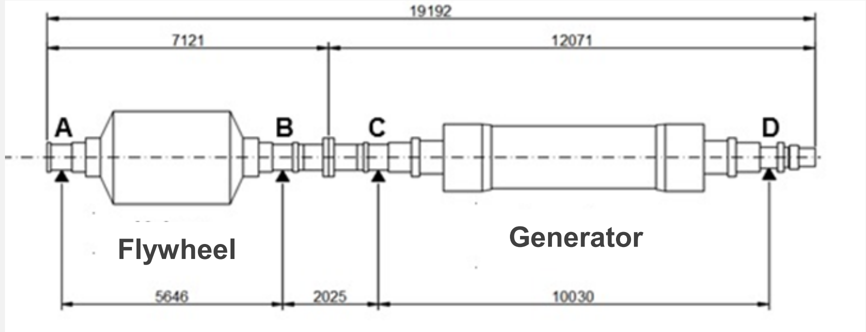
04 Restoration Phase

During grid restoration phases, they can enhance reactive power margins (voltage profile), support the fast re-energization of HVDC links, and accelerate the restoration of loads

Rate of Change of Frequency (RoCoF)



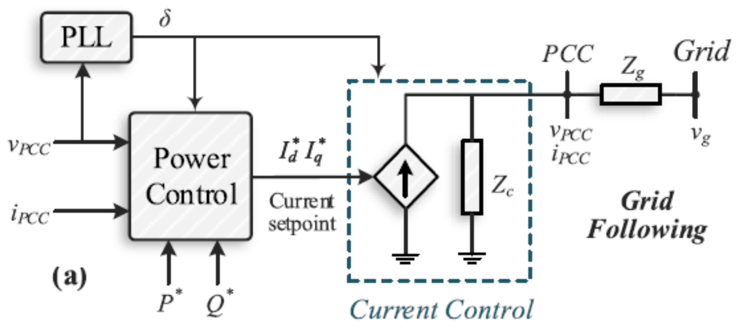
Typical dimension of generator with flywheel



Introduction to Grid Forming technology (GFM)

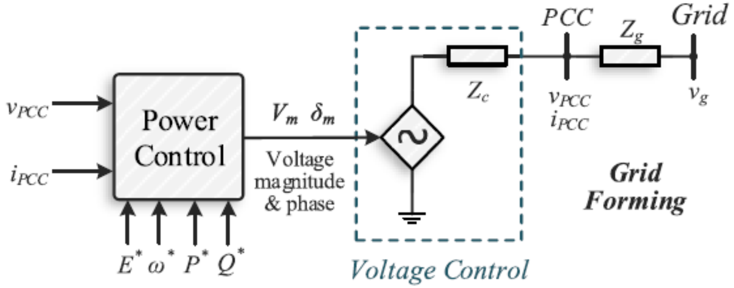
From Grid Following (GFL) to Grid Forming (GFM)

Grid Following Inverter



PLL critical element. Requires a **stable grid** to operate correctly.

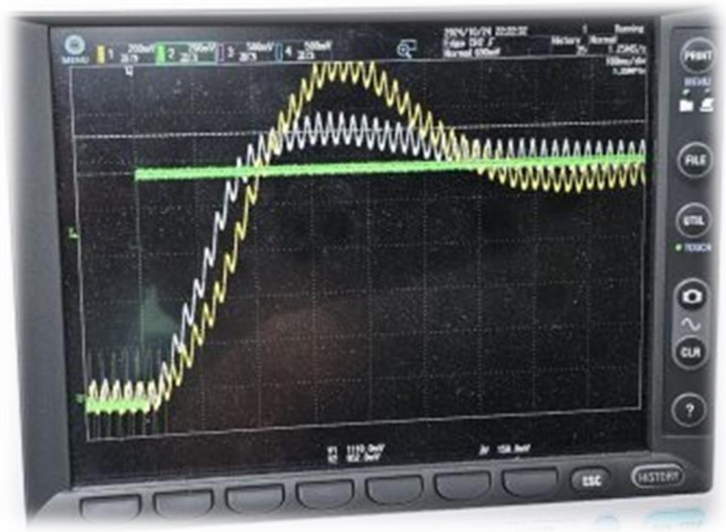
Grid Forming Inverter



- Does **not require a PLL** to be synchronized with the grid.
- It sets Voltage amplitude and frequency according to various logic controls, with lower risks of being affected by **grid disturbances**.

Terna tested GFM technology at the Storage Lab in Codrongianos, Sardinia, confirming its stable operation through various tests among **P-Q control**, **frequency response**, **short-circuit**, **black start.** The trial provided **valuable insights**, to support future technical and regulatory developments, ensuring a **reliable and efficient** National Electric System in a renewables-based future.

Power Step GFM response in VSM (Virtual Synchronous Machine) control with two different value of inertia H (*Codrongianos Storage Lab test*).



Conclusions

Towards a secure, resilient and carbon-neutral power system

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Enabling Factors For The Energy Transition in the electricity sector

System requirements

Grid Developments

- ***Increased transport capacity***
- ***Synergy with previous Development Plans***
- *Development of* ***innovative solutions to increase transit limits***

RES Development

- *Targets for 2030:*
  - ***107 GW of wind and solar capacity***
  - ***63% coverage of electricity needs***
  - ***-55% CO_2 emissions***

New storage capacity

- *Targets for 2030:*
  - ***+71.5 GWh*** *of storage capacity (net of existing PS)*
  - *Of which* ***50 GWh*** *new utility-scale storage capacity*

Markets for EU adequacy and integration

- *Revision of capacity market rules for* ***delivery years 2025 to 2028***
- ***Full integration with European balancing markets***

Regulated tools

OUTPUT-BASED REGULATION

CENTRALIZED CFDs

MACSE CENTRALIZED AUCTIONS

CAPACITY MARKET

CM essential to ensure the adequacy of the system

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Thank you
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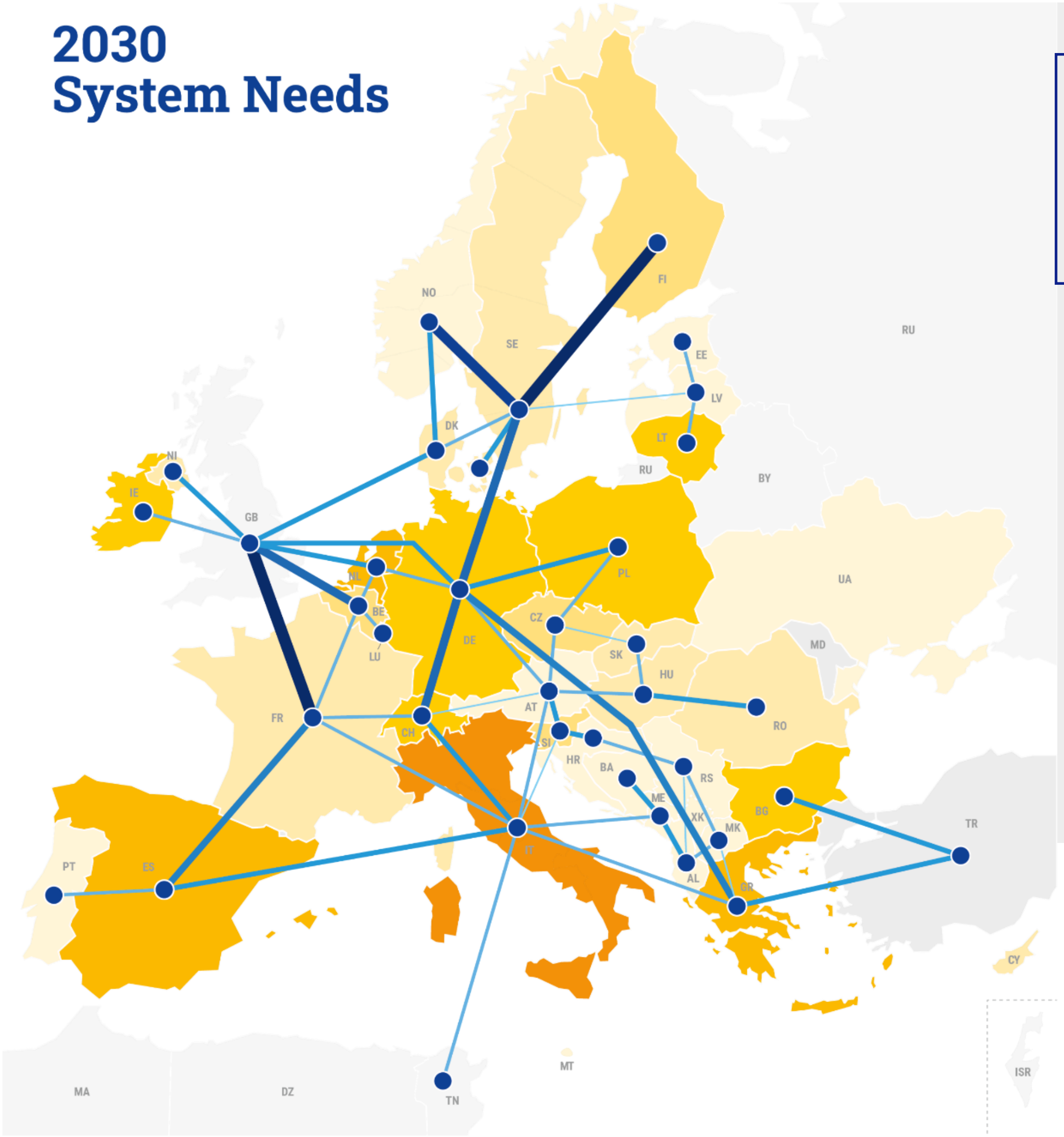
Backup

Infrastructure requirements of the European electric system



— by 2030

ENTSO-E study indicates that, in addition to the **161 GW** of planned cross-border capacity, an additional **88 GW** and **56 GW** of storage capacity would be cost-efficient

Investments

This increase in capacity represents an investment of approximately **5 billion euros** per year.

Benefits

It would result in an annual **socio-economic welfare benefit of 8 billion euros.**

Additional investments in the electricity grid and storage infrastructure could enable Europe to lower system costs and surpass its 2030 objectives

Cross-border capacity increases in 2030 (additional to 2030 starting grid)

- 1 – 500 MW
- 501 – 1,000 MW
- 1,001 – 2,000 MW
- 2,001 – 3,000 MW
- 3,001 – 4,000 MW
- 4,001 – 5,000 MW
- > 5,000 MW

Storage capacities per country in 2030

- 0 – 100 MW
- 101 – 500 MW
- 501 – 1,000 MW
- 1,001 – 5,000 MW
- 5,001 – 10,000 MW
- 10,001 – 20,000 MW
- > 20,000 MW

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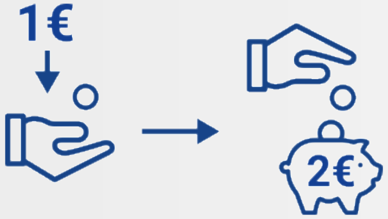
Three key outcomes of the European Development Plan (TYNDP 2024)

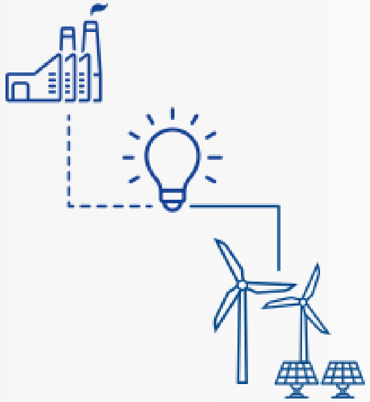
1

By 2040, every euro invested in the power grid will generate more than 2 euros in system cost savings.



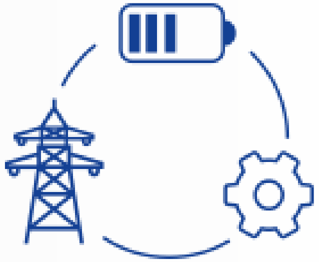
2

The implementation of System Needs helps decrease reliance on carbon-intensive power generation and electricity imports from outside the EU.



3

Current infrastructure projects address only a portion of the identified System Needs. Further initiatives and measures are needed to enable the timely deployment of power grid infrastructure



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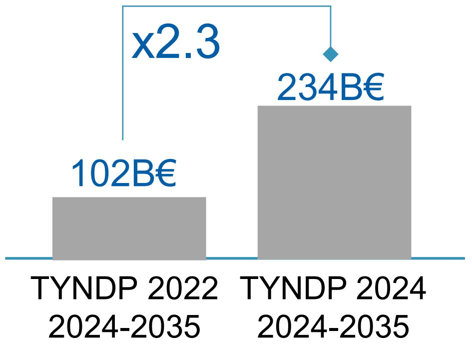
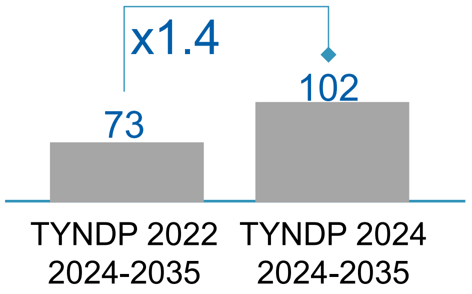
HVDC Systems and Emerging Grid Challenges

EU HVDC Demand (Onshore, Offshore) – European Development Plan TYNDP

Capex - B€



Number of Installations



Source: ENTSOE

- **HVDC transmission solutions** offer the ability to transfer large amounts of energy over long distances, along with electrical functionalities suitable for managing a more advanced and complex transmission system.
- At the **EU level** (source: TYNDP ENTSO-E), there is a strong demand for **HVDC systems** (onshore and offshore), expected to be **10 times higher** than in Terna's **Development Plan 2025** over the next 10 years.
- This demand is further amplified by **global market needs**.

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HVDC Systems and Emerging Grid Challenges

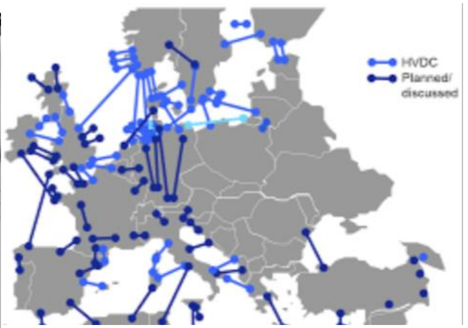
Issues Arising from the Surge in HVDC Demand

Sharp Increase in HVDC Demand – Context

Transmission Networks (HVDC)

Offshore Installations

HVDC Merchant Lines and Grid Interconnectors



Main Criticalities

Cost Volatility

- Risk of high cost variability due to strong HVDC demand and limited supplier availability

Financing Capacity

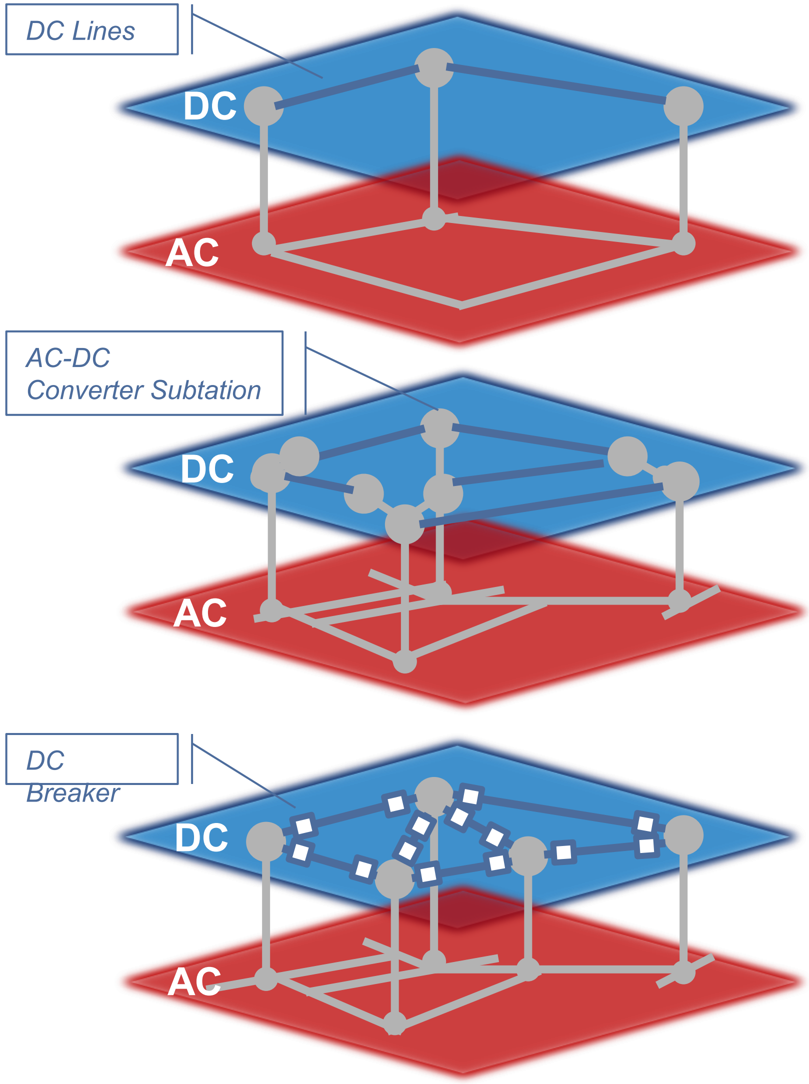
- Growing difficulties in securing funding for Transmission Grid development projects
- Need for access to public financing (e.g., CEF, EIB, NRRP, World Bank, etc.)
- Uncertainty regarding timely access to funding

Realization Timelines

- Saturation of HVDC manufacturing capacity (cables, converter stations) poses a significant risk to delivery timelines and project efficiency

DC Circuit Breaker: new advanced DC technologies

Hypergrid and DCCBs to integrate renewables sources and provide grid services



Multi-terminal HVDC [1]

- **Simple multi-terminal system** with multiple interconnection points (e.g. SA.CO.I.).
- **No meshing** and **no redundancy** in the DC system in the event of a fault.
- **Alternative solution to a single AC line**, as a connection between two asynchronous zones or for interconnecting an offshore wind farm.

Stand-alone HVDC P2P

- **DC point-to-point lines,** where a DC circuit with two Converter Substation is added to the classical transmission line.
- **It may consist of a combination of HVDC LCC and VSC lines,** and different lines may operate at different voltages.
- **It requires more complex flow control** to keep the network frequency stable in the case of isolated or weak AC networks.

DC grid with DC Breakers

- **Fully meshed DC system,** like an AC network. Connections within the DC network are possible **without additional converter substation**.
- **Savings in terms of converter substations number** compared to stand-alone point-to-point HVDC links.
- Only solution that guarantees the appropriate **redundancy** and **selectivity in DC, thanks to DC Circuit breakers**.

[1] *Multi-terminal VSC HVDC for the European supergrid: obstacles – D. V. Hertem, M. Ghandharia – 2010*

Energy Framework

Key legislative and regulatory tools to enable the energy transition.

01 REGULATION

*Evolution towards an **output-based regulation** to stimulate investments (ROSS, Remunerazione per Obiettivi di Spesa e di Servizio)*

02 CENTRALIZED CFDs

*The draft **FERX** decree will provide financial support for 67,2 GW of new RES) – First auction of the FER Transitional mechanism to be held in 2025*

03 CAPACITY MARKET

Now a well-established reality, the 2028 auction will be held after the first MACSE auction

04 MACSE CENTRALIZED AUCTIONS

*Defined fixed-term **contracting mechanism for storage capacity** (MACSE) - First auction September 2025*

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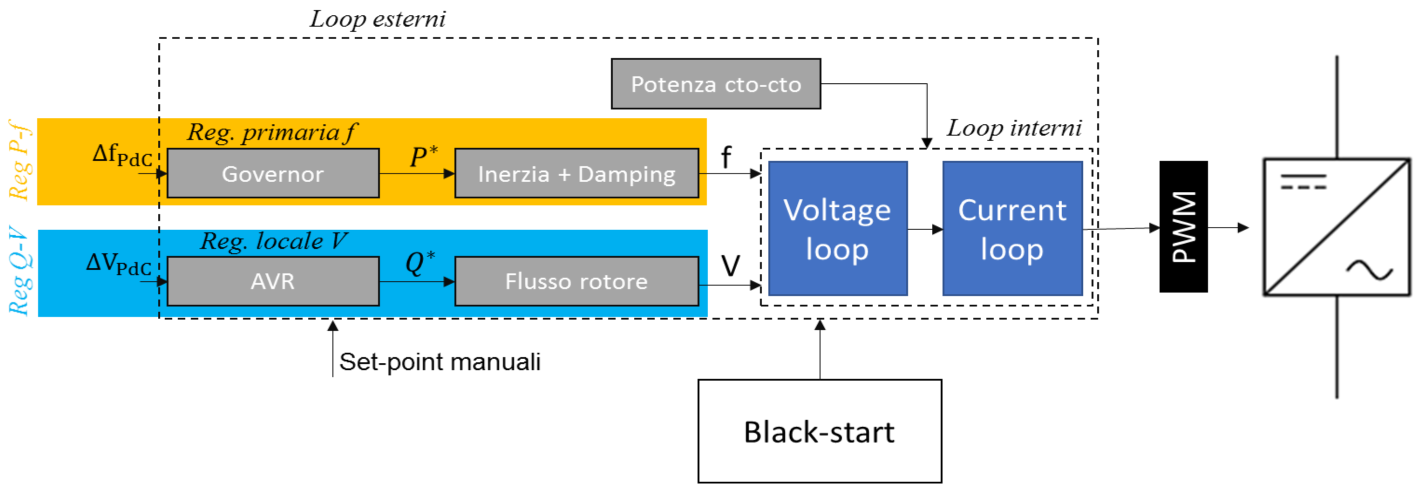
Introduction to the technology of Grid Forming

The Virtual Synchronous Generator (VSG)

Description

A **Virtual Synchronous Generator (VSG)** is a control strategy for power electronic inverters that allows them to mimic the physical properties of a traditional synchronous generator, such as rotational inertia, damping, and synchronizing power. By emulating these characteristics through software, VSGs help stabilize grid frequency and voltage, especially in grids with a high penetration of renewable energy sources that lack inherent inertia.



1 **Voltage source**
The control voltage (amplitude and phase) is equivalent to the no-load electromotive force of the rotating synchronous machine

2 **Inertia**
Emulates the crankshaft slippage

3 **Rotor flux control**
Emulates the armature reaction of the rotating synchronous machine

4 **Governor e AVR**
They emulate the frequency and voltage controls at the plant's power plant with respect to target values

5 **Cto-cto power**
Cto-cto current delivery (within the limits of the inverter overload curve)

6 **Black-start**
Energize the bar and support for local network reactivation

Introduction to Grid Forming technology (GFM)

From Grid Following (GFL) to Grid Forming (GFM)

Current technology: Grid Following

Most grid-connected inverter systems use Grid Following inverters. There are controllers that can regulate P and Q, but with a delay that can limit the stability benefits (inertia, oscillation damping, short-short power).

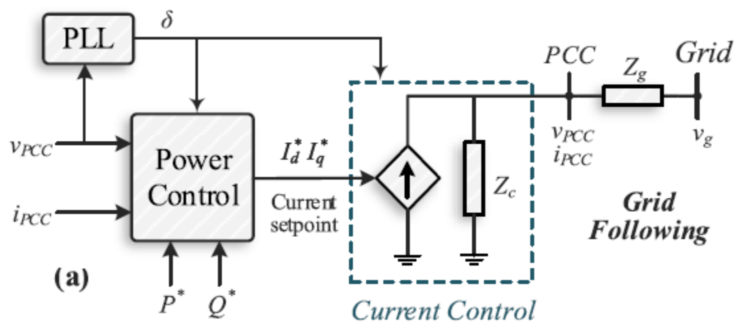
Grid Forming

GFM was created to manage isolated or weak microgrids. In the absence of synchronous machines to maintain frequency, inverter control techniques have been developed that allow batteries to emulate some of the physical behaviors of **synchronous machines**.

Grid Forming to stabilize interconnected networks

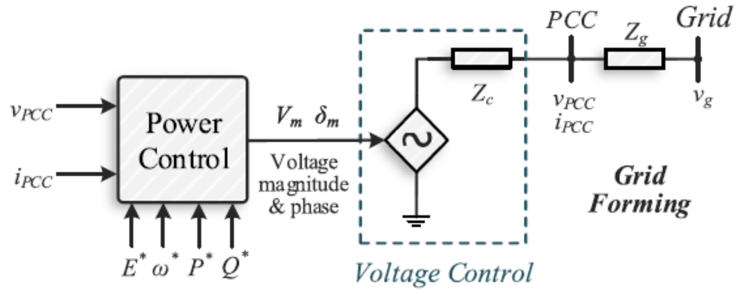
The idea of exploiting the characteristics of GFM machines to provide **grid stability** in light of the progressive reduction in thermoelectric power plants has recently gained ground. The challenge is to enable the safe operation of numerous interconnected Grid Forming systems.

Grid Following Inverter



PLL critical element. Requires a **stable grid** to operate correctly.

Grid Forming Inverter



- Does **not require a PLL** to be synchronized with the grid.
- It sets Voltage amplitude and frequency according to various logic controls, with lower risks of being affected by **grid disturbances**.
- Stable in **weak grids**.

GFM Perspective for TSOs

Why TSO?

Benefits for the grid

The GFM can provide valuable support to grid stability in conditions of high penetration of inverter-based systems, **reducing dependence on traditional fossil fuel plants** and thus CO2 emissions.

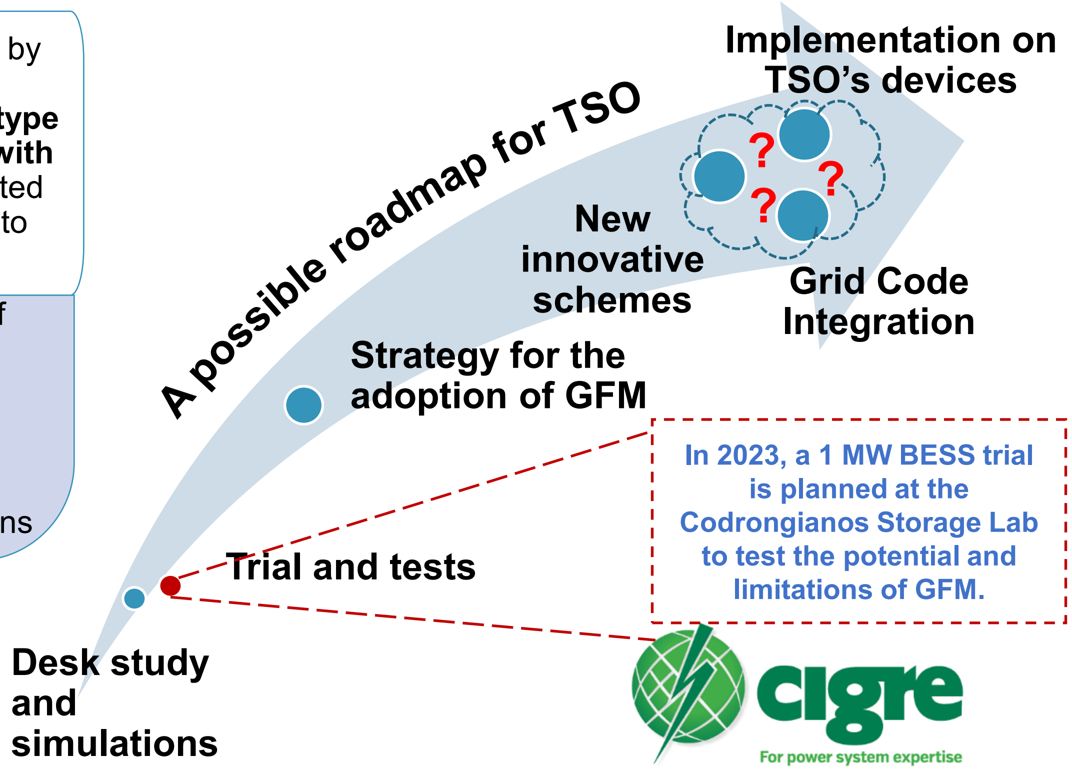
Potential moderate costs

Compared to a GFL system, a GFM system **requires software and control differences with minimal hardware modifications**. Even when compared to a synchronous compensator, the GFM inverter could be the winner because it **is more economical, has virtually no footprint and can be applied to all inverter-based systems** in widespread use nationwide. On the other hand, one must take into account the overload capabilities and energy limits due to the primary source, which are more limiting than those of a synchronous compensator.

Need for strategy and testing to define the adoption

Without a technical, economic and strategic assessment conducted by the TSO and shared with the regulator, it will be difficult for GFM to spread in Italy. The **TSO needs to move quickly to test the prototype features** in order to master the technology, **accelerate its spread with reliable, low-cost market products**, and thus anticipate the expected widespread adoption of inverter-based systems. It is up to the TSO to decide which **strategy to pursue**. Three possible paths are:

- GFM implementation on **devices managed by TSO**
- **Regulatory requirement** as a mandatory requirement for certain types of generators
- Introduction of **incentive schemes** to promote the adoption of technology in future installations



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Conclusions and Future Perspectives for the Italian Electricity System

Energy and Digital Transition

The **energy and digital transition** in Italy requires an extraordinary effort in **planning, implementation, and innovation.**

Greater integration of renewables, with over 65 GW of new capacity by 2030 and 94 GW by 2035.

More robust and flexible grids, enabled by solutions such as HVDC, synchronous compensators, energy storage systems, and new voltage and frequency management strategies.

Reduction of CO_2 emissions, enhanced efficiency, and improved security of the power system.

Alongside technical aspects, it is essential to have long-term financial **instruments to attract investments** and reduce uncertainty.

Capacity markets, MACSE, and FER X contracts help stabilize revenues and support projects with high capital requirements.

The combination of effective regulation and innovative financial tools will enable addressing price volatility, promoting economic sustainability, and achieving decarbonization goals.

Financial Instruments

The integration of advanced technological solutions and appropriate financial mechanisms represents the strategic lever to build a secure, resilient, and carbon-neutral power system

It’s time for Q&A

Moderator : Pierre Coudereau

It’s time for Coffee Break

Retour 11:00

CIGRE France Conference

GB energy strategy and transmission evolution

Mark Waldron, National Grid Electricity Distribution

For power system expertise

Bâtiment Gaston Berger - INSA Lyon
16 octobre 2025

National Grid Electricity Transmission

- In the UK, National Grid **develop, own and maintain** the electricity transmission network across England and Wales.
- We transfer electricity generated from windfarms and other power sources to transport it across our network of **pylons, cables, overhead lines and substations**
- We move electricity around the country, helping heat and power homes and businesses along with connecting communities to the energy they need.

GB Electricity Transmission Owners (adapted from Ofgem)

In Britain, the System Operator is separate from the Transmission Owners (TOs). The National Energy System Operator (NESO) directs how electricity flows, while TOs develop, own and maintain the network

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System Operator

NESO
National Energy System Operator

- NESO is the independent public body responsible for operating and planning the electricity and gas systems in Great Britain.
- It was established in October 2024 when it separated from National Grid plc and became publicly owned, but operationally independent from government and industry.
- Full operational separation requires that the two entities – NESO and NGET – no longer share control systems, infrastructure, or facilities.
- The role of the system operator includes:
  - **Real-time system operation:** Balancing electricity supply and demand every second to maintain grid stability.
  - **Strategic planning:** Developing long-term plans for infrastructure to support net zero goals.
  - **Coordination:** Managing the queue of new electricity projects and advising government and Ofgem on energy policy.
  - **Market facilitation:** Supporting competition and innovation in energy markets.

NESO is like the air traffic controller of the energy system – ensuring everything flows smoothly, safely, and efficiently, but not owning the planes (infrastructure).

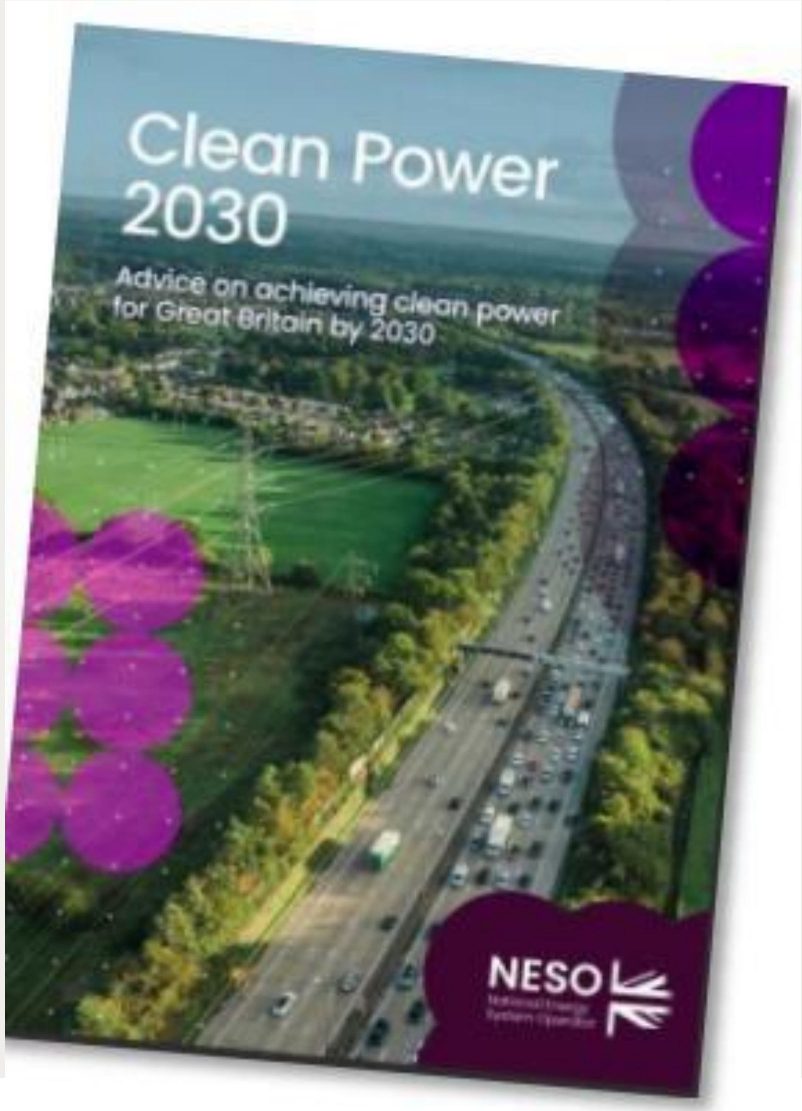
Transmission Owners

nationalgrid ScottishPower Scottish & Southern Electricity Networks

- Transmission Owners (Tos) own and maintain the physical infrastructure of the high-voltage electricity transmission network – such as the cables, pylons, and substations.
- In England and Wales this role is held by National Grid, while Scottish Power Transmission and SSEN Transmission operate in Scotland
- The role of the Transmission Owner includes:
  - **Asset management:** Building, maintaining, and upgrading transmission infrastructure.
  - **Network reliability:** Ensuring the physical network is robust and capable of delivering electricity across regions.
  - **Coordination with NESO:** TOs work with NESO to ensure infrastructure supports system needs and future planning

TOs owns, builds and maintains Electricity Transmission assets.
Provides Transmission Services to the System Operator by making available its Transmission Systems. Manages operational switching, system access, faults, alarms and safety.

NESO concludes that Clean Power for Great Britain by 2030 is achievable



"I think it's an incredibly stretching target,". "If it went perfectly along current regimes, it wouldn't get there. So, it needs to go perfectly along reformed regimes."
Alice Delahunty, President of Electricity Transmission, National Grid

1 **Cost Neutral**
NESO's report suggests that achieving clean power by 2030 will be cost neutral for consumers.

2 **Distribution Networks**
The distribution networks will play a critical role in the deployment of renewable generation

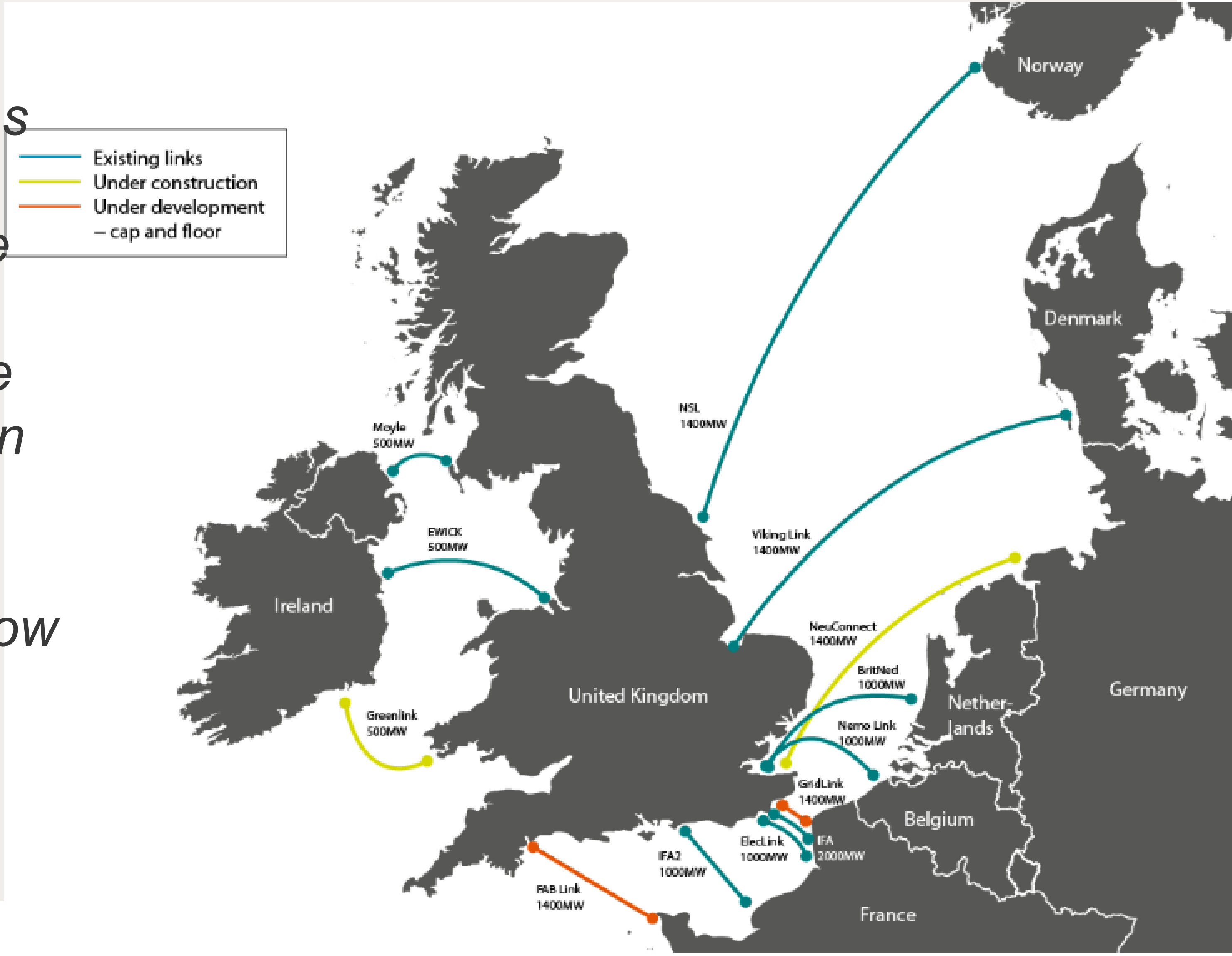
3 **Cross-Cutting Enablers**
Clean power will only be achieved by 2030 by taking different actions, with 6 key cross-cutting enablers identified in the report.

4 **Interconnection Growth**
The CP2030 report supports the growth of interconnection, enabling more flexible and resilient energy systems.

5 **Transmission Expansion**
Current plans for transmission expansion are sufficient, but some acceleration may be required.

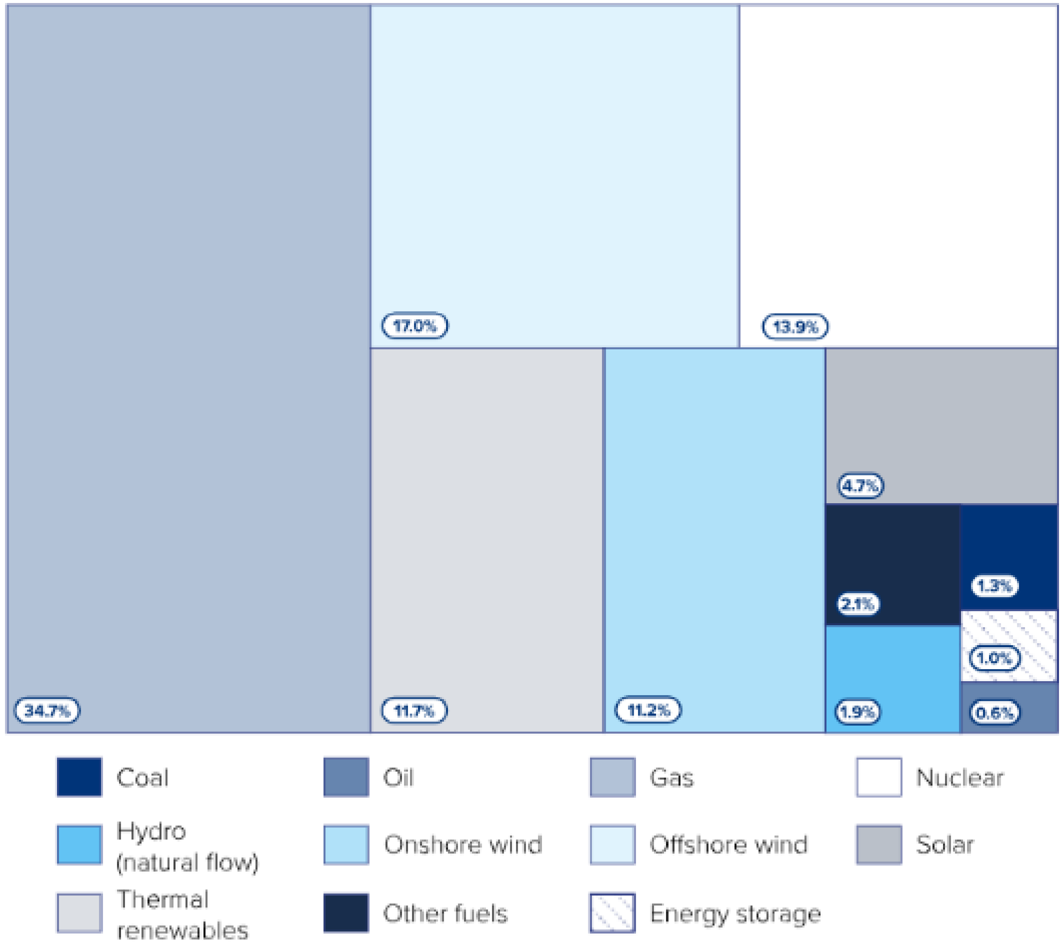
Clean Power 2030 definition

"In a typical weather year, the 2030 power system will see clean sources produce at least as much power as Great Britain consumes in total over the whole year, and at least 95% of Great Britain's generation; reducing the carbon intensity of our generation from 171gCO_2e/kWh [grams of carbon dioxide equivalent per kilowatt hour] in 2023 to well below 50gCO_2e/kWh in 2030"



Generation evolution

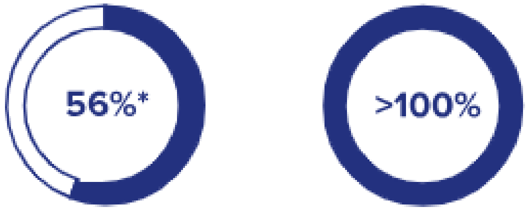
Figure 1: Shares of electricity generated (GWh), 2023



Metrics

Clean sources produce at least as much power as Great Britain consumes in total.

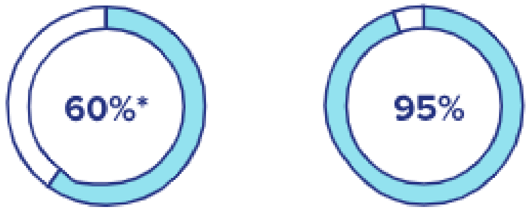
2023 | 2030 Clean Power



▼ 44 points below target

Clean sources produce at least 95% of Great Britain's generation.

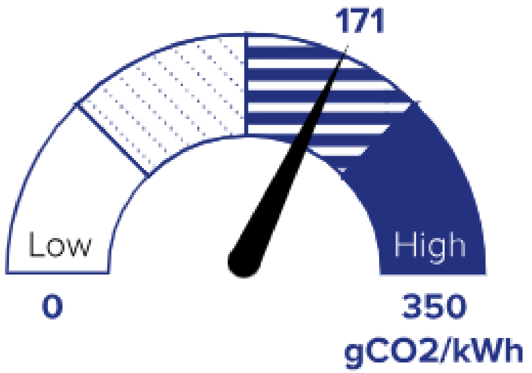
2023 | 2030 Clean Power



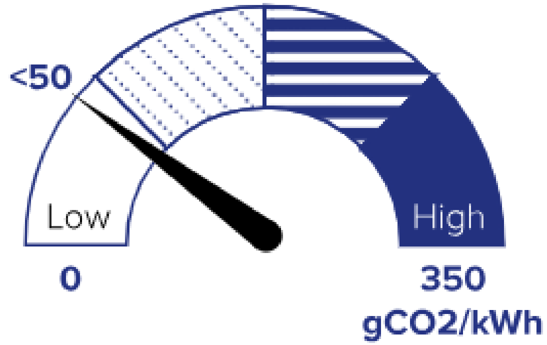
▽ 35 points below target

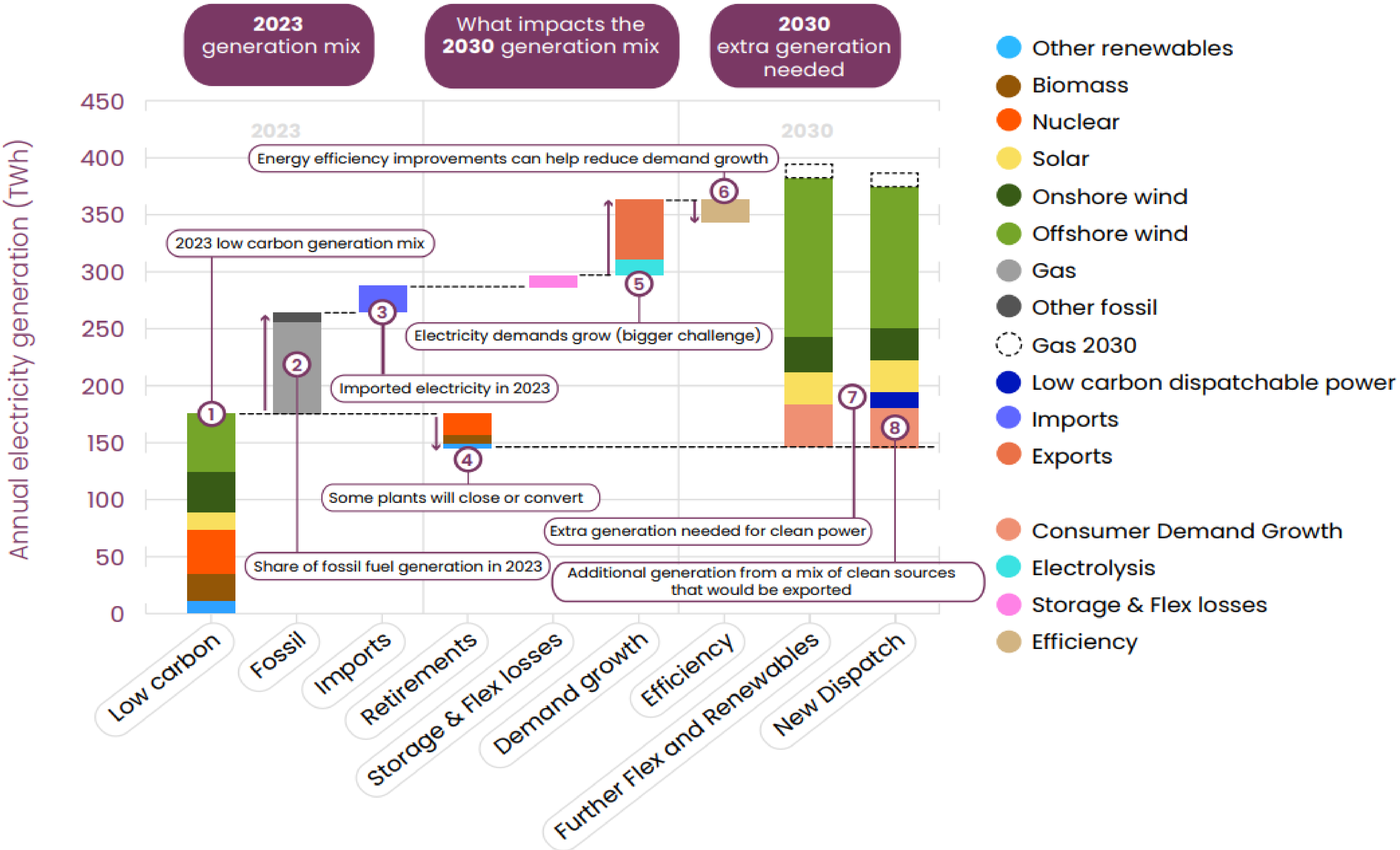
Emissions intensity of well below 50gCO2e/kWh by 2030

2023



2030 Clean Power





2023 generation mix
What impacts the 2030 generation mix
2030 extra generation needed
Annual electricity generation (TWh)
450
400
350
300
250
200
150
100
50
0
2023
2030
Energy efficiency improvements can help reduce demand growth
2023 low carbon generation mix
Electricity demands grow (bigger challenge)
Imported electricity in 2023
Some plants will close or convert
Extra generation needed for clean power
Share of fossil fuel generation in 2023
Additional generation from a mix of clean sources that would be exported
Low carbon
Fossil
Imports
Retirements
Storage & Flex losses
Demand growth
Efficiency
Further Flex and Renewables
New Dispatch
Other renewables
Biomass
Nuclear
Solar
Onshore wind
Offshore wind
Gas
Other fossil
Gas 2030
Low carbon dispatchable power
Imports
Exports
Consumer Demand Growth
Electrolysis
Storage & Flex losses
Efficiency

Figure 7: Generation in 2030 in the NESO 'Further Flex and Renewables' and 'New Dispatch' scenarios, compared to current generation (TWh)

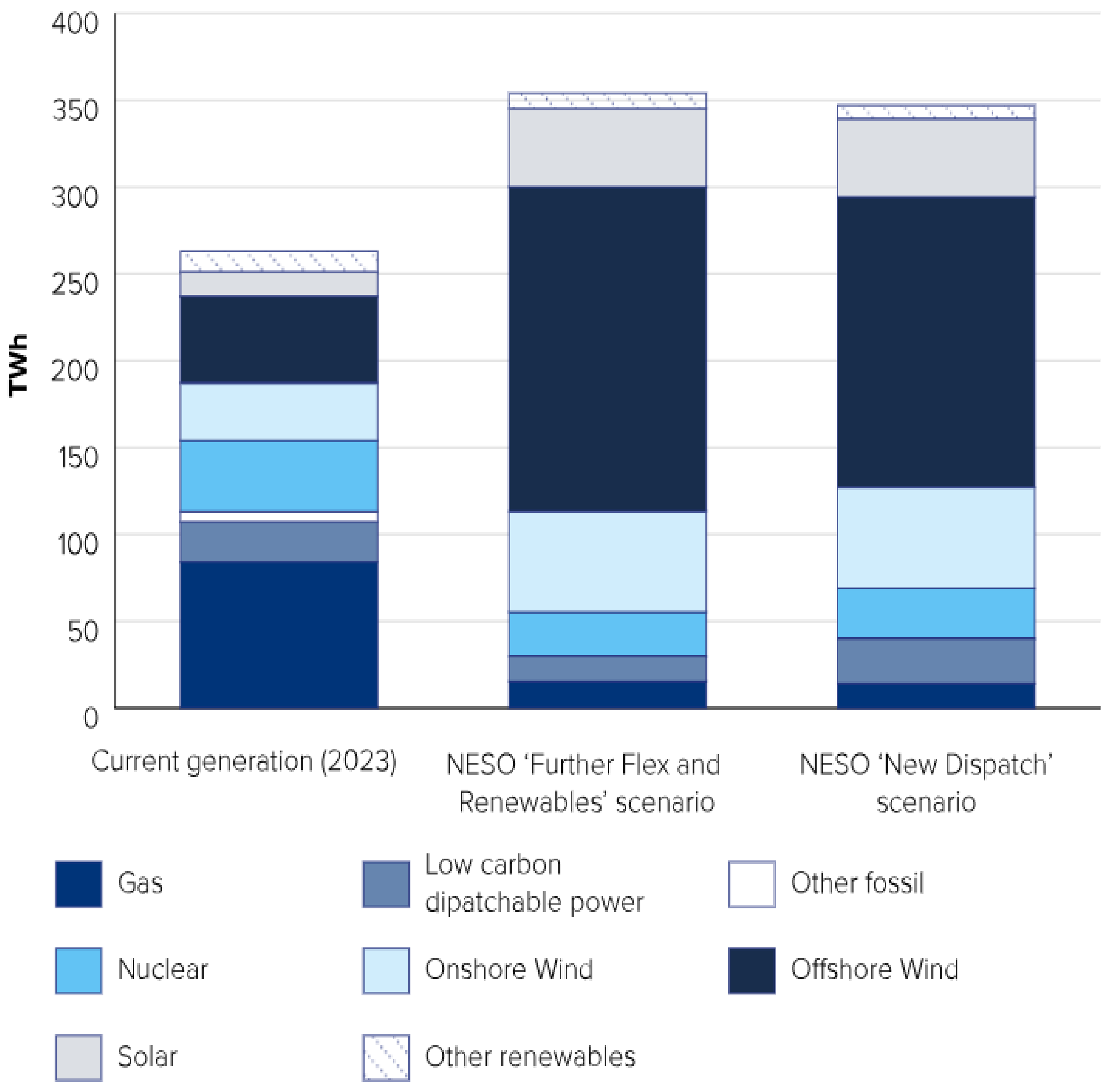


Figure 6: Installed capacity in 2030 in the NESO 'Further Flex and Renewables' and 'New Dispatch' scenarios, compared to current installed capacity (GW)

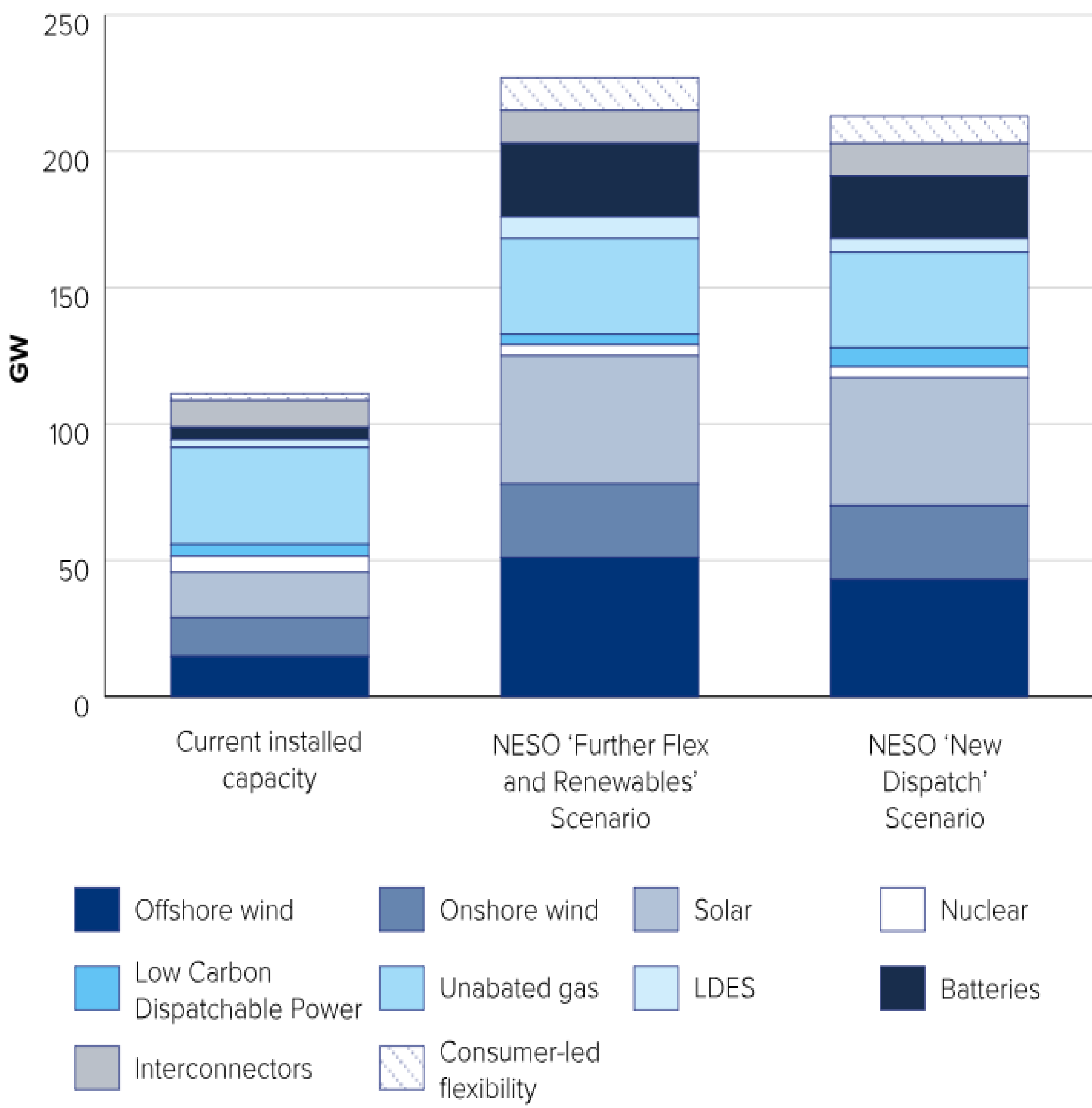
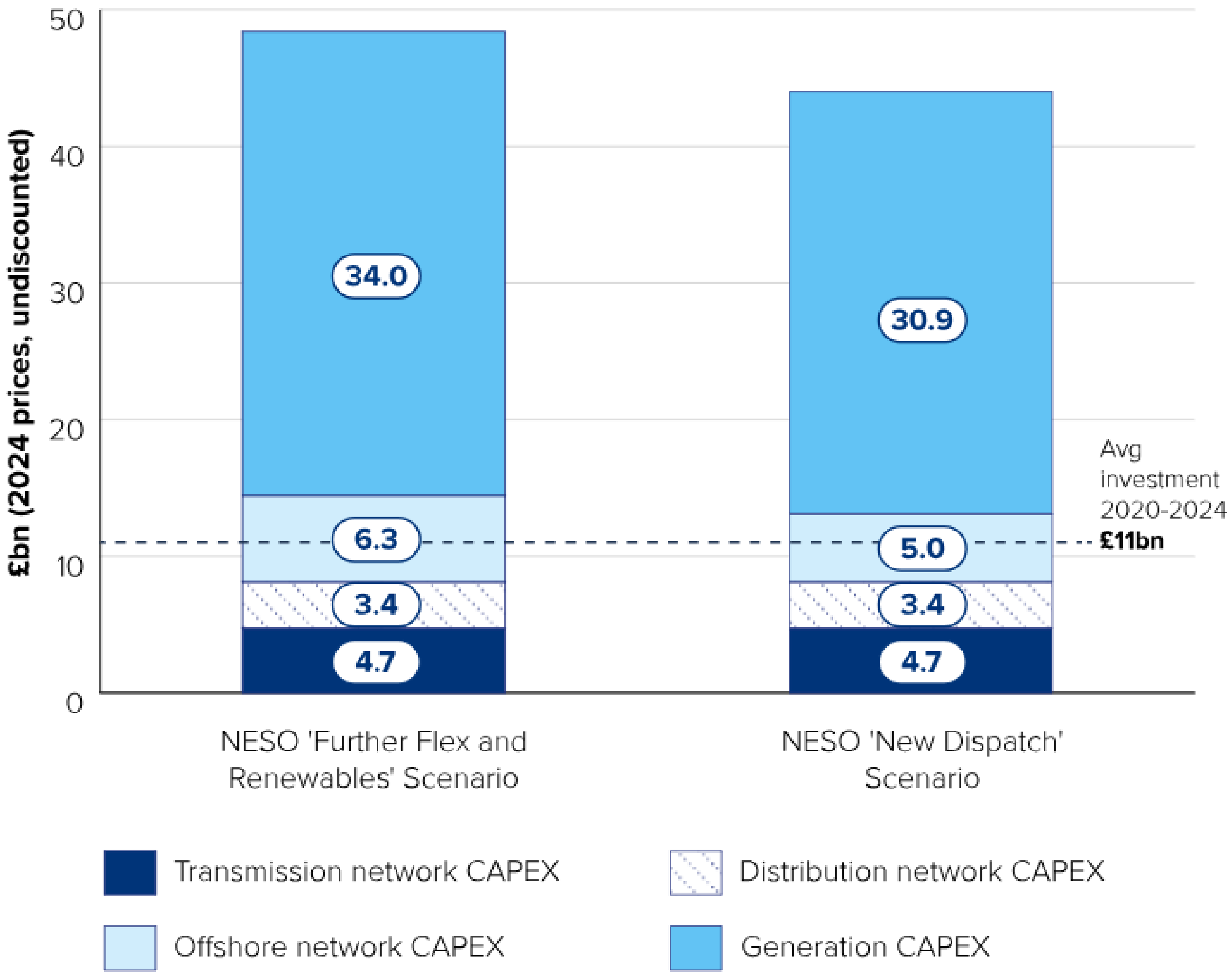
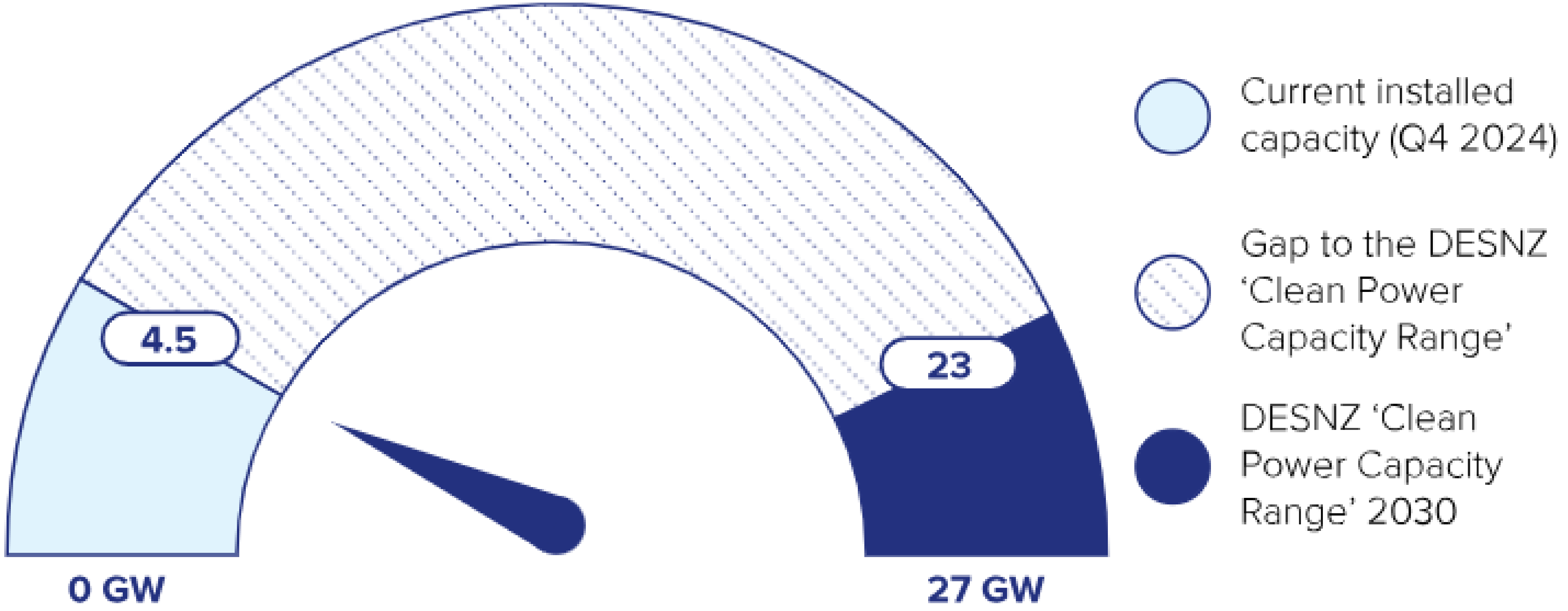


Figure 9: Average annual investment in the NESO 'Further Flex and Renewables' and 'New Dispatch' scenarios, 2025-2030, £ billions, 2024 prices, undiscounted



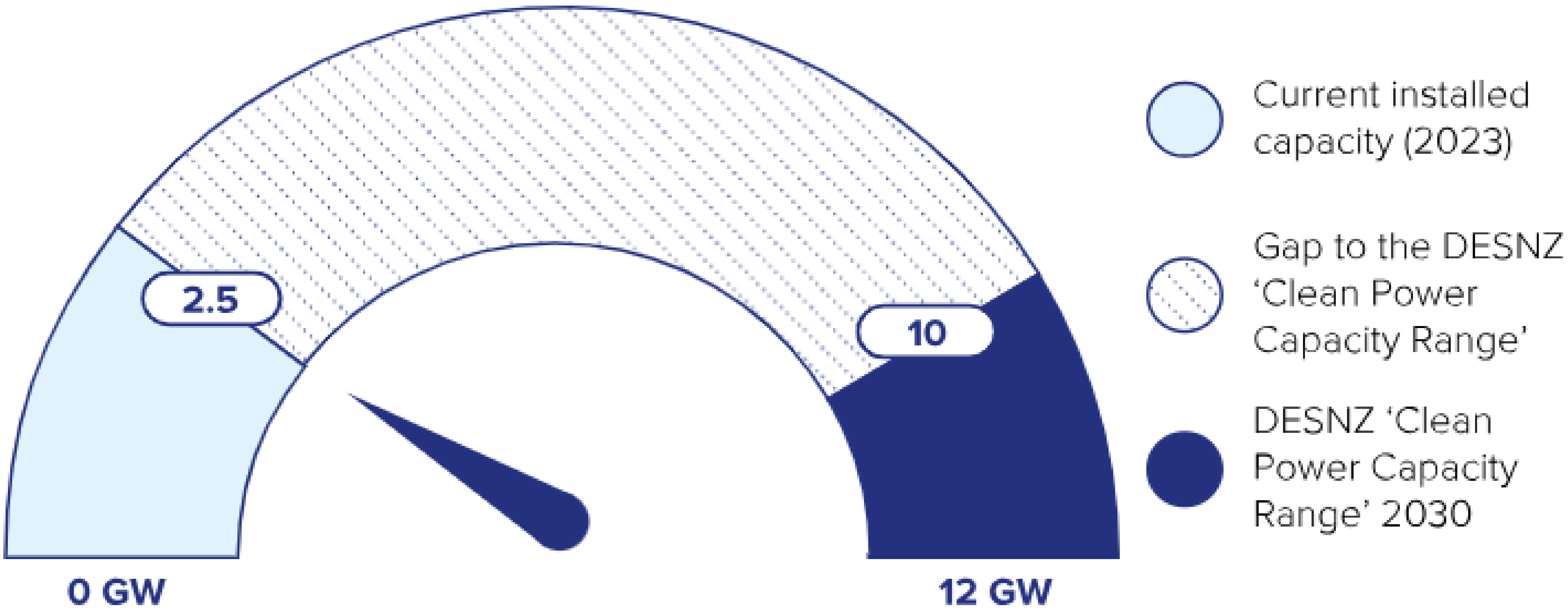
Battery Storage

Current installed capacity compared to the DESNZ 'Clean Power Capacity Range' in 2030 (GW)



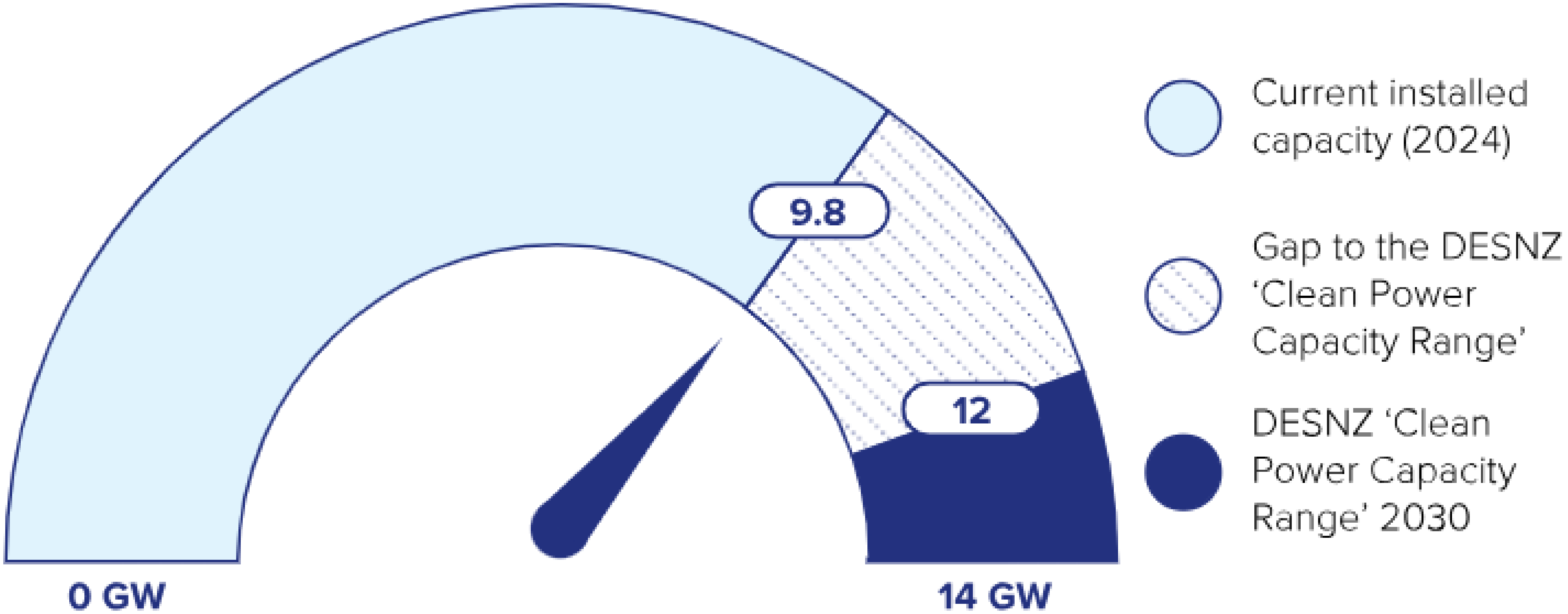
Consumer-led Flexibility

Current installed capacity compared to the DESNZ 'Clean Power Capacity Range' in 2030 (GW)

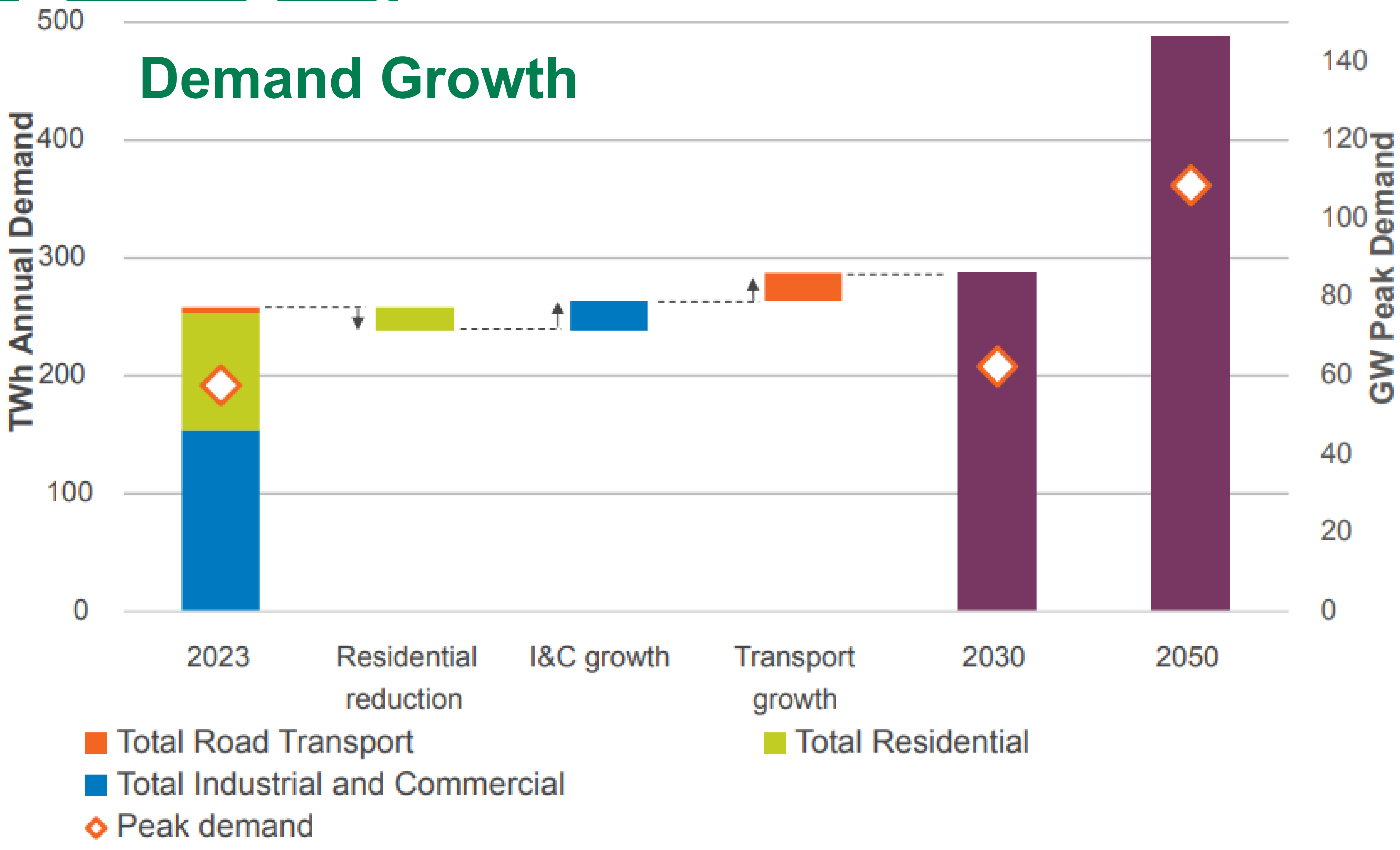


Electricity Interconnection

Current installed capacity compared to the DESNZ 'Clean Power Capacity Range' in 2030 (GW)



Demand Growth



Demand side flexibility capacity at peak; further flex and renewables

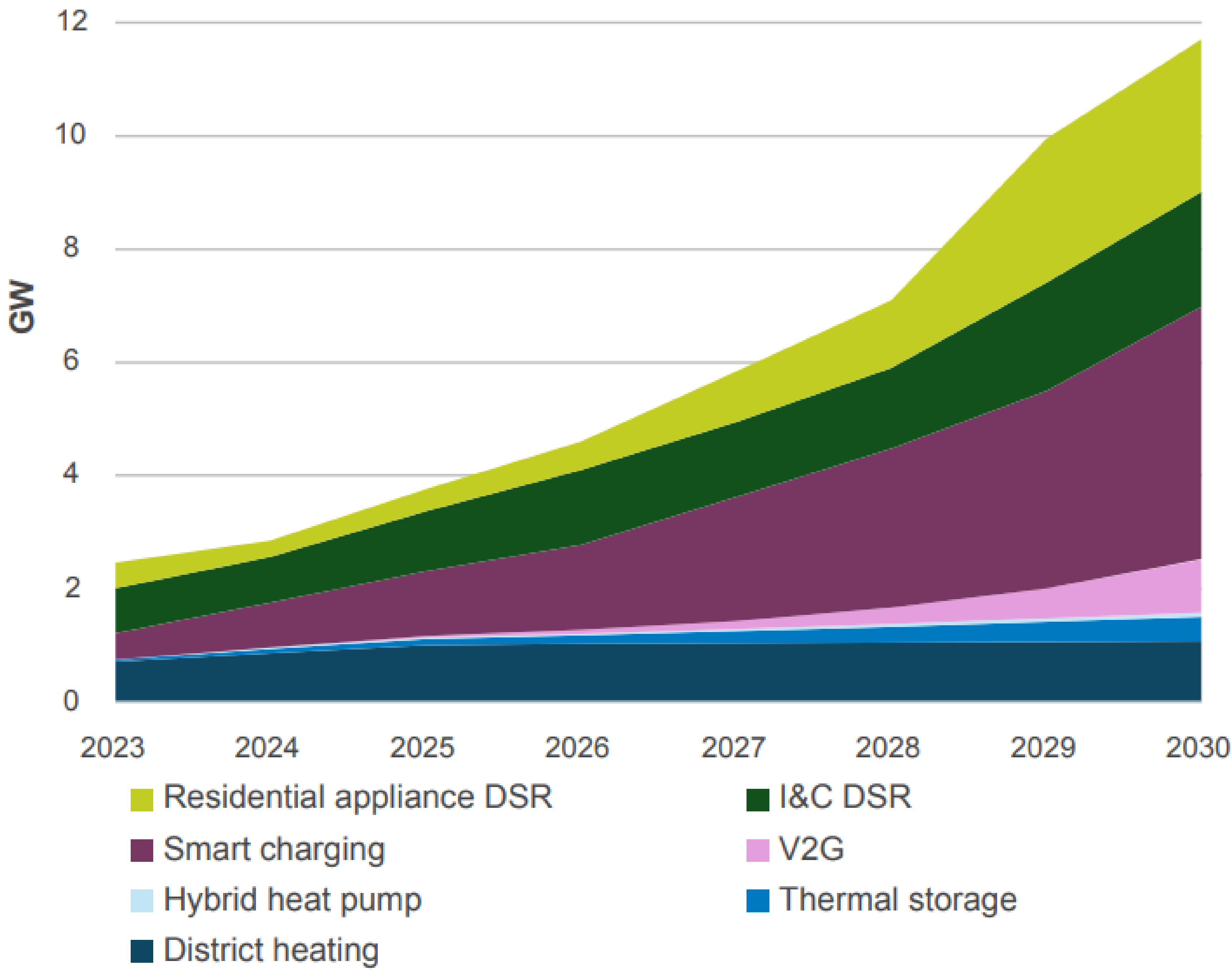
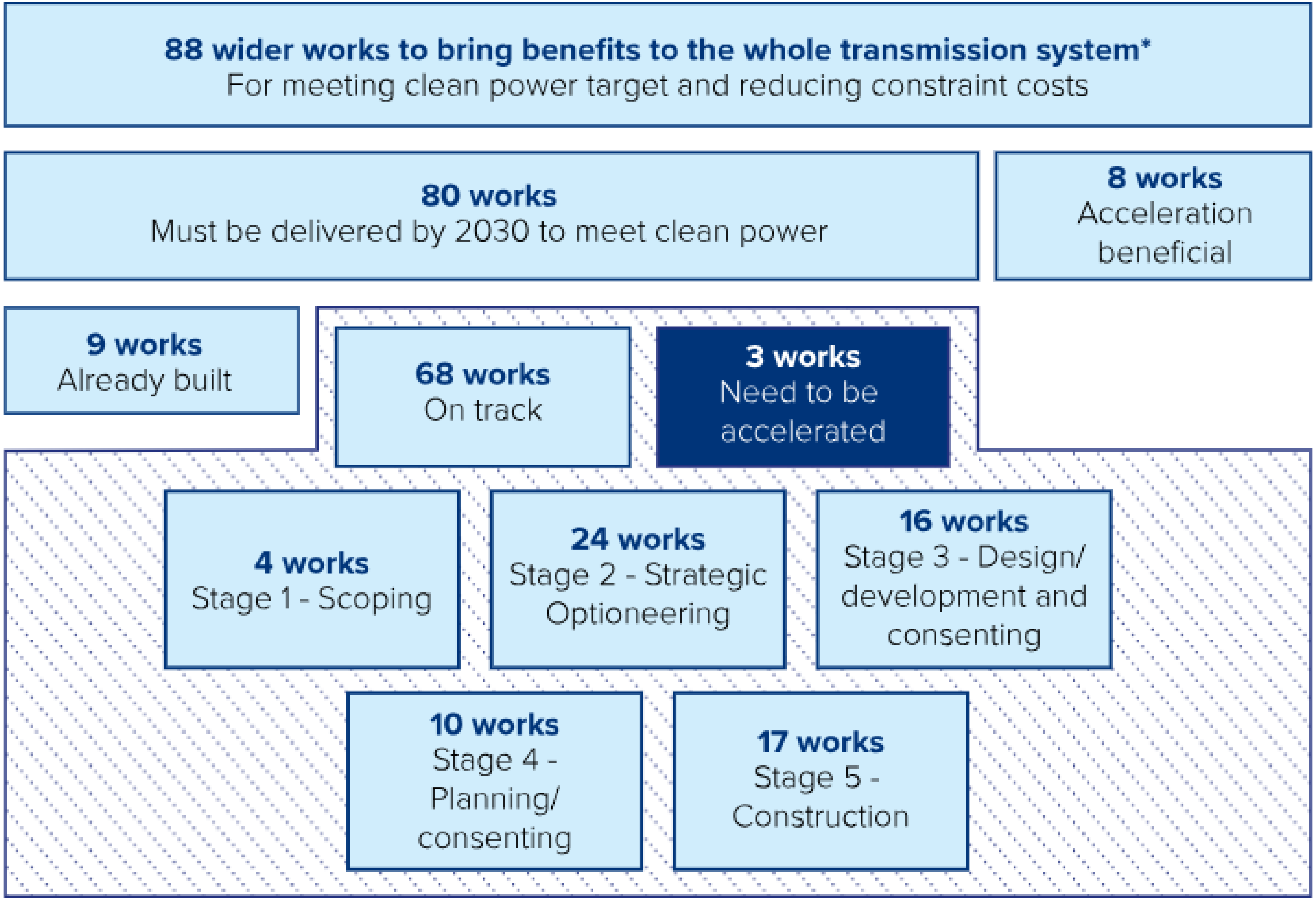


Figure 11: Transmission network project maturity and delivery timeline



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Strategic energy planning

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Gas network planning
Confirm **gas,** and potentially **hydrogen**, network transmission needs

Offshore coordination
Connect offshore wind in a coordinated way

Zero carbon operations
Ensure a zero carbon energy system can be operated

Strategic spatial energy plan
Map potential **electricity** and **hydrogen generation** and **storage** infrastructure for **GB**

Centralised strategic network plan
Plan to develop and assess **electricity**, **gas,** and potentially **hydrogen**, **transmission networks**

alignment

Regional energy strategic planner
Develop **whole system, cross-vector regional plans** with input from local actors

Clean power 2030
Government **Clean Power Action Plan by 2030**

Future energy scenarios
Supply and demand pathways to meet net zero

Connections reform
Ensure ready projects aligned with strategic plans **can connect**

Review of electricity market arrangements
Reform electricity markets to achieve net zero cost-effectively

NESO
National Energy System Operator

The CSNP framework applied to electricity network planning processes

We will holistically plan wider reinforcements on the onshore transmission network alongside the offshore network and identify opportunities for interconnectors and offshore hybrid assets.

Identify

- **SSEP** will map out the energy supply with network and demand over time
- **FES** supports and augments the analysis

Develop

- Individual reinforcement options will be identified by Transmission Owners, NESO or third parities.
- It will take into consideration both onshore and offshore
- It will consider different resilience risks to ensure that there is security of supply

Appraise

- Individual options will be combined to form a diverse range of GB designs
- Designs will be filtered on economic criteria with a broad range of options taken forward
- Assessment criteria will then be used based on:
  - **Environment**
  - **Community**
  - **Operability**
  - **Deliverability**

Decision making

- The preferred GB design will recommend which network reinforcements enter the delivery pipeline
- **Ofgem** decide on investments made

NESO National Energy System Operator

Aims of CSNP

Ensure efficient energy network development by holistically planning the onshore and offshore electricity networks, and strategic gas and hydrogen networks.

Plan strategically, ahead of need, to enable investments required to ensure reliable, clean and affordable energy.

Accelerate delivery of network by providing certainty on the needs case and strategic parameters of options to support planning and regulatory processes.

Conduct a consistent, robust and transparent assessment on a broad range of network options considering multiple assessment criteria.

A Transformative Shift: Reimagining the Energy Landscape

The Changing Landscape

Profound transformation towards cleaner, sustainable energy sources

A New Era of Electricity

Fundamental overhaul of electricity transmission and distribution systems

Gas Sector Evolution

Strategic decarbonization and modernization of gas infrastructure

Hydrogen's Emerging Role

Developing hydrogen as a critical component of clean energy transition

Net Zero Opportunity

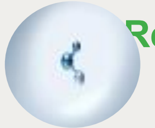
Exciting challenges and innovative solutions for UK's energy future

Practical constraints: aging infrastructure, land, supply chain, planning, system access

The Role of Electricity Transmission

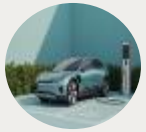
Powering the Future

lectricity transmission is key to delivering clean energy efficiently& reliably to meet growing power demands



Renewable Energy Dependencies

Renewable technologies depend on decarbonized electricity to achieve true sustainability



Cross-Sector Electrification

Transportation, heating, and industrial processes are increasingly electrifying to reduce carbon emissions and achieve decarbonization goals.

Building on Past Success

We can learn from the CEGB's mid 1900's network modernisation, which dramatically expanded power access

New Challenges Await

Modernising the UK's electricity transmission network will require strategic planning… whilst keeping the lights on with today's network

FUTURE OF THE NETWORK

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Mid 1900's **Similar drivers, different locations** **2025**

" After nationalisation in 1948, it was decided to build a 275 kV grid to enable power stations to be build around the coal mines, etc. and transfer the electricity around the country."

"To realise this vision, we must systematically upgrade our electricity transmission network in the coming years to ensure it remains fit for future, resilient, intelligent and efficient to deliver net zero."

Long-Term Vision is aligned

" The 400 kV system should last, at present estimates, until about 2000 before the 780 kV grid system is needed. "

"One approach we think has potential is the construction of an ultra-high voltage onshore transmission network of up to 800kV."

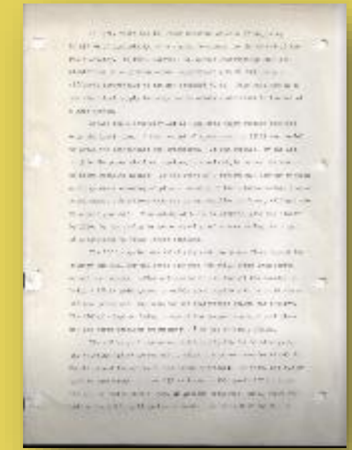
… BUT the Challenges are different today

Electricity was new and a benefit

New network and earlier vintages of technology

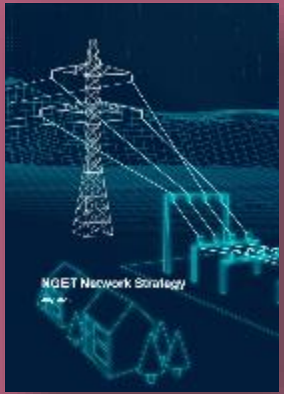
Electricity is expected and a necessity

The new and existing network - technologies need to coexist



CEGB Induction Manual

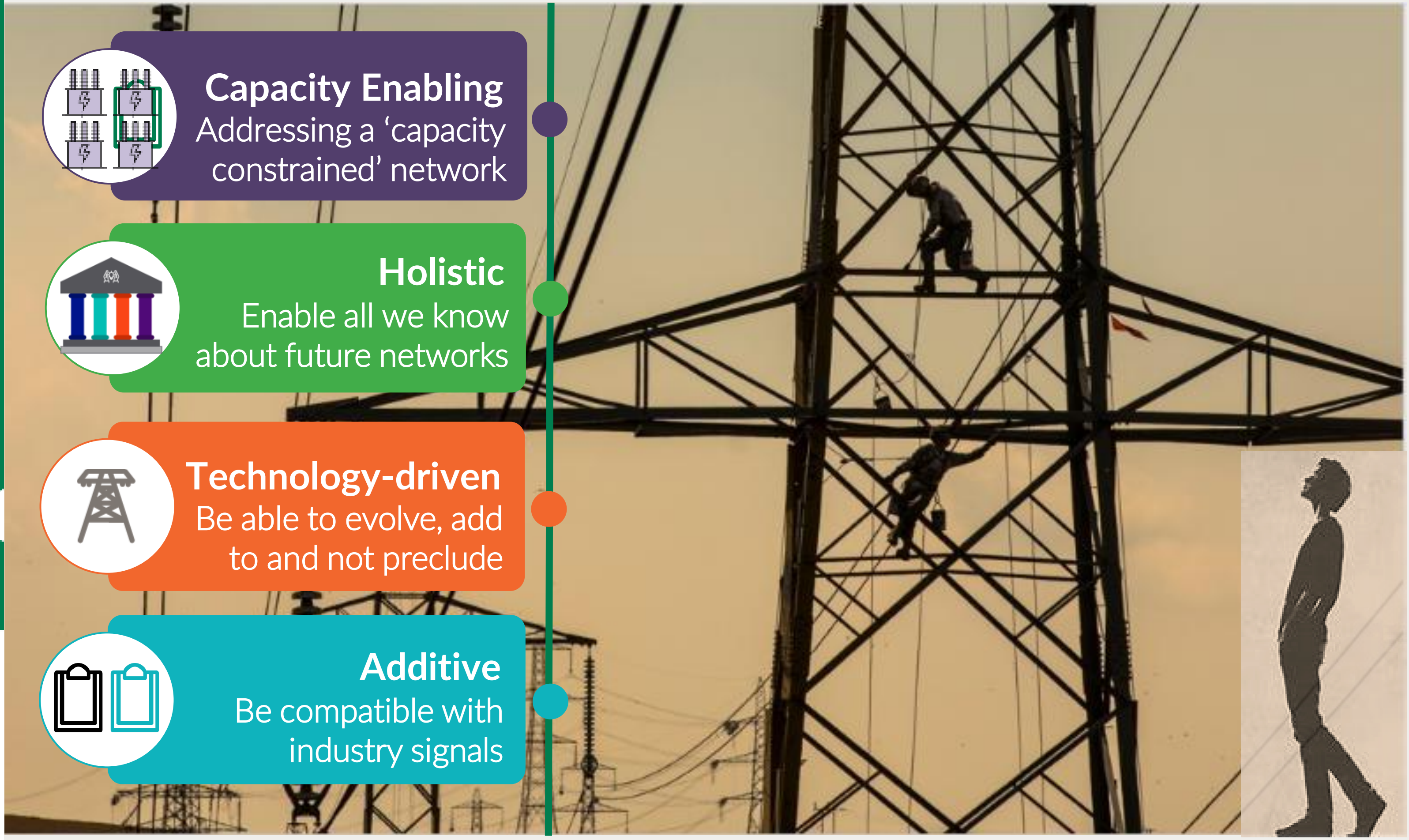
Future Network



NGET Strategy

Future Network Development ’Step Back’

Strategically & systematically upgrade the electricity network based on all we know now, & not preclude future needs



Capacity Enabling
Addressing a ‘capacity constrained’ network

Holistic
Enable all we know about future networks

Technology-driven
Be able to evolve, add to and not preclude

Additive
Be compatible with industry signals

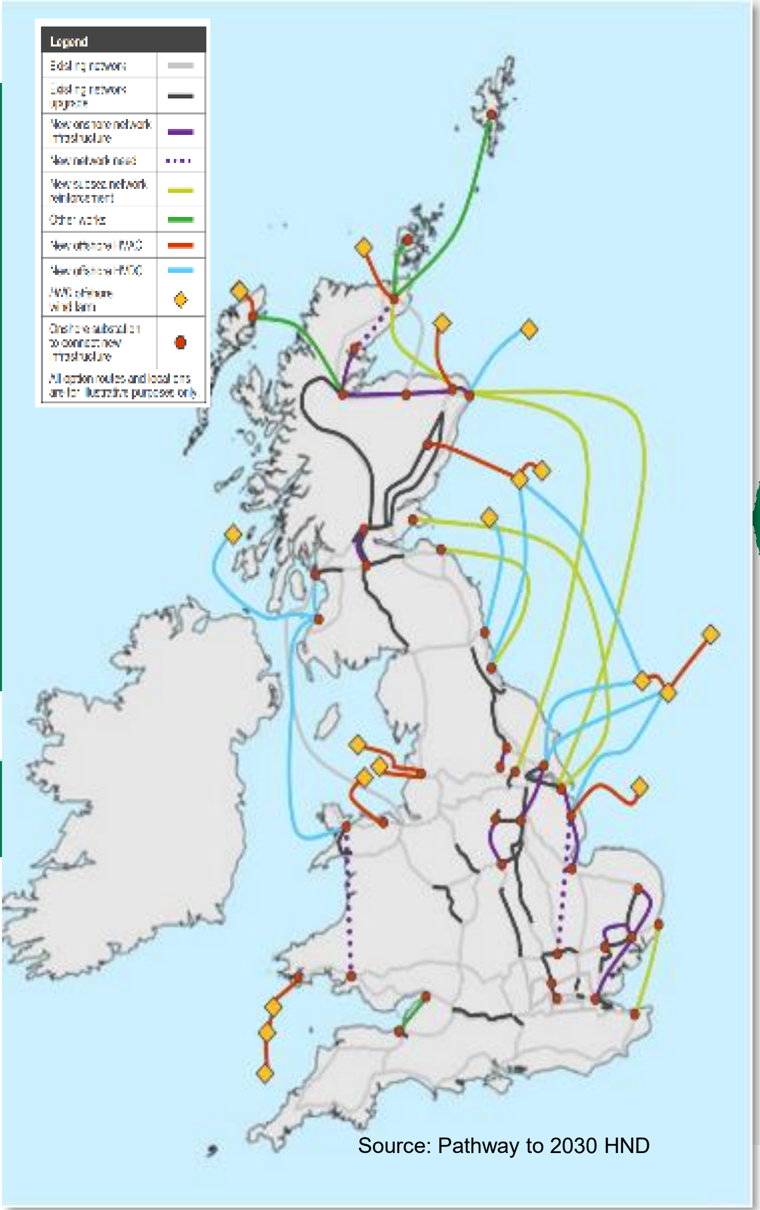
Shaping our network to 2050 and beyond: a super-supergrid

“One approach we think has potential is the construction of an ultra-high voltage onshore transmission network of up to 800kV.” “superimposed on the existing. a super-supergrid”.

“This new grid would enable bulk power transfers around the country, with strategically located ultra-high-capacity substations supporting the connection of big energy sources to big demand centres via the new network.”

A network plan that enables <u>*all customers and stakeholders*</u>, rather than building a network for *specific customers or stakeholders*

The Transmission Network Evolution 2030 and beyond



Source: Pathway to 2030 HND

The network will include:

- Extensive & layered onshore and offshore network reinforcement
- Extensive adoption of Offshore HVDC
- Meshed, radial, and linked AC & DC topologies, including AC connections between DC links
- Multiple landing points in E&W for high concentrations of power injection

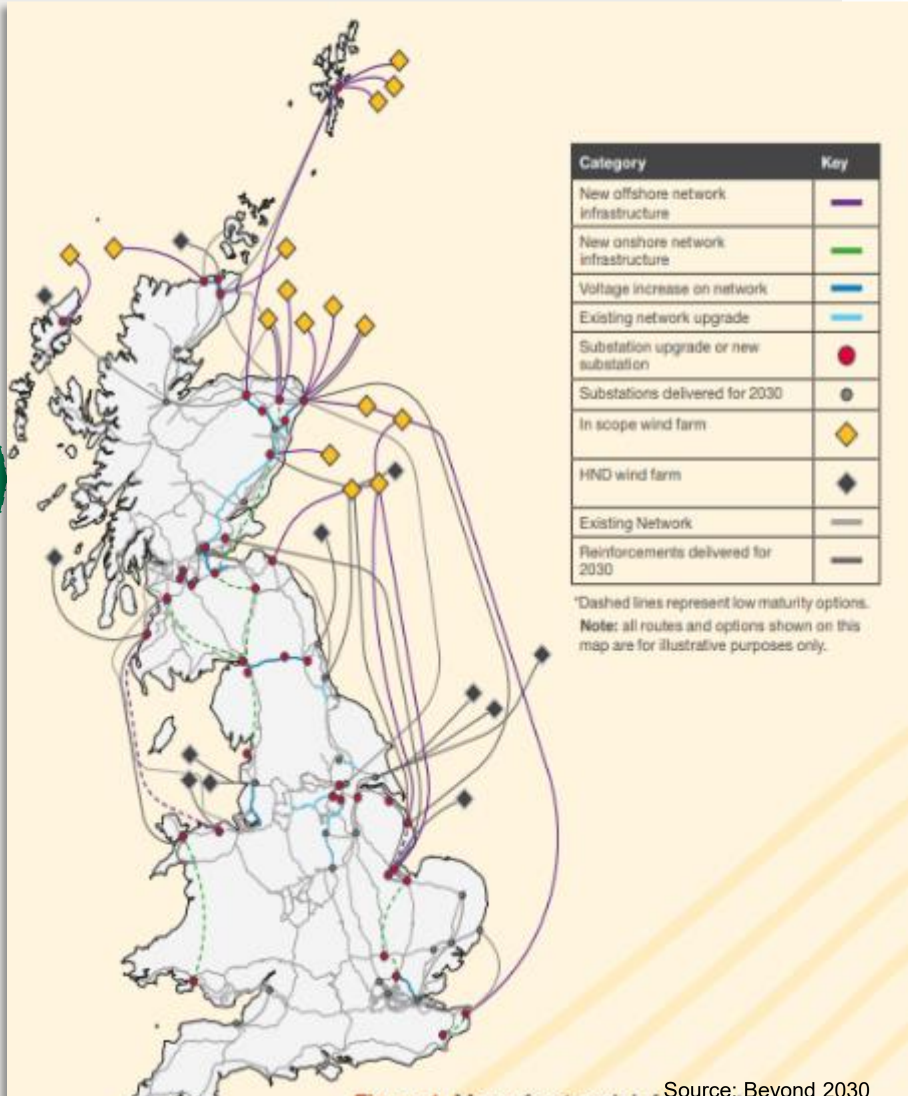


Figure 1. Map of network infrastructure to be delivered beyond 2030

Source: Beyond 2030

Transmission network evolution in six key areas

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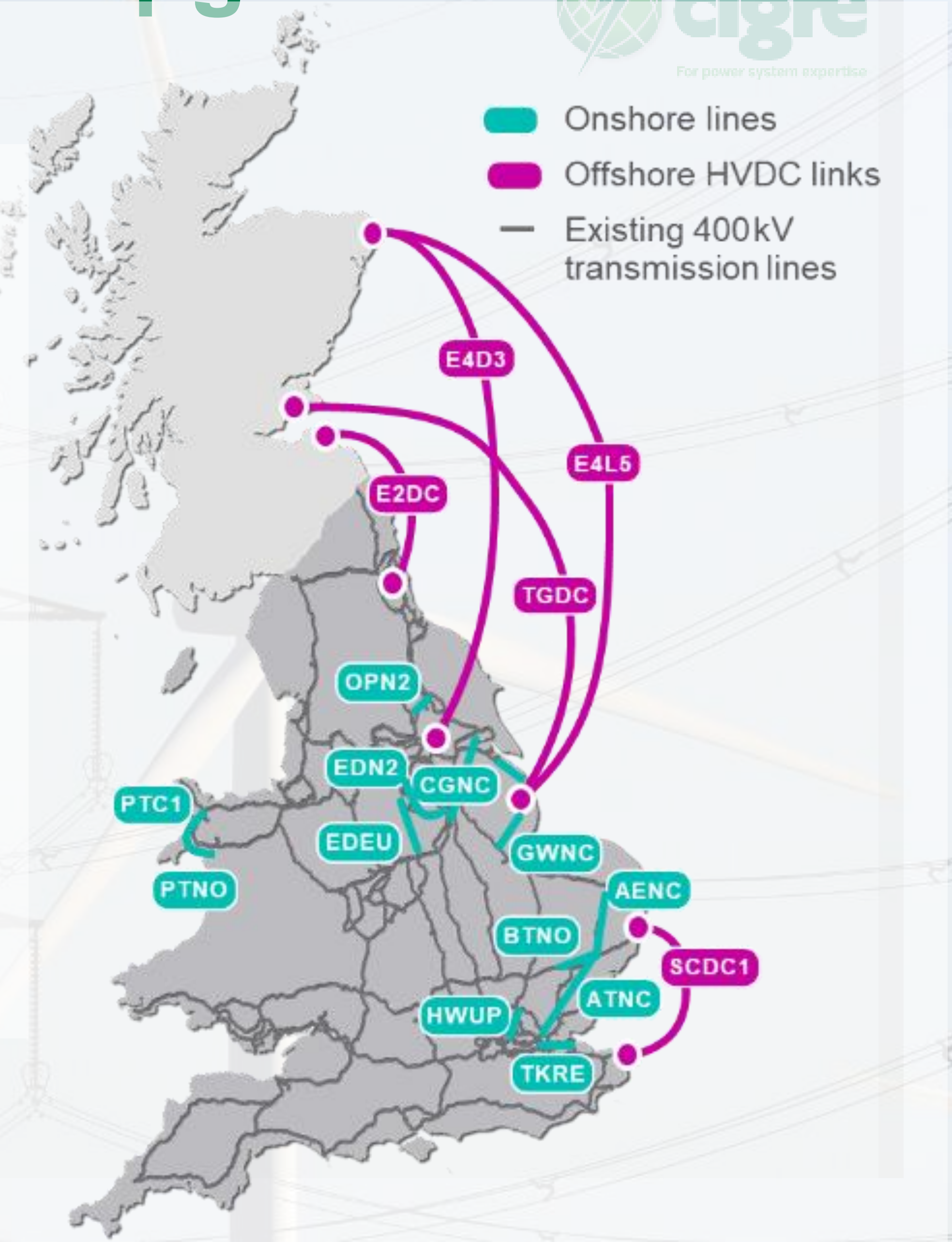
	Offshore Works	Offshore Connection Works	The Built Network	Onshore Connection Works	Bulk Power Transfer Works	Operability & Resilience Works
Pre- 2030	← Plan in progress for the first offshore EGL links →		Plans prepared to maintain assets during a growth phase	Connections Reform Ph1 2026 - 2030 Review in 2025	CP30 analysis based on 2022 data. 2025 (Review Completed)	Assessment for Wider Network in T3 submission Specific review for connections (Initiated) Review in 2025
2030- 2038*	HND1 / HNDFUE 2025 (Extensive Review)	Some consideration in HNDFUE by NESO 2025 (Extensive Review)	Circuit and site intervention alignment, with later refinement. Standardisation & design management.	**Connections Reform Ph2** **2030 - 2035** 2025	tCSNP2 / tCSNP2 Refresh **2030 - 2038** 2025	Coordination of portfolio of new technologies needs be secure and focus on connections needed 2025
Post- 2038	← Strategic offshore **networks** →		Asset Lifecycle management of multi-generational technology networks	← Strategic network of **hubs and circuits** →		Create opportunities in resilience **operability challenges**

Projects as part of the Great Grid Upgrade

- **A**ccelerated **S**trategic **T**ransmission **I**nvestment
- **17** major new projects across England and Wales contributing towards delivering the Great Grid Upgrade
- They are delivered by a specifically - formed **Strategic Infrastructure (SI) business** which is part of National Grid Electricity Transmission (NGET).
- The projects will contribute towards the UK's goals of connecting **50GW** of offshore wind by **2030.**



Transmission plan for 2026-2031

Upgrading c.3,500km of our overhead lines

New network control centre & control system

Upgrading 10% of our existing substation fleet

5 new power flow control installations across 4 major north-south routes

c.1,100km new circuits delivered; including c.1,000km offshore

25 new substations delivered in RIIO-T3 of which there are five shown on the map (from RIIO-T2 reopeners)

Further 15 new substations to be delivered beyond RIIO-T3

Nuanced Regional and Local Needs

Our Future Network Blueprints recognise that to include all needs, our future network plans must consider local and regional variations.

Regions have been defined using geographical and electrically (broadly) separable sections of the E&W electricity network.

1. **Electrically** - accounting for network challenges such as power transfer in/out/ through the region, and access for outages.
2. **Geographically** – accounting for customer demographic, anticipated stakeholder needs, existing and planned network locations.

Each region contributes to a coordinated national picture, meaning ‘strict’ or ‘loose’ geographical definition does not impact outcomes.

Engagement in these regions to date has informed the principles for our regional strategies at a macro-level.

We expect these to be continually refined based on increasingly granular regional engagement and nuanced stakeholder needs.


01

Executive summary

Our future network blueprint strategy

Strategic Network Design

Standards and Network Architecture

Technology Adoption (HVDC, FACTS)

Safe, Reliable Future Operation

Solution Pace, breadth of needs addressed

Decision Making & Solution complexity

Supply Chain & Physical Requirements (Land, space)

Industrial & societal Partnerships & Co-creation

Network Resilience

Existing Network Integration (on/ offshore, energy/electricity, Regional/ local, access/ design,/ construction)

End to end data compatibility

Digital technology adoption

Skills and Capability Diversity

Opportunities & further work; our design approach

Review & contribute to Future Network Blueprints

Provide feedback and comments on proposed network development strategies, contribute to next phase.

Energy Sector Data Standardisation

A means of data & intel collation, sharing, digitisation & visualisation for consistent, coordinated regional energy plans/ decision making

'Fit for future' Socio-economic assessments & Frameworks

Able to quantify the enduring societal and industry benefits of strategic networks that are *'built once, built right'.*

Modular and Standardised Equipment

Developing adaptable, plug-and-play infrastructure components that enable rapid deployment, reduce complexity, remain compatible with existing networks, and support expansion strategies.

Energy Resilience for 2050

Understanding the future shocks and stresses, and mitigating actions on an evolved and interconnected energy landscape (gas, hydrogen, electrity, water, telecoms, GDP)

Network Modeling

Digital Twin technology for near terms network optimisation and long term probabilistic network assessment of options/ portfolios of options.

Transmission Technology Innovation

Continuous research and development of high-capacity transmission technology & integration - design, asset management & operation perspectives

Technical Challenges

Some technical challenges must be addressed through industry and supply chain collaboration to enable a coordinated network approach.

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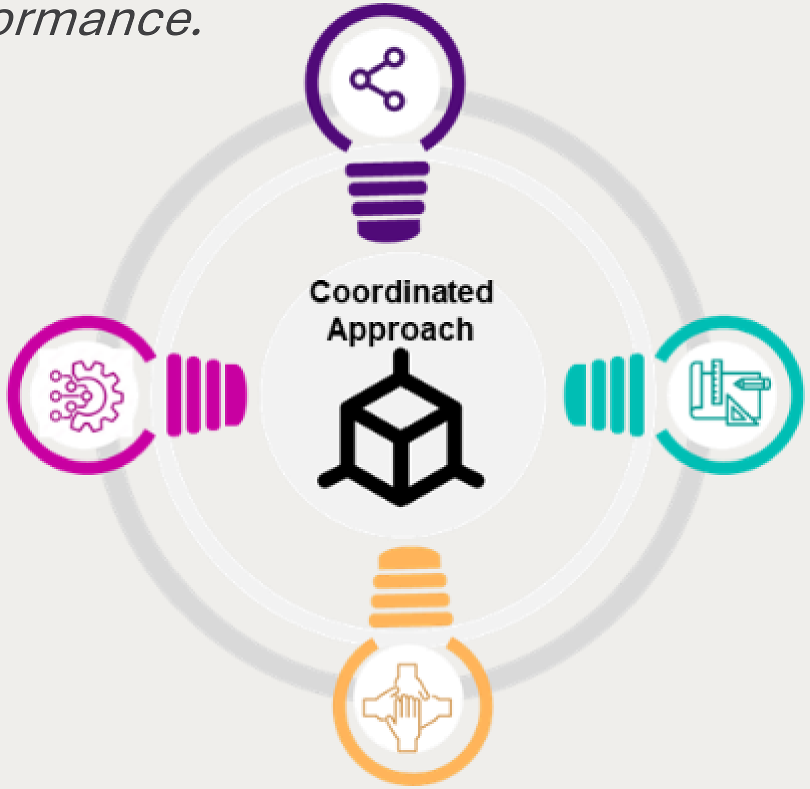
Operability and Interfaces with today's / future grid

From system access challenges to installing new equipment, to standard designs, through to AC/DC interface interactions, and detailed power quality and dynamic performance.

Technology Choice

Requires solutions that can be developed and delivered 'in time' for net zero and 'checkpoints' (e.g. 2035), but should also not build in obsolescence.



Physical and electrical design

Dictated by evolving challenges: land take/ space for substation sizing/ capacity, system access, supply chain availability, environmental and community impacts.

Reliance in global supply chain and global skills

It starts with power system engineers designing a safe and reliable network from the outset, all the way through to the delivery of the resulting infrastructure projects.

CIGRE France Conference

Proposals for the Spanish grid development after the 28th April evento

Javier Iglesias (REE)

For power system expertise

October 2025

1. The Spanish Electricity System. General Magnitudes & Evolution
2. The Network Development Plan 2021-26
3. The Iberian Blackout. 28th April 2025
4. Measures & Developments after 28th April 2025
5. The Proposal for the Network Development Plan 2026-31

The Spanish Electricity System

General Magnitudes and Evolution

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The Spanish Electricity System

Diversity of Energy Resources and Highly Meshed Grid

Important Increase of Renewables in Last Years (Management: Curtailments & Backing)

Goals for Carbon Reduction in Line with EU policy

Generation Deficit in Central & NE; Congestions

Limitted Excahnge Capacity with EU

High short-circuit power

Dependence on water reserves

Dec-2024

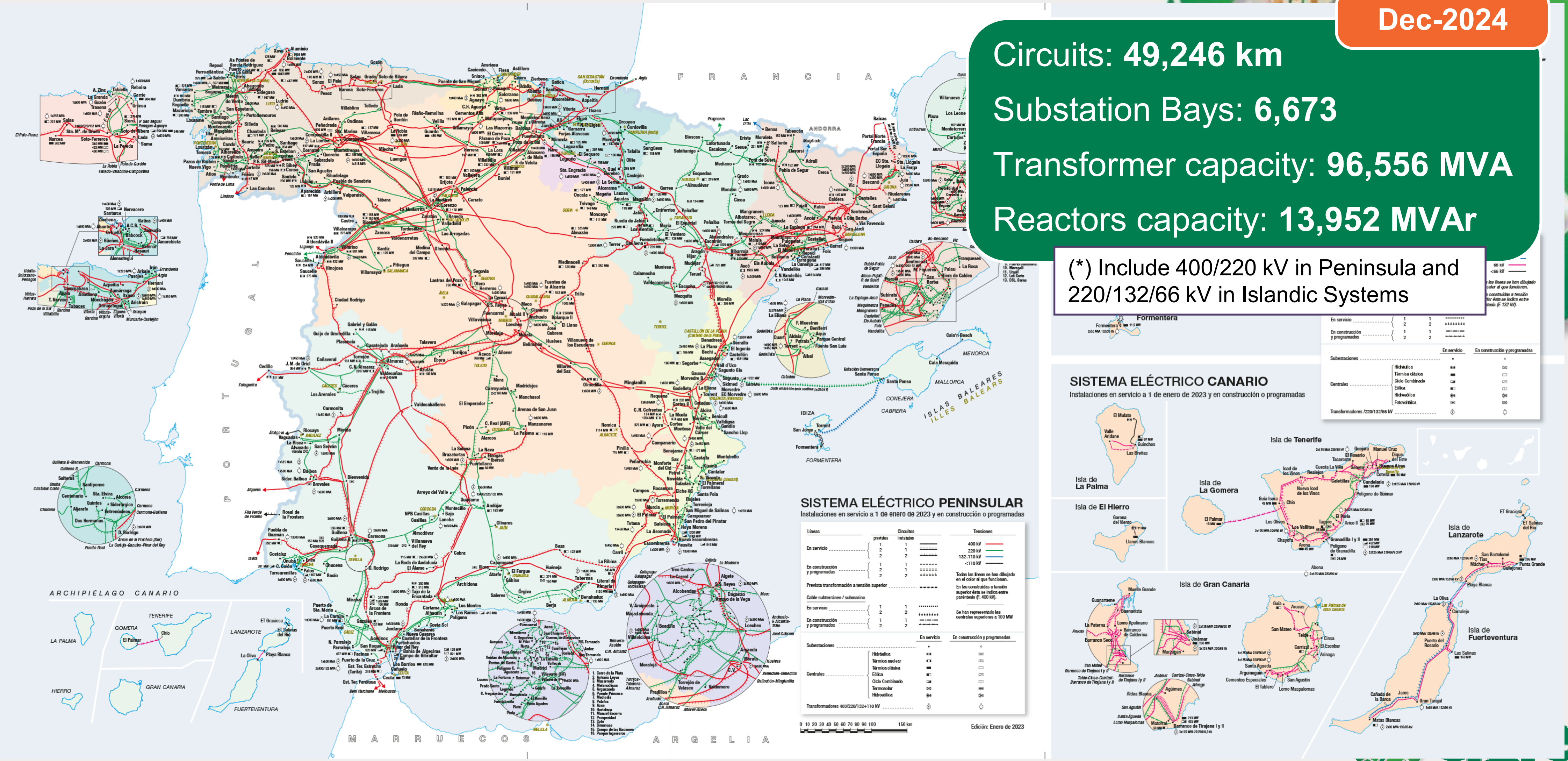
Installed Capacity: **129 GW**

Annual Consumption: **249 GWh**

Historic Peak Winter Load: **47 GW**

Historic Peak Summer Load: **43 GW**

Map of the Spanish Transmission System



Dec-2024

Circuits: **49,246 km**

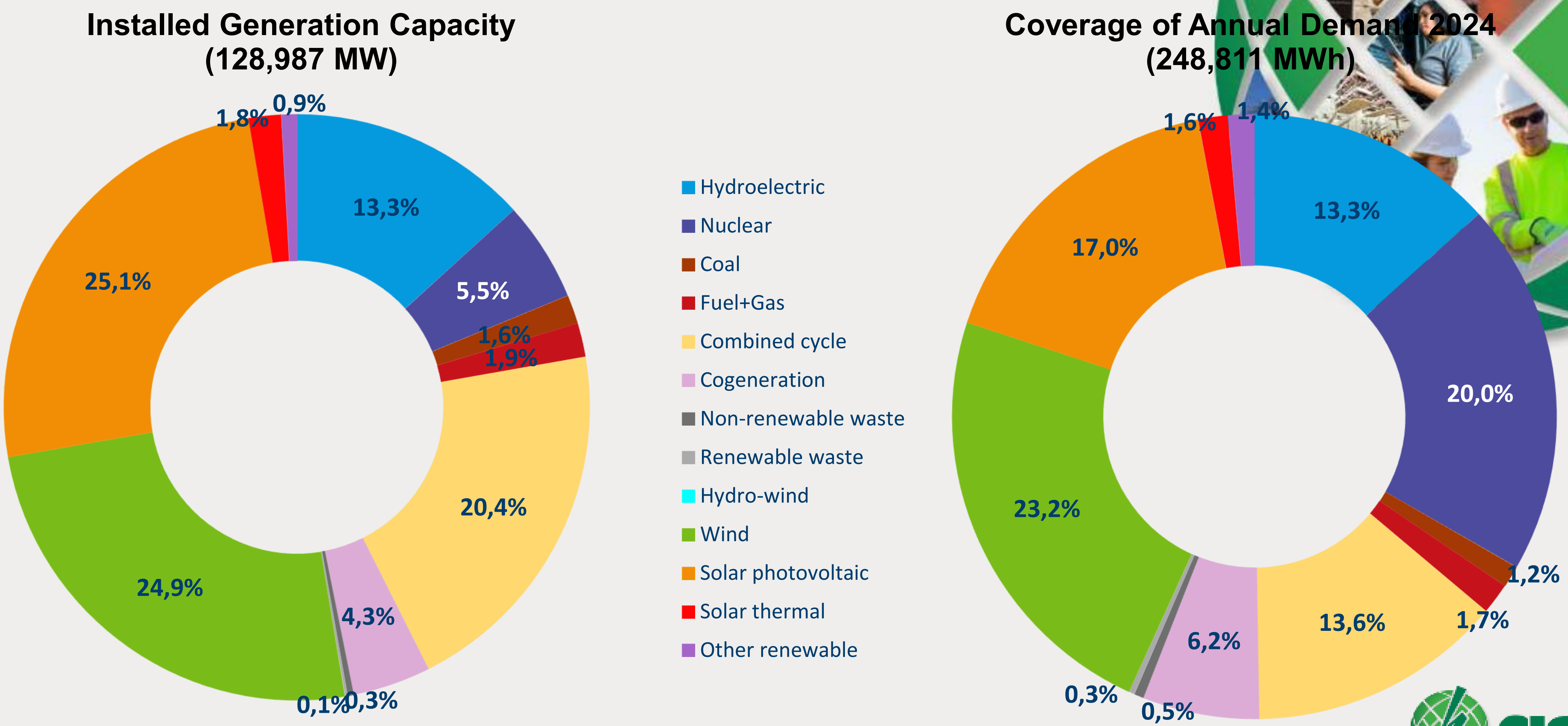
Substation Bays: **6,673**

Transformer capacity: **96,556 MVA**

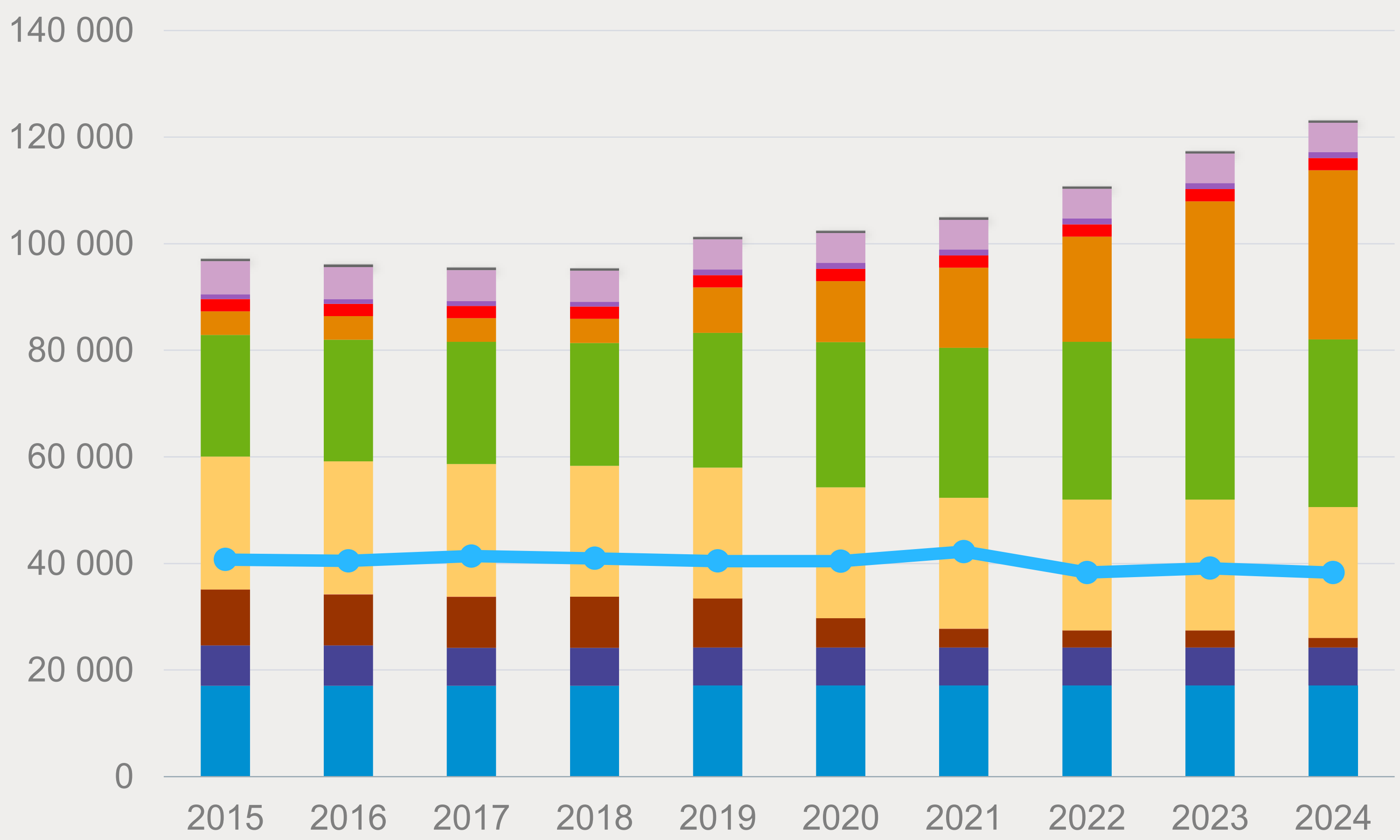
Reactors capacity: **13,952 MVAr**

(*) Include 400/220 kV in Peninsula and 220/132/66 kV in Islandic Systems

National Electricity System, Spain (Dec 2024)

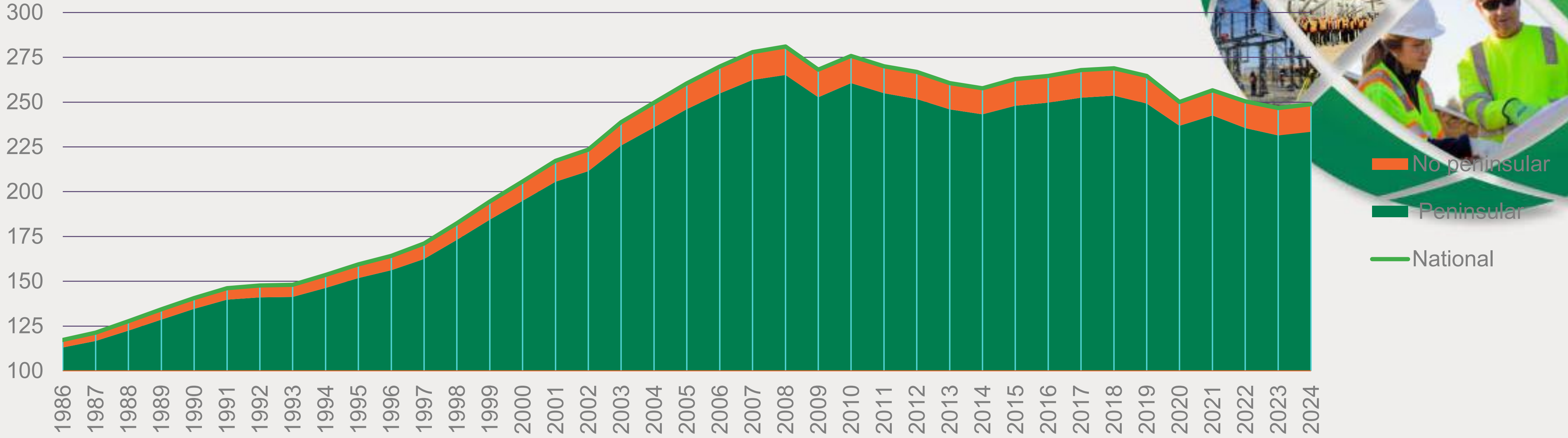


Annual Evolution of Installed Power in Peninsula (MW)



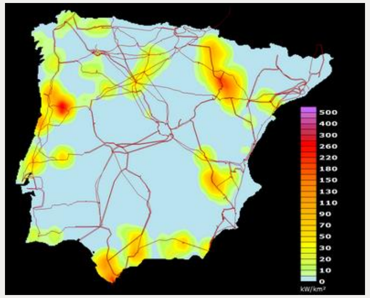
(1) Other renewables include biogas, biomass, marine hydraulics and geothermal.

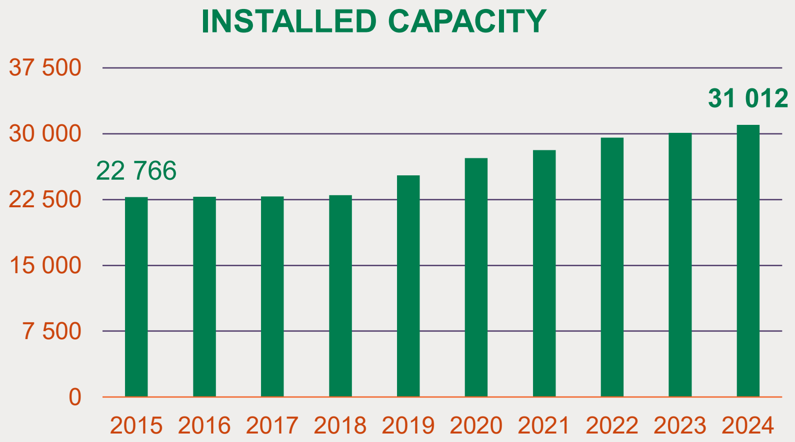
Evolution of the Electricity Demand (TWh)

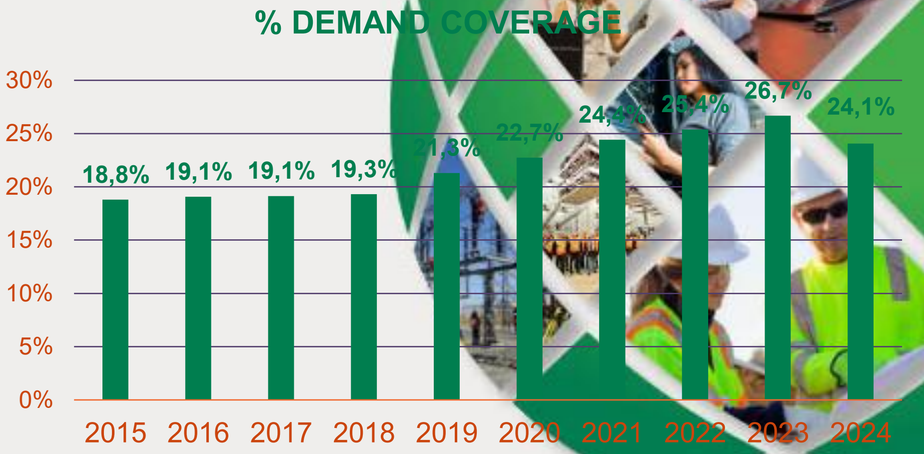


Renewable Evolution

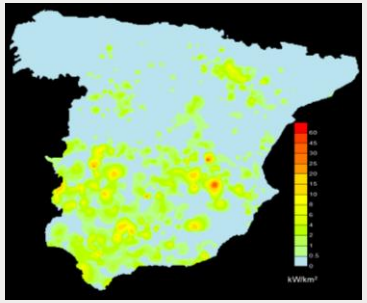
Wind

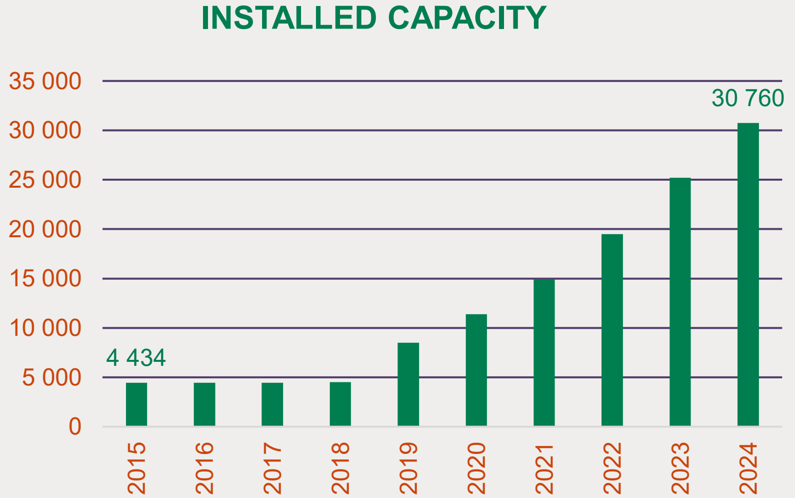


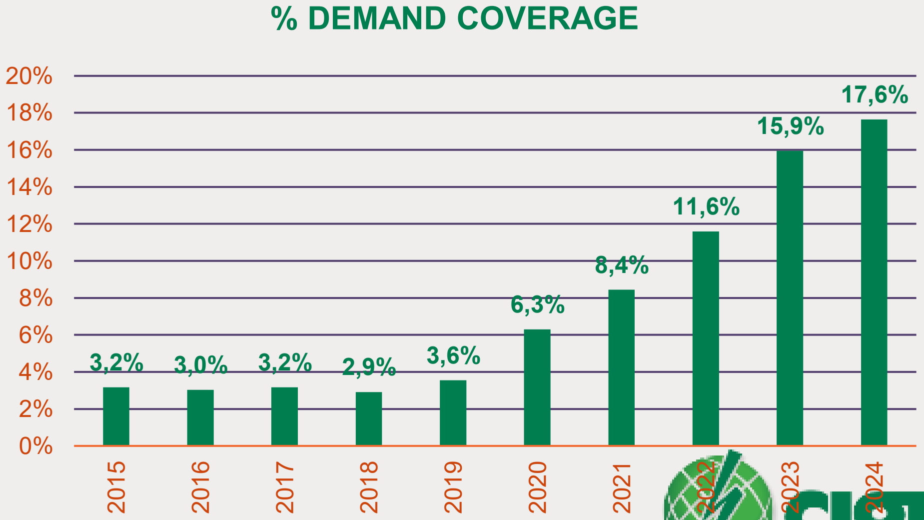




Solar PV







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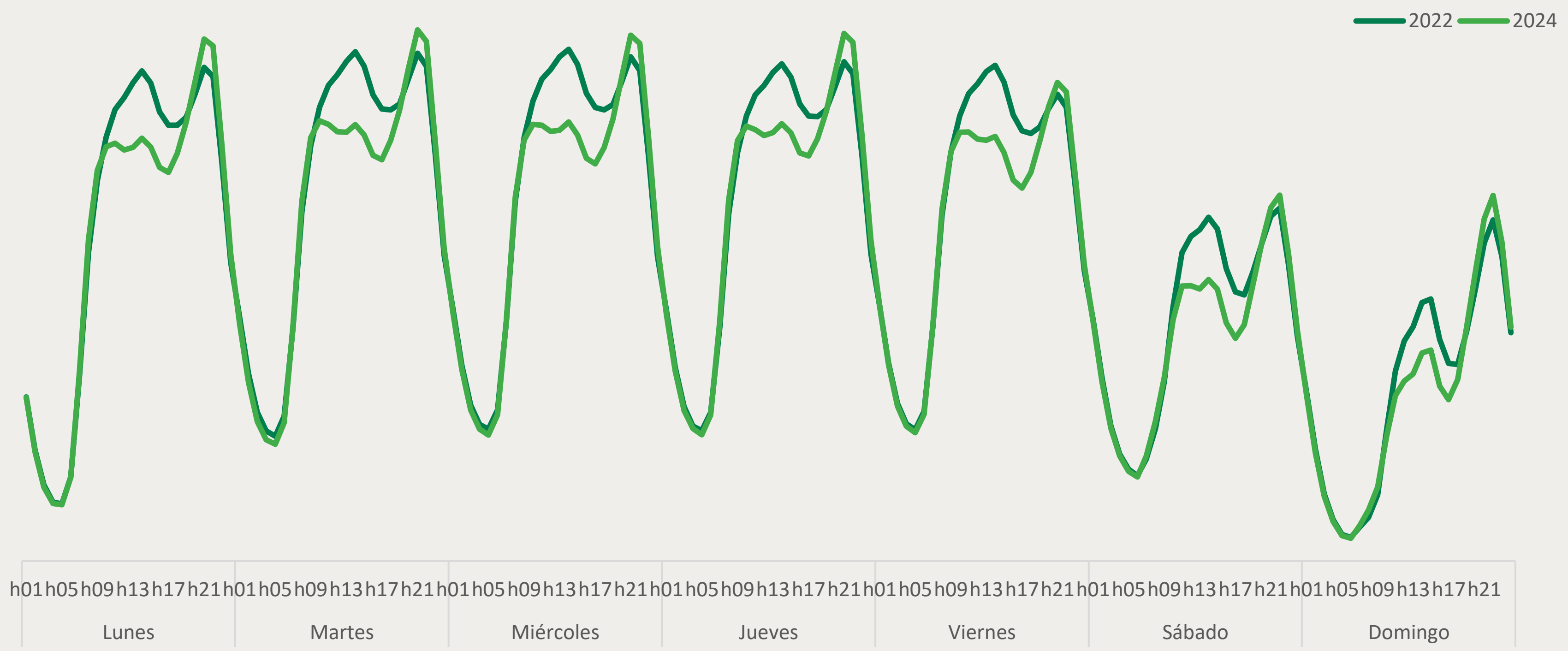
Observability: “Behind the meter” consumption

Comparison of the weekly **average** curve **2022** vs. **2024**: Effect of Self-Consumption



The Network Development Planning 2021-26

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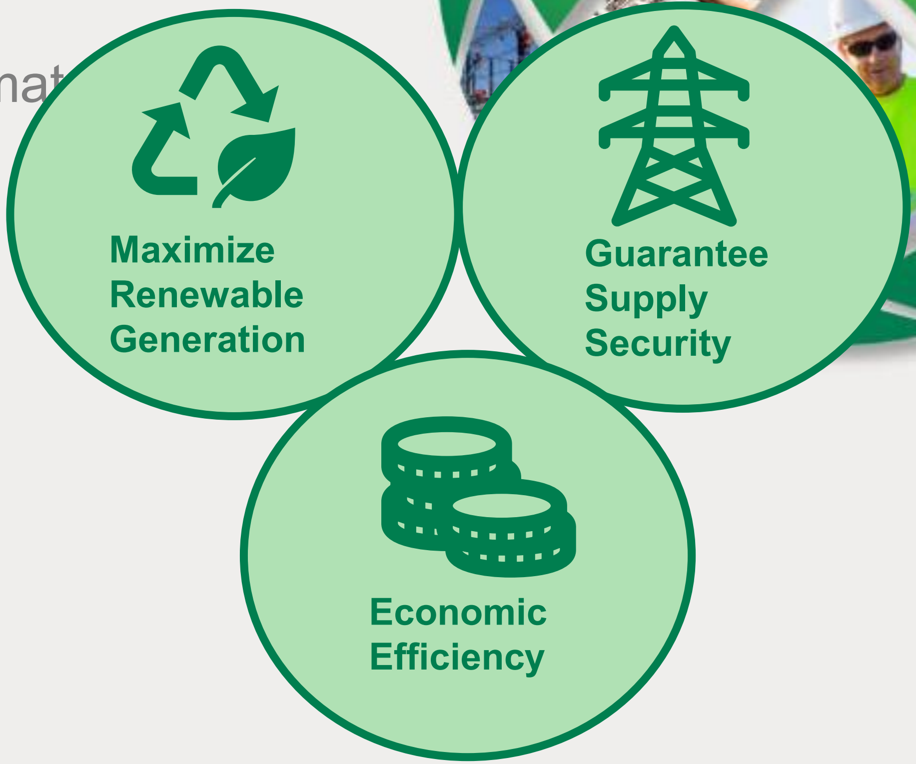
The Network Development Plan 2021-2026

1. Published in April 2022 (current plan).
2. Complex Process for Approval (+2k subjects, +3k allegations)
3. Fulfill requirements of National Plan for Energy & Climat



4. With 3 main Principles: Renewables, Security, Economy

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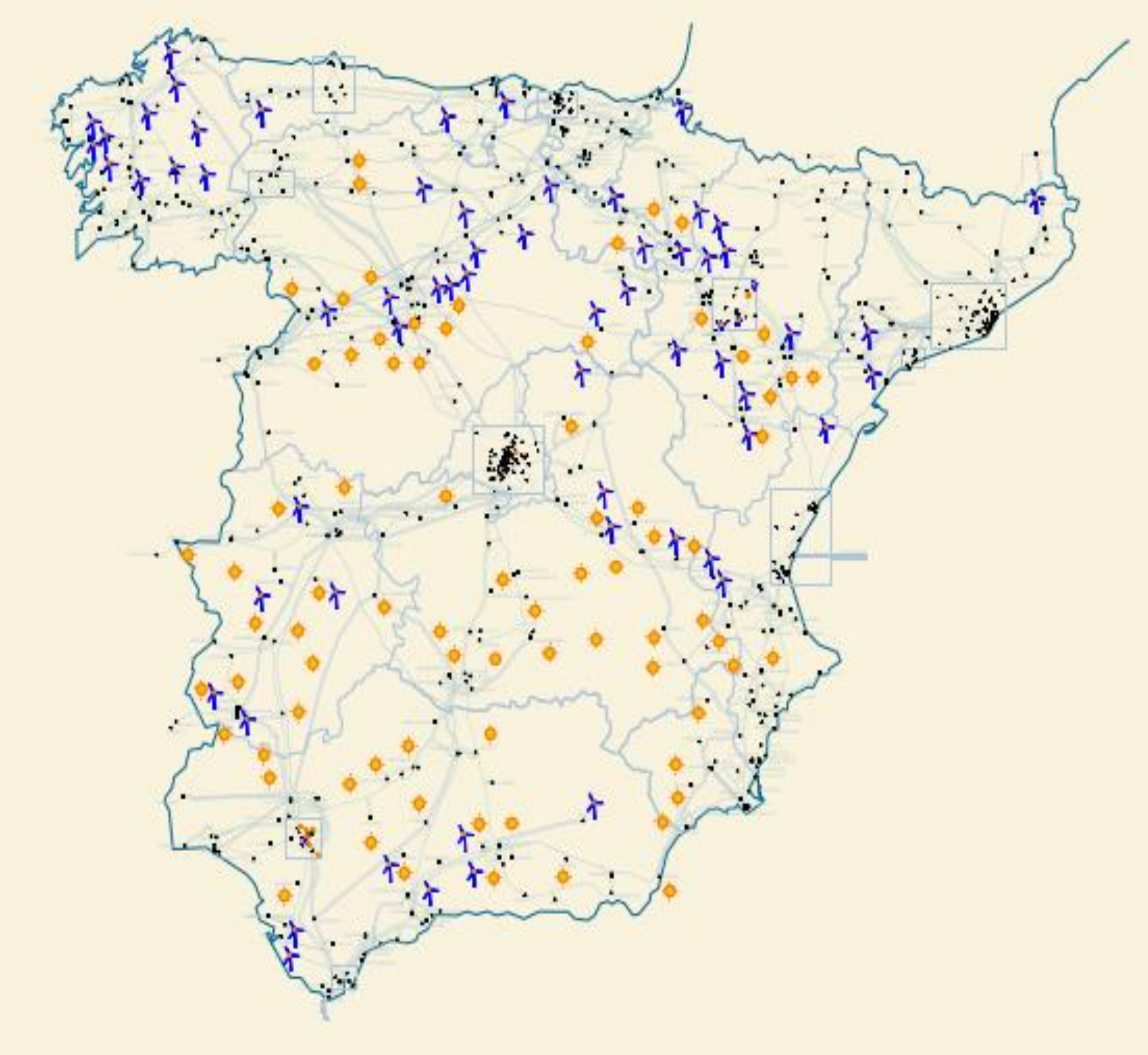
A Plan Focused on the Generation

1. Requests for connection:
   Wind 63 GW, **Solar 267 GW**

1. Based on Hypothesis for new locations for the generation under the scenario, instrumented by an indicator measuring the location's **probability of success**

2. Maximizing the Existing Grid
   Reducing Losses
   International Connections (TYDNP)



Overall impact of the plan

Investment of **€ 7 billion**, that will boost economic development (GDP & employment)

2700 km new OHL, **7000 km** uprating, **700 km** DLR, **700 km** submarine cable, **800** Subst. Bays

67% of the share will be green energies by 2026

CO_2 emissions in electricity system will stand at **17 MTn** (66% reduction vs. 2019).

New infrastructures will generate savings of more than **€ 1.6 billion** for the system

The Iberian Blackout

Event on the 28th April 2025

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28th April Iberian Blackout. The Event

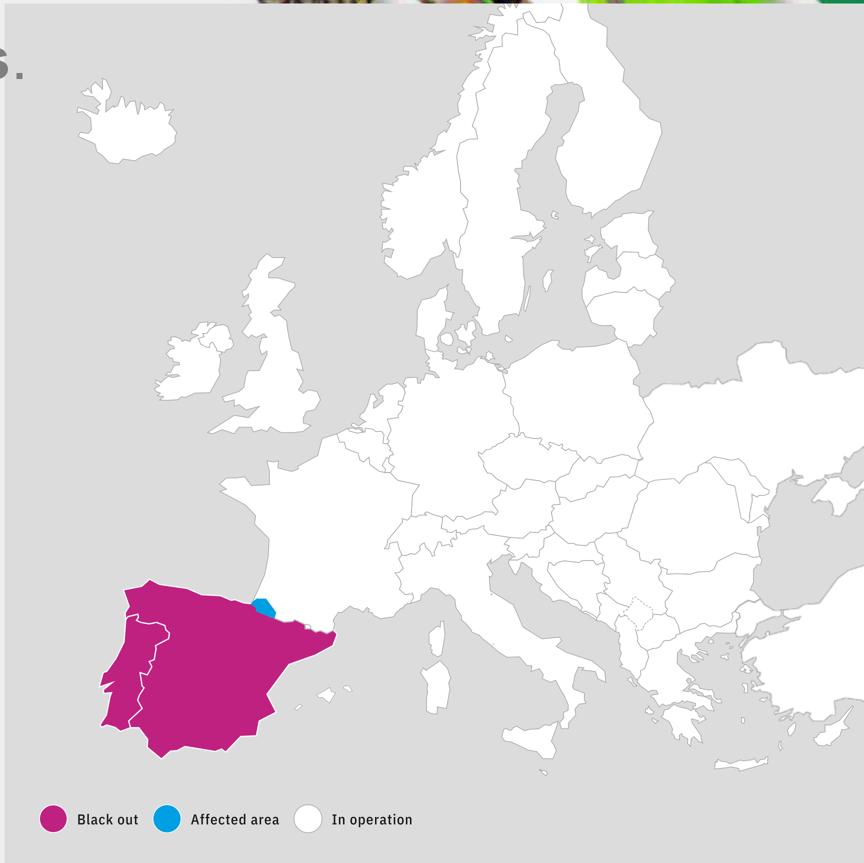
1. **12:33 h** (CEST). Power systems of ES & PT experienced a **Blackout**.
   A small area in France, close to the border also affected for a limited duration
1. Exact Causes still under **Investigation** (ENTSO-e Expert Panel)
   Refer to: https://www.entsoe.eu/publications/blackout/28-april-2025-iberian-blackout/

1. Blackout Resulted from a **Complex Sequence of Events**.

   - The Panel has established a preliminary chronology
   - Will be updated and complemented with additional info.

2. Series of **oscillations**, **countermeasures**,
   Generation trips… cascade effect until collapse

1. No **Failures** of the Transmission Grid,
   Nor **Cyberattack**,
   Nor Unusual **Weather Event**

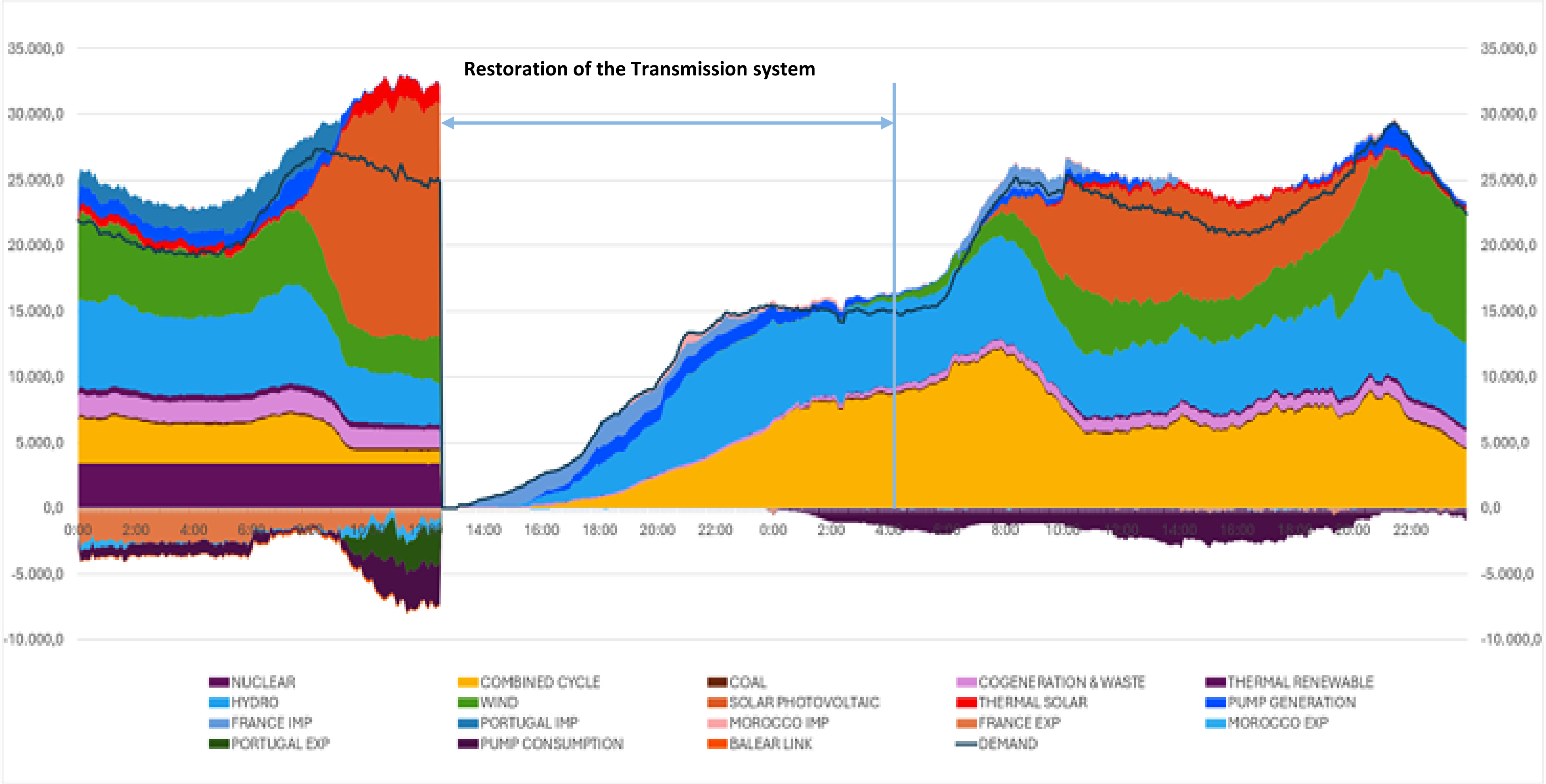


Restoration After the Blackout

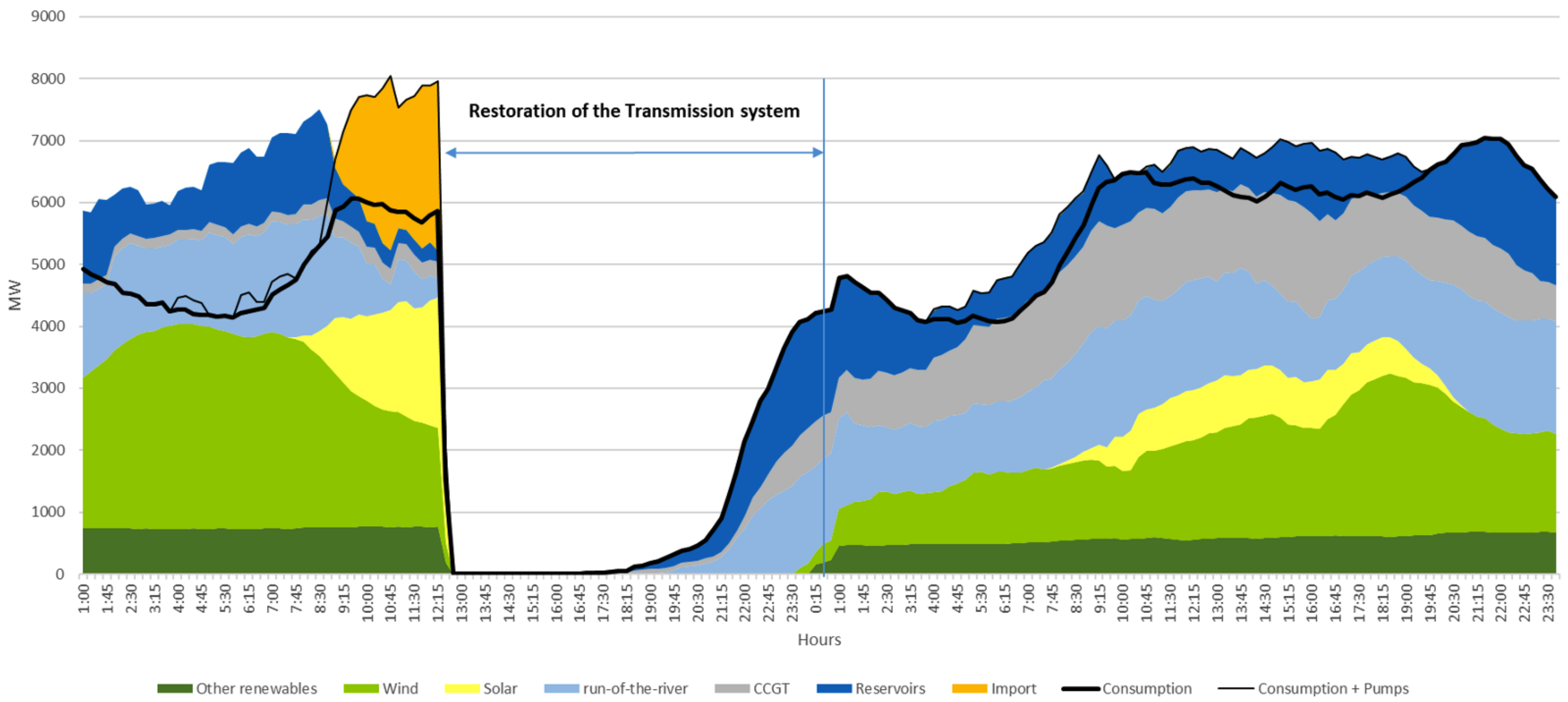
1. **No failures** on the transmission grid, which facilitated the process
2. Established **procedures** & **protocols** activated **immediately** following the incident.
3. Thanks to **black-start processes** in certain power plants & the support of **interconnections,** creating **islands** to stabilize Voltage.

12:44 (CEST)	The first 400 kV OHL France-Spain re-energized.
13:04 (CEST)	The interconnection Morocco-Spain (submarine cable) re-energized.
Until 13:30 (CEST)	Several hydropower plants launched their black-start processes to initiate restoration of the system.
13:35 (CEST)	The Eastern 400 kV OHL France-Spain re-energized.
18:36 (CEST)	The first 220 kV tie-line Spain-Portugal re-energized, speeding up restoration in Portugal.
21:35 (CEST)	The Southern 400 kV tie-line Spain-Portugal re-energized.
00:22 (CEST) (29/04/2025)	The restoration process of the transmission grid completed in Portugal.
04:00 (CEST) (29/04/2025)	The restoration process of the transmission grid completed in Spain.
14:36 (CEST) (29/04/2025)	The system was connected with the Balearic system and normalized.

Spain. Generation Curve on 28th April



Portugal. Generation Curve on 28th April



Transmission Grid Considerations for Restoration

1. Grid performed correctly thanks to a **Resilient Design** & the **Maintenance Condition**
2. Personnel committed & organized. Importance of **Recovery Plans & Training**
3. **Coordination** (Control Centers activated immediately according to the procedures):
   - **Maintenance Center (CMI2).** Monitores Equipments, initial diagnostic of assets, analyze alarms, supervise auxiliary systems and coordinates with the Dispatch Center for prioritization
   - **Telecommunication Supervision Center (CST).** Operates the redundant communication centers that monitor the parameters of the communication grid to control the performance and support the Dispatch
4. The **HV Equipment, Protection & Control Systems** performed correctly. Only minor issues reported (e.g. cable termination failure). Also **Telecommunications Grid**
5. All remote maneuvers completed without incidents (**+4000 switchgear**). No damages.
6. **Auxiliary Systems:** All covered by emergency generators & battery systems.

Measures & Developments after April 28th

Initial Proposals & Urgent Actions

Proposals (among others)

1. Proposals to Improve **Voltage Control:**
   - Approval of **Operating Procedures** aiming to regulate R-T Generator's V Control
   - System resources for continuous & dynamic V control (**SYNCONs / STATCOMs**)
   - Impulse regulations to reinforce V control within the **Distribution Network**
2. Proposals to Improve **Generation Management:**
   - Regulate **Overvoltage Protection Settings** on generation to avoid disconnections
   - Regulate the **Ramp Profile** for generation schedule changes (controlled vs. abrupt)
   - Provide sufficient **Observability** of self-consumption and update requirements
3. Proposals to Improve **Operation Tools** (various measurements).
4. Proposals to **Accelerate Permitting Processes.** (New NDP, Projects, Grid Access…)

The Proposal for the Network Development Plan 2026-31

The New Network Development Plan 2025-2030

- Already **launched** in March-25 (process takes 1-2 years)
- Already increased the **limits of annual investments** (Distribution & Transmission)
- Includes **Obligation** (TSO, DSOs), **Penalty** Mechanisms, **Incentives** to Gen & Demand
- Strategic **Environmental** Approval in progress
- Will be focused on the **DEMAND:**
  - New industrial demand & others (railway)
  - New Data Centers
  - Particular attention to STORAGE

Overall Figures

Investment of **€ 13.5 billion**

4000 km New OHL; **9500 km** OHL refurbished or uprated

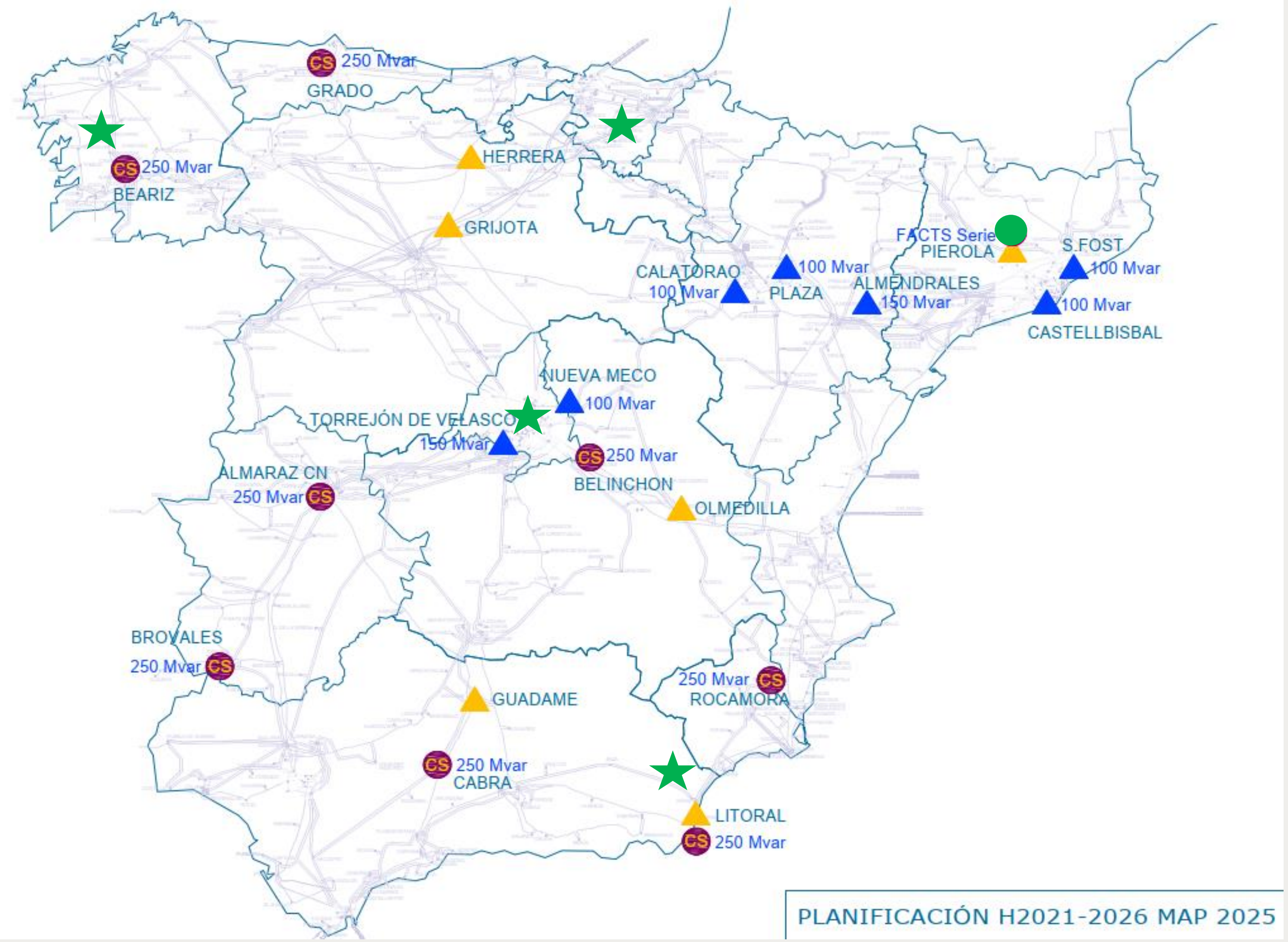
1500 km New underground cables

1900 New Substation Bays; **280** Bays refurbished

20% of the transmission grid uprated or refurbished

Additional Modification of the Network Development Plan to include measures for Voltage Control

- Peninsula
  - **8** SYNCONs (2000 MVAr total)
  - **7** New Reactors (650 MVAr total)
  - **6** Renovation Reactors (900 MVAr total)
  - **60** Additional Controlled Switching Relays
  - **1** FACTS series
  - **4** STACOMs (2 in service, 2 in construction)
- Canary Islands System
  - **2** SYNCONs (50 MVAr) (+2 in construction)
  - **2** New Reactors (13 MVAr total)
- Balearic Islands System
  - **1** SYNCON (100 MVAr) (added to 1 under construction)
  - **1** New Reactors (20 MVAr total)



Thank you!

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It’s time for Q&A

Moderator : Pierre Coudereau