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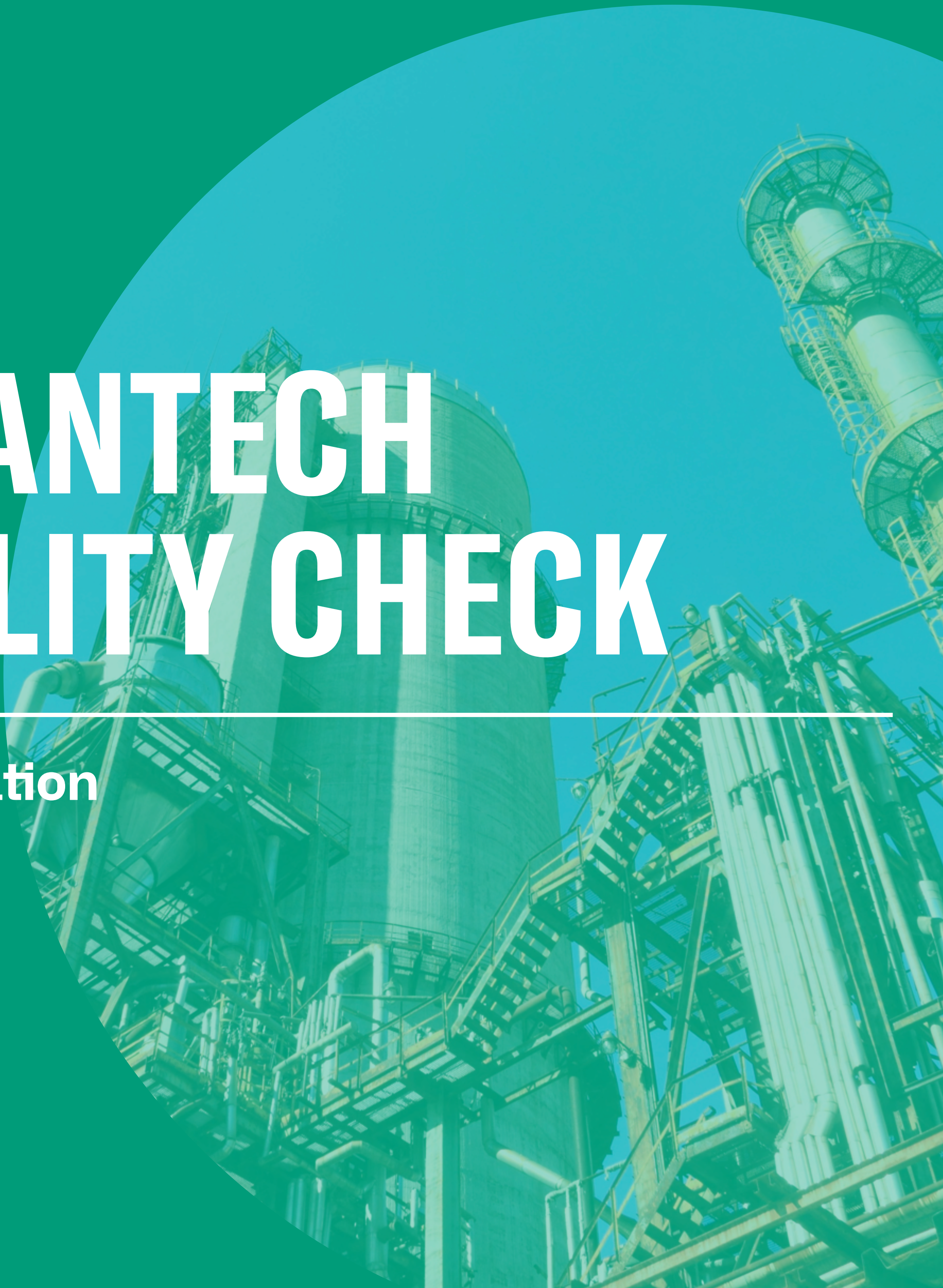
CLEANTECH REALITY CHECK

Electrification



CLEANTECH REALITY CHECK

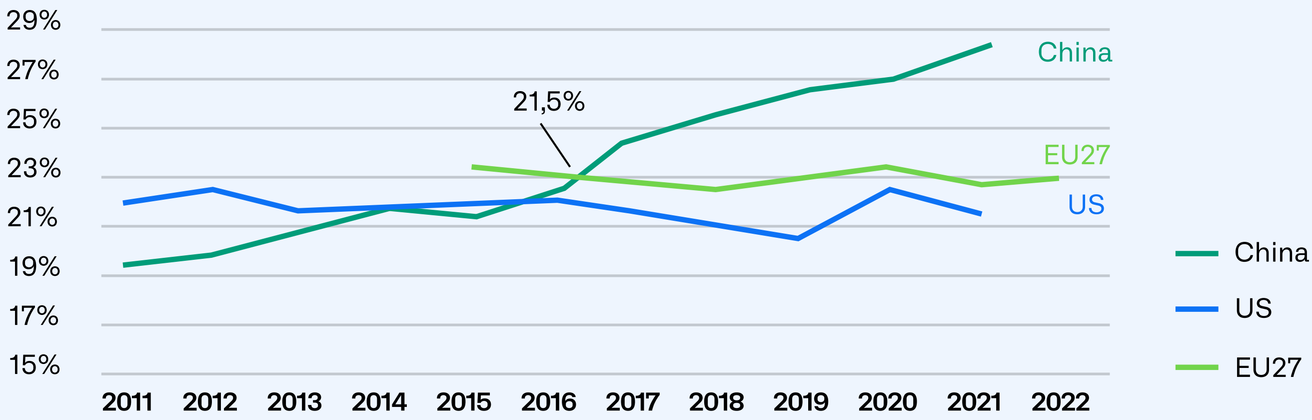
THE ELECTRIFICATION MIRAGE FOR EUROPE?

EUROPE NEEDS A JOLT OF ELECTRICITY DEMAND IF IT WANTS THE CLEAN INDUSTRIAL DEAL TO SUCCEED

By **Ann Mettler,** Vice President - Europe and **Julia Reinaud**, Senior Director - Europe, **Breakthrough Energy**

- Europe routinely speaks about 'electrification' as if it is happening. But data tells a different story: demand is flat – and has been for years. In other words: the much-touted electrification revolution in Europe is (so far) failing to materialise.
- Despite ambitious rhetoric and policy initiatives, the stark reality is that Europe is not rising to the occasion and does not currently have the speed and scale required to meet its targets and is nowhere near China's electrification drive. This is yet another example of a divide between assumptions and on-the-ground realities.
- This disconnect has very serious spillover effects: with so little additional demand for electric-based technologies and long queues to connect to the electricity system, there isn't the necessary boost to provide the abundant and affordable clean electrons that industry needs to decarbonise.
- And manufacturing sectors are hurting, too. Despite our supposedly ambitious clean energy transition and renewable targets, our home-grown wind sector is on its knees. Yet another indicator that we need to stress-test the presumably inevitable trajectory towards electrification.
- At the root of this issue is a disjointed policy plan: while going all in on renewables for years, there has only very recently been an accompanying strategy for energy storage and grid modernisation. This is an essential piece of the puzzle because as we all know the sun doesn't always shine and the wind doesn't always blow. The seeming inability to think of – and build towards – a modern energy **system** means that storage and grids are now lagging far behind. Moreover, the rollout of renewables has been uneven with much faster deployment of solar, de-coupled from wind.
- It will be imperative that the EU's (existing) Grid Action Plan and (forthcoming) Electrification Strategy provide an honest stock-take that includes a more holistic approach. They need to connect the dots between a volatile energy system, squeezed industry, and the clean technology enablers that can provide solutions to both – such as Long Duration Energy Storage to absorb and use these clean electrons at all times, and Thermal Energy Storage to electrify Industrial Heat as flexible demand.
- The bottom line is that much of Europe's approach simply doesn't add up and therefore calls for an urgent reality check.

Electrification rate by country



Source: Eurelectric's Power Barometer (2024) based on IEA's Country Energy Profile (2024)

The Cleantech Reality Check is published jointly by Breakthrough Energy and Cleantech for Europe, with analytical support provided by Systemiq.

CLEANTECH REALITY CHECK

THE ELECTRIFICATION MIRAGE FOR EUROPE?

- Electricity demand across the continent has remained stubbornly flat at 22% of final energy demand since 2010, a significant deviation from the EU's renewable energy goals, which target a 37-40% electrification rate by 2030.
- This Cleantech Reality Check highlights three pivotal technologies with the potential to drive electrification across the continent: Long Duration Energy Storage (LDES), industrial heat electrification, and grids extension and modernisation. By examining the progress and challenges associated with these technologies, it reveals that without immediate, coordinated action to accelerate offtake and deployment, Europe's clean energy transition and its broader climate goals are at significant risk.

OFF-TRACK — ON-TRACK

LONG DURATION ENERGY STORAGE

LDES technologies store and convert energy for longer time periods (8+ hours). LDES becomes critical in regions with >50% of variable renewable electricity sources in their electricity mix, to ensure a reliable electricity supply. Several countries in the EU have reached or are close to reaching this threshold.

- Electrochemical (power-to-power): e.g., flow battery, metal air
- Mechanical (power-to-power): Pumped-Hydro Storage PH or other less traditional technologies such as compressed or liquid air
- Thermal (power-to-heat): heat storage e.g., molten salt or heat storage bricks
- Chemical (power-to-x): Storage of e.g., hydrogen or ammonia before they are used as fuel or chemical feedstock

Thermal LDES presents advantages: simplicity of technology (compared to PHS that are harder to build), near-term cost competitiveness vs. fossil-based heat, especially in regions with lower renewables cost or curtailed renewable energy.

INDUSTRIAL HEAT ELECTRIFICATION

Industry represents 10-15% of EU final energy demand (1,800 TWh). Industrial heat is categorised into three ranges of temperature : low (<100°C) at 15-25% of demand, medium (100-400°C) at 30-40%, high (>400°C) at 45-55%. For low-temperature range, industrial heat pumps and thermal energy storage (Power-to-Heat) and e-boilers are the preferred solution, with heat pumps offering the highest efficiency. Medium temperature heat range is currently not feasible for heat pumps. Therefore, it will need to rely on other technology such as Thermal Energy Storage. High temperature heat electrification solutions are process-specific (e.g., electric furnaces) and still nascent, therefore shifting the near-term focus on <400°C range.

GRID INFRASTRUCTURE

Grids connect power generators to power consumers via high-voltage transmission lines, substations, and distribution systems. They play a crucial part in a net-zero economy where electricity is likely to supply up to 70% of final energy demand. Two complementary type of actions are required for grids: buildouts, which can take up to 10 years of development in Europe; and modernisation of existing assets, representing an opportunity to deploy new technologies to enhance existing grid framework in a shorter timeframe. All in all, the grid system requires significant action to not only meet EU's climate goals, but also powering Europe's energy system and maintain stability with increasing variable renewables in the grid.

	Long Duration Energy Storage	Industrial Heat Electrification	Grid Infrastructure
Required in place or pace by 2030 Breakdown of requirement	**~130 GW** **Pumped-Hydro Storage:** ~65 GW **Novel LDES technology:** ~65 GW *Novel LDES includes Thermal, Chemical, or Electrochemical (non-Li-ion) Energy Storage*	**~425 TWh** **Low range (<100°C):**): ~175 TWh **Med range (100-400°C):** ~200 TWh	Distribution **17M km** — **250k km/year** of buildout pace to reach target Transmission **0.8M km** — **10k km/year** of buildout pace to reach target
Progress	**0.8 GW of novel LDES** is operational today **3.7 GW of novel LDES** under development	**50-100 TWh** in low-to-medium range	**Current build out pace [required increase]** **80k km/yr** [x3] **0.5k km/yr** [x200]
What is working well	• Power market reform gives signals for energy storage development • Flexibility assessments methodology finalisation • Countries starting LDES auctions	• Successful use cases for some deployed projects • Power market designs going in right direction • Access to wholesale prices with renewable electricity source	• Highly reliable and functional grid • Leading European grid cable manufacturing supply • Increased policy awareness of importance of grid
What is not working well	• Lack of clear revenue model for LDES • Lack of targets and action plan on flexibility and storage • Lack of level playing field with other technologies	• Lack of financing options and fiscal incentives • Issues of technology awareness and scalability • Unsupportive grid connection processes and fees	• Lack of forward-looking planning and legislated targets • Lack of financing structures and incentive schemes for innovation and infrastructure development • Permitting and compliance processes resulting in backlog and limited pace of expansion • Cable industry is under pressure and fully booked production lines

Notes: All sources for data points are provided in the three sectoral briefs for Series 2.

CLEANTECH REALITY CHECK

THE ELECTRIFICATION MIRAGE FOR EUROPE?

ARE THE ENABLING CONDITIONS FOR RAPID SCALE UP IN PLACE?

- In place and sufficient
- In place and insufficient
- Missing
- No applicable

DEMAND ENVIRONMENT ENCOURAGES EARLY OFFTAKE

Missing	Missing	Missing	Legislated targets set an ambitious horizon for technology adoption
Missing	In place and insufficient	In place and insufficient	Sufficient coordination between relevant sectors and government bodies
Missing	In place and insufficient	In place and insufficient	Permitting and approval processes matching pace of required uptake

SUPPLY ENVIRONMENT ENABLES ECONOMIES OF SCALE

Missing	Missing	Missing	Revenue mechanisms aligned with uptake of required solutions
In place and insufficient	In place and insufficient	Missing	Subsidies and incentives targeted to de-risk innovation
In place and insufficient	In place and insufficient	No applicable	Initiation of demand via government-backed market mechanism

MARKET IS FACILITATED AND COORDINATED

Missing	Missing	In place and insufficient	Technology awareness across key stakeholders
In place and sufficient	In place and insufficient	In place and sufficient	Technology and/or enabling infrastructure are mature
In place and insufficient	In place and insufficient	Missing	Pace of innovation adoption meets sectoral needs

ACTION AGENDA

Key actions and interventions areas to develop the EU electrification system

	LONG-DURATION ENERGY STORAGE	INDUSTRIAL HEAT ELECTRIFICATION	GRID INFRASTRUCTURE
1	Develop storage targets and action plan, including LDES targets in Nationally Determined Contributions (NDCs) and National Energy & Climate Plans (NECPs)	Increase awareness of technology, to decrease perceived risk and enable access to funds	Implement an integral strategic vision and targets for coordinated EU network buildout and modernisation
2	Provide incentive mechanism that is aligned with positive externalities to improve business case	Provide supportive ecosystem for novel technologies, starting from sectoral mandates up to novel technology inclusion	Reform investment paradigm and financing structures to stimulate investment in a future-proof grid
3	Introduce innovative financing facilities and structures focused on project de-risking for novel LDES technologies	Introduce de-risking mechanisms for novel technologies, focused on demand-side (industry)	Address slow permitting and approvals that limits pace of capacity expansion
4	Introduce a fit for purpose power grid regulation to streamline solicitation process and adjust fees accordingly	Provide clarity on prices and taxes related to fossil fuels moving forward	Provide financial incentives to de-risk and speed up adoption of new technologies by system operators

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ELECTRIFIED INDUSTRIAL HEAT

Charging up the industry

What is electrified industrial heat ?

Industrial heat represented 10-15% of the EU's final energy demand (1,800 TWh) in 2020, and is categorised into three ranges of temperature: low (<100°C) representing 15-25% of demand, medium (100-400°C) 30-40%, and high (>400°C) 45-55%.[1] For the low-temperature range, industrial heat pumps and thermal energy storage (Power-to-Heat, or PtH) and e-boilers are the preferred solution, with heat pumps offering the highest efficiency. Medium temperature heat range is currently not feasible for heat pumps, therefore will need to rely on other technology such as Thermal Energy Storage. High temperature heat electrification solutions are process-specific (e.g., electric furnaces) and still nascent, therefore shifting the near-term focus on the <400°C heat demand range.

Key take-aways

- Currently, only 100 TWh of EU industrial heat is electrified, mostly in low-heat range, way off from the ~425 TWh needed to reach EU's 1.5°C goals in 2030. In the next five years, ~350 TWh more Power-to-Heat (PtH) must be installed, which requires €100-150 billion of investment for PtH technology and up to €300 billion for accompanying the buildout of renewables.
- Recently, Thermal Energy Storage (TES) solutions deployed in industrial facilities have shown positive signs of economic viability. However, a scalability issue persists, mostly factored by lack of technology awareness and difficulty in accessing financial instruments or incentive mechanisms, which are often geared to other PtH technologies.
- The EU must increase the awareness of industry stakeholders and financiers towards PtH technology, in particular novel ones such as TES. Impact-aligned incentive mechanisms could support a stronger business case for industry heat electrification deployment.

ELECTRIFIED INDUSTRIAL HEAT

CHARGING UP THE INDUSTRY

STRATEGIC OBJECTIVES FOR EUROPE

- **Decarbonise 50-75% of industry-related emissions** attributable to industrial heating[1]
- Accelerate **electrification goals** to **decrease reliance on fossil fuel** imports from other countries (e.g., natural gas)
- Allow higher **penetration of renewables** into the EU grid
- Maintain **industrial competitiveness and jobs** by decoupling costs from fossil fuel volatility risks, which contributed to 35-45% of EU aluminium, zinc and silicon production taken offline[2]

CURRENT PROGRESS OF HEAT ELECTRIFICATION IN THE EU

OFF-TRACK — ON-TRACK

STATUS: NOT ENOUGH PROGRESS As The EU focuses on 2030 decarbonisation goals, electrifying industrial heating is still off-track due to low deployment rates, especially in the medium (100-400°C) and high (>400°C) temperature ranges.

<100 TWh industrial heat in low-to-medium range was delivered via electrified technology in 2022[2]

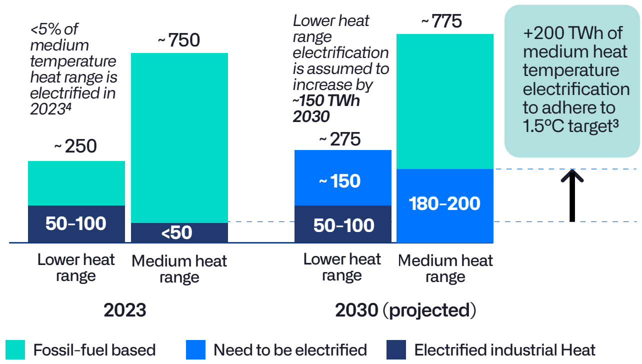
~425 TWh of heat in low-to-medium range required by 2030 to reach 1.5°C[3]

ELECTRIFICATION IS SHOWING SIGNS OF PROGRESS, BUT NOT MUCH IN MEDIUM HEAT RANGES

- Less than 10% of the EU's industrial heat is electrified, mostly in the low-heat range. To reach 1.5°C goals in 2030, **~350 TWh** (~6x current capacity) more Power-to-Heat must be installed in the next five years.
- **~200 TWh** of medium temperature industrial heat needs to be electrified **in 2030**. This requires accelerated commercial deployment of Thermal Energy Storage solutions of **~40-50 TWh/year** in the next five years.
- To reach the required electrification levels, around **€100 to 150 billion of investment for PtH technology is required,**[5] and up to **€300 billion** for accompanying renewables buildout.[6]

Electrification of industrial heat demand <400°C

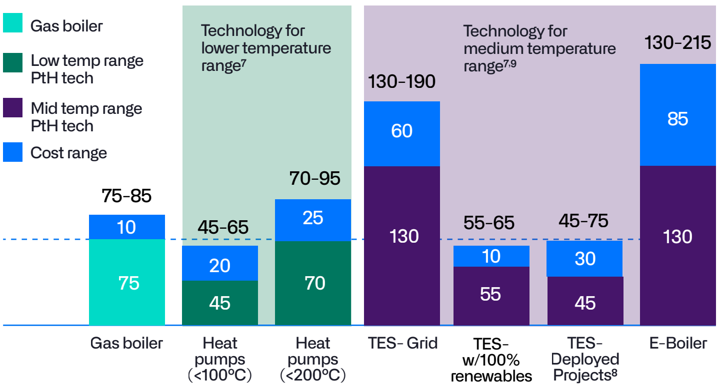
TWh



LOW TEMPERATURE HEAT HAS ACHIEVED AN AFFORDABILITY TIPPING POINT, BUT MEDIUM HEAT IS STILL FAR FROM COST COMPETITIVENESS IN MOST CASES

Comparison of 2030 cost of heat for Thermal Energy Storage (TES) Power-to-Heat technologies[7]

€/MWh-thermal



- For lower heat ranges (0-100°C), electrified heat technology is close to reaching cost parity with gas boilers.
- For medium range, the main barrier for Power-to-Heat is wholesale electricity price and grid fees, resulting in 20-40% cost difference.[7]
- The main drivers to achieve cost competitiveness are onsite pairing with renewables and project tailoring to site.

Notes: 1. Decarbonizing Industrial Heat- an important puzzle piece to solving climate change (CleanTech for Europe, 2023) | 2. EURElectric Power Barometer 2024 | 3. Climate Action Tracker Paris Agreement Compatible Sectoral Benchmarks (2020) | 4. Based on assumptions that deployed heat pumps and Power to Heat technologies are in industries with lower heat demands. | 5. Based on CAPEX assumptions from Global ETES Opportunity (Systemiq, 2023) | 6. Assuming 70% Wind and 30% Solar PV balance for VRE mix, CAPEX for Offshore Wind is at €2300-2800/kWh and CAPEX for Utility scale Solar PV is at €800-1200/kWh, sourced from European Commission Directorate-General for Economic and Financial Affairs: The Development of Renewable Energy in the Electricity Market (2023) | 7. Numbers are calibrated for EU from Global ETES Opportunity (Systemiq, 2023) | 8. Based on 3 case studies of deployed Thermal Energy Storage projects in Spain and Germany. Technical details around % mix of dedicated VRE and grid electricity used are not available. | 9. Using assumptions of 95% efficiency of Power-to-Heat technologies, and VRE is dedicated to supply Power-to-Heat technologies, and LCOE from Global ETES Opportunity (Systemiq, 2023) and World Energy Outlook 2024 (IEA)

ELECTRIFIED INDUSTRIAL HEAT

CHARGING UP THE INDUSTRY

ENABLERS – WHAT IS GOING WELL

SUCCESSFUL CASES FOR DEPLOYED PROJECTS

Low energy prices make electrified industrial heating cost competitive with gas boilers in the Nordic & Iberic regions. Furthermore, with Thermal Energy Storage (TES) technology being able to retrofit existing fossil power plants installations, the required initial investments are reduced.

START OF FLEXIBLE DEMAND ASSETS INTEGRATION TO THE HEAT & POWER SYSTEM

Several EU Member States have started the integration of flexible assets into their heat & power system by conducting flexibility assessments (e.g., Spain, Netherlands) and mandating heat decarbonisation roadmaps (e.g., Germany), which supports TES deployment.

ACCESS TO WHOLESALE PRICES WITH RE SOURCE

Energy-intensive industrial sites can access wholesale power prices by connecting TES technology to a renewable electricity (RE) source, either directly or through a private wire. This reduces the cost of heat greatly, depending on geographic location.

BARRIERS – WHAT IS NOT GOING WELL

LACK OF FINANCING AND FISCAL INCENTIVES

In most EU countries, with the exclusion of countries such as Spain and Germany, TES technology does not have demand-side mechanisms to leverage as point of entry. Support mechanisms are lacking, such as public incentives (accessible for Li-ion batteries and heat pumps) and project de-risking mechanism (e.g., first loss guarantees, direct financing).

AWARENESS AND SCALABILITY ISSUES OF TECHNOLOGIES

Even with successful pilot and implementation projects, electric heat technology solutions are facing issues to scale up due to low awareness of technology from industry and low electrification of targeted industries. The EU's Emissions Trading Scheme 2 (ETS 2) is expected to increase electrification but will only be launched in 2027.

UNSUPPORTIVE GRID CONNECTION PROCESSES AND FEES

TES technologies face challenges due to lengthy processes industries encounter when increasing or adjusting grid connection capacity. Generally, industry also lack access to the grid's dynamic price signals and do not have additional revenue streams from ancillary (e.g., capacity payments).

ACTION AGENDA – WHAT NEEDS TO BE DONE

1. **Increase awareness of technology:** Electrified heat technologies outside of heat pumps are still not well known, resulting in higher perceived risk profiles or lower access to funds to de-risk the projects. For example, in Germany, hydrogen is seen as the main replacement of natural gas, while TES technologies are not yet considered in planning and analysis.

2. **Provide supportive mechanisms to build competitive business cases:** Introduce specific criteria for sectors that can act as lead-markets for clean industrial heat applications to promote novel Power-to-Heat technologies. Incentives (e.g., revenue mechanism) and fees (e.g., grid fees) should also reflect externalities outside of decarbonising heat e.g., curtailment avoidance, grid balancing services, and off-peak demand. Schemes should also be more inclusive to novel technologies, as these have to showcase business case certainty for cost effective heat decarbonisation to accelerate scalability by 2030.

3. **Introduce de-risking mechanisms for novel technologies, focused on demand (industry):** Mechanisms such as guarantees should focus not only on CAPEX but also on OPEX (e.g., power price guarantee) to provide additional incentive for project implementation, which is critical in cost improvements for novel Power-to-Heat technologies in medium and high-temperature heat ranges. The EU-Catalyst partnership is a good example on de-risking novel technologies for industrial heat.

4. **Provide clarity on prices and taxes related to fossil fuels moving forward:** Currently, industrial players are skeptical of fully adopting heat electrification technologies due to uncertainty on energy prices and other costs related to it in the coming years, increasing project risk.

"Increasing the collective awareness of both industrial actors and financiers is critical to accelerate the uptake of electrified industrial heat solutions and power-to-heat technologies in sectors that need to reduce their emissions if we want to reach our decarbonisation goal."

Susanne König, Chief Finance Officer of **Kraftblock GmbH**

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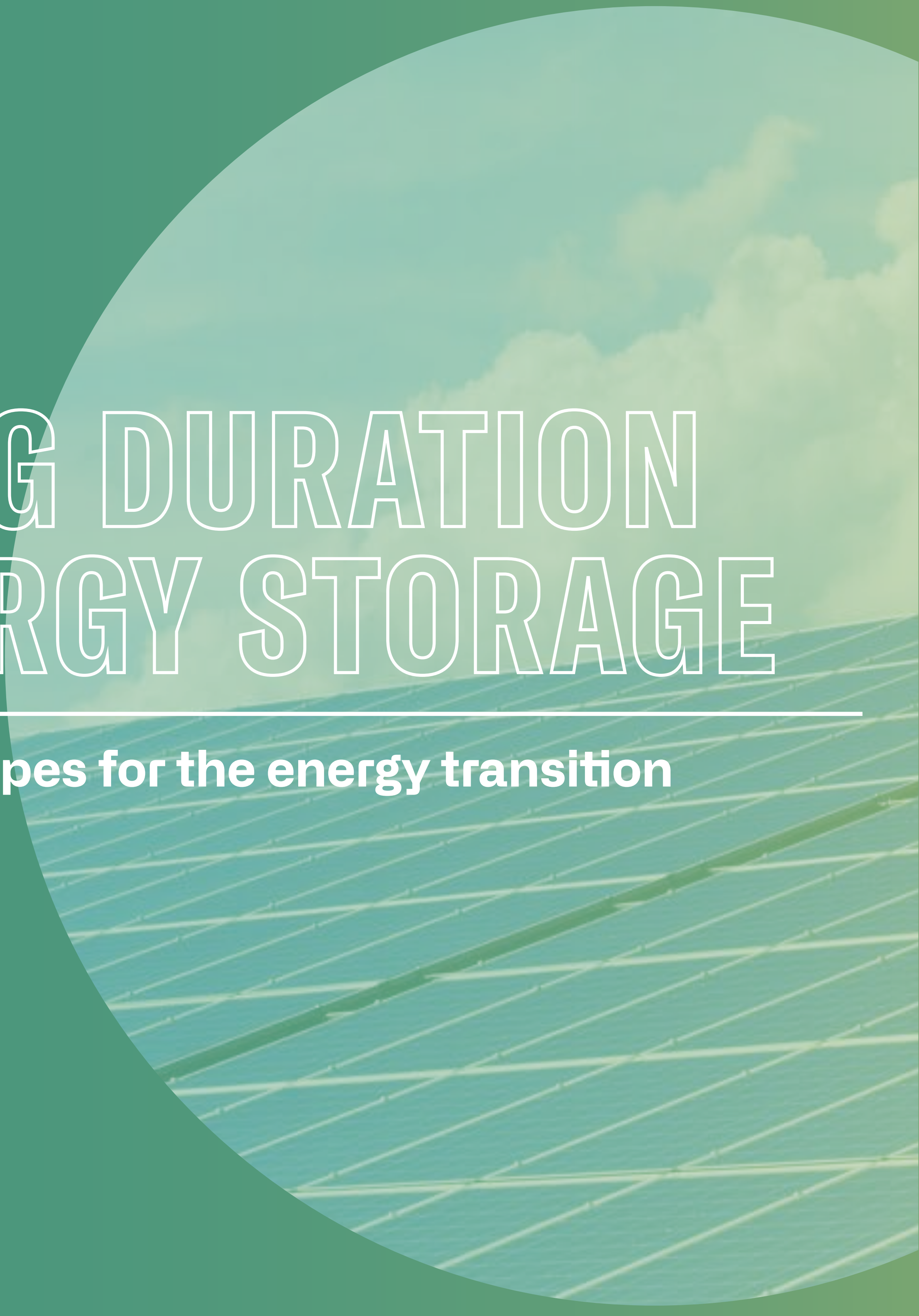

LONG DURATION ENERGY STORAGE

Storing hopes for the energy transition

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CLEANTECH REALITY CHECK

LONG DURATION ENERGY STORAGE

Storing hopes for the energy transition

What is LDES ?

Long Duration Energy Storage (LDES) technologies store energy for long time periods (> 8 hours), to be used at a deferred time through reconversion or as a different carrier. LDES provide profile smoothening and curtailment avoidance for renewables. LDES solutions consist of :

- Electrochemical (power-to-power): e.g., flow battery, metal air.
- Mechanical (power-to-power): Pumped-Hydro Storage or other less traditional technologies such as compressed or liquid air.
- Thermal (power-to-heat): heat storage e.g., molten salt or heat storage bricks.
- Chemical (power-to-x): Storage of e.g., hydrogen or ammonia before they are used as fuel or chemical feedstock.

Currently, Pumped-Hydro Storage, the most mature LDES technology, faces limitations due to geographic needs such as water proximity and elevation. Other LDES solutions are therefore needed. Specifically, thermal LDES solutions have an advantage of simplicity of technology for installation. Thermal LDES can also displace fossil thermal power plants in district heating, as well as near-term cost competitiveness vs. fossil-based heat source especially in regions with lower renewables cost or curtailed renewable energy.

Key take-aways

- The EU needs ~200 GW of non-fossil fuel storage to reach 55% decarbonisation by 2030, of which ~130 GW is LDES. Of the 130 GW, 65 GW will be served by Pumped-Hydro Storage (PHS), and 55-65 GW by novel LDES technologies. To achieve this objective, the EU is required to install 10 GW/year in the next five years.
- LDES recently gained momentum due to a power market reform, mandates for country-level flexibility assessments, and the initiation of storage auctions in several countries. However, barriers to LDES deployment remain and include the lack of specific goals and action plans, resulting in uncertainty in permitting processes and an unleveled playing field with other (shorter duration) storage technologies such as Li-ion batteries.
- Moving forward, the EU must start laying the foundation for LDES scale-up. This starts with setting targets and action plans, introducing incentives and de-risking mechanism to increase business case viability, as well as adjusting grid regulation to support LDES integration into the power system.

LONG DURATION ENERGY STORAGE

STORING HOPES FOR THE ENERGY TRANSITION

STRATEGIC OBJECTIVES FOR EUROPE

- **Provide flexibility and enable renewables growth** in power market, as the EU's 42.5% renewables target by 2030 cannot be achieved with a stable energy system without storage and penetration of variable renewable power is exceeding 40% in six Member States.[1]
- **Reduce curtailment of renewable electricity by 5-10%[2] in 2030**, saving significant administrative costs (at around €10-20 billion)[2]
- Provide **clean dispatchable power and grid balancing mechanism** that can be produced domestically, reducing **dependency on imported fossil fuel for grid balancing** supply
- Support retrofitting of fossil assets that conserve existing skillset during operation and provide **additional jobs with new skillsets**

CURRENT PROGRESS OF LONG DURATION ENERGY STORAGE IN THE EU

OFF-TRACK — ON-TRACK

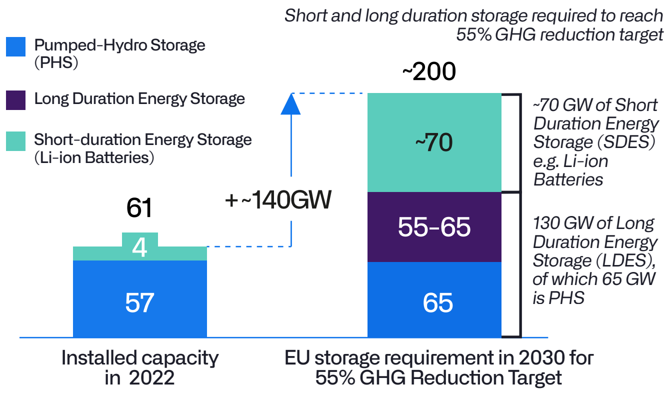
STATUS : NOT ENOUGH PROGRESS In order for the EU to reach their renewable energy goal in 2030, the yearly deployment rate of LDES - especially novel LDES technologies - needs to expand in the next five years.

0.8 GW of novel LDES technology is operational[7] and **3.7** under development[7] out of additional **65 GW** required by 2030.

A RAPID DEPLOYMENT OF LDES IS NEEDED TO REACH THE EU'S RE GOALS IN 2030

- The EU needs ~200 GW of non-fossil fuel storage to reach 55% decarbonisation by 2030, of which ~130 GW is LDES[3] (incl. Pumped-Hydro Storage (PHS)).
- Only ~57 GW of LDES storage is currently deployed. All 57 GW is PHS, a technology that is projected to max out at 65 GW by 2030. In the next five years, 55-65 GW of novel LDES technology outside of PHS is required, equal to installing 10 GW/year.
- 118 TWh of renewables is projected to be curtailed in 2030. Deploying 55-65 GW of additional LDES can help reduce 5-10% of curtailment, assuming each 10 GW LDES helps avoid 2-4 TWh renewables[5] curtailment.

Installed and required storage capacity in the EU[3]
GW

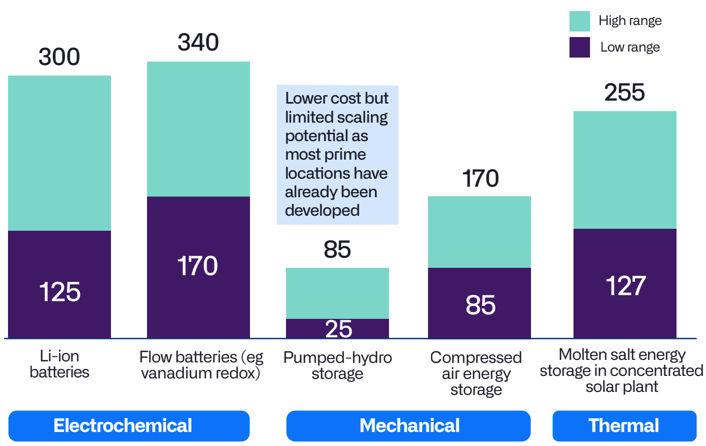


LDES COSTS ARE HARD TO COMPARE TODAY BUT OPTIMISTIC ESTIMATES MAY RIVAL GAS GENERATION BY 2030.

Updated in December 2024 to reflect EU-focused ` LDES cost comparisons

- Comparing LDES costs is challenging due to the lack of Europe-focused surveys, varied technology capabilities (e.g., energy capacity, power output, efficiency), and differing costs across use cases like frequency regulation, peak shaving, or grid stability.
- New storage technologies, such as liquid CO2, are showing strong traction and are deploying first projects in Europe.
- By 2030, the Long Duration Energy Storage Council 2024 annual report[6] indicates that LDES installation costs could drop significantly – up to 60% for electrochemical and mechanical solutions and 50% for thermal – making the lowest estimates competitive with gas generation.

Levelised cost of storage (LCOS) in 2024[7]
€/MWh



Notes: 1. European Environment Agency – Share of VRE in each country | 2. ACER 2024 Market Monitoring Report – assuming €4B per 10 TWh curtailed (in Germany) | 3. Study on energy storage: Contribution to the security of the electricity supply in Europe: EU Directorate General of Energy (2020), using METIS-Baseline 2030 Scenario, aligned with 55% GHG Reduction targets and 37% VRE penetration compared | 4.Making Clean Power Flexy (EMBER, 2023) | 5. Scenario Deployment Analysis for Long-Duration Electricity Storage: A study of the benefits of Long-Duration Electricity Storage technologies on the GB power system (LCP Delta, 2023)| 6. Long Duration Energy Storage Council (2024), 2024 Annual Report | 7. All costs are extracted from Rahbari, H. R., Mando, M, Arabkoohsar, A, Sciencedirect (2024), Real-time modeling and optimization of molten salt storage with supercritical steam cycle for sustainable power generation and grid support | 8. Systemiq calculation using Cost Projections for Utility-Scale Battery Storage: 2023 Update (NREL) and 0.04 – 0.05 $/kWh LCOE | 9. LCOS of LDES technologies are derived from Real-time Modeling and Optimisation of Molten Salt Storage with Supercritical Steam Cycle for Sustainable Power Generation and Grid Support (H.R. Rahbari et al., 2024)| 10. Power-to-Heat technologies are calculated based on reconversion from heat/gas to power. 11. 2024 LDES Annual Report (LDES Council, 2024)

LONG DURATION ENERGY STORAGE

STORING HOPES FOR THE ENERGY TRANSITION

ENABLERS – WHAT IS GOING WELL

POWER MARKET REFORM GIVES SIGNALS FOR ENERGY STORAGE DEVELOPMENT

The 2022 EU power market reform has kickstarted several supportive policies such as grid fee reductions (e.g., Germany) and incentives for off-peak demand (e.g., Denmark), or public financing (e.g., Spain).

FLEXIBILITY ASSESSMENTS METHODOLOGY FINALISATION

Transmission System Operators (TSOs) of EU countries are starting to submit flexibility assessments that includes non-fossil fuel technology, where LDES is expected to play a role in providing system flexibility as renewables penetration continues to grow.

COUNTRIES STARTING LONG-DURATION ENERGY STORAGE AUCTIONS

LDES auctions have started in several countries (e.g., Italy, Germany, Ireland), giving momentum to the deployment of LDES technologies in the power system.

BARRIERS – WHAT IS NOT GOING WELL

LACK OF CLEAR REVENUE MODEL FOR LDES

Lack of revenue mechanisms for LDES hinders the development of strong business cases for new projects. Storage technologies also experience double-charging of fees and go through two different permitting and solicitation processes as both consumers and producers/generators of electricity.

LACK OF TARGETS AND ACTION PLAN ON FLEXIBILITY AND STORAGE

Unlike for renewable energy and grids, countries do not have to commit to action plans and targets for storage, including LDES. This leaves LDES technology out of electricity system planning and analysis, and limits awareness of the technology.

LACK OF LEVEL PLAYING FIELD WITH OTHER TECHNOLOGIES

Novel LDES often gets less acknowledgement and awareness than other more stablished storage technologies like PHS and Li-ion. This results in an unleveled playing field, from access to public mechanisms (innovation funds), or revenue schemes (capacity payments) that are key to support their deployment.

ACTION AGENDA – WHAT NEEDS TO BE DONE

1. **Develop storage action plan and target:** The EU can accelerate this by regulating member states to develop storage, flexibility targets and action plans that include assessments of storage needs and are tied to Nationally Determined Contribution (NDCs) and National Energy & Climate Plans (NECPs), as well as commission national-level studies on LDES technology to mainstream the cause. These should include LDES use for all relevant sectors (electricity, heat, industry and transport).

2. **Provide supportive ecosystem to build compelling business cases for novel technologies:** Fiscal incentives must be adjusted to accommodate novel LDES technologies that bring positive externalities to the energy system such as flexibility, balancing or fossil fuel displacement. Supportive incentives such as revenue mechanisms (e.g., capacity payments) can accelerate deployment that is critical for technology and cost improvements.

3. **Offer novel de-risking mechanisms:** De-risking instruments, such as blended finance and public guarantees (e.g., USA Department of Energy's Loan Guarantees or the EU-Catalyst Partnership) can help scale novel LDES technologies. The EU should introduce or facilitate public guarantees to reduce project and counterparty risks and incentivise private investment in novel storage technologies.

4. **Develop a fit for purpose power grid regulation:** Review grid regulation related to storage technologies, starting from storage asset classification, adjusting grid costs (fees, taxes and levies), and a faster and more unified storage grid access solicitation process as generator and consumer, to streamline deployment of LDES technologies.

"Developing clear energy storage and system flexibility targets that are both technology-inclusive and directly tied to Nationally Determined Contributions would enable the accelerated deployment of long duration energy storage technologies that provide a range of powerful grid, economic, and social benefits to the EU energy system."

Julia Souder, Chief Executive Officer - **LDES Council**

Breakthrough Energy   Cleantech for Europe   With analyses led by SYSTEMIQ

CLEANTECH REALITY CHECK

GRIDS

Strengthening the backbone of the EU's decarbonisation efforts

What are grids ?

Power grids connect power generators to power consumers via high-voltage transmission lines, substations, and distribution systems. They play a crucial part in a net-zero economy where electricity is most likely to supply up to 70% of final energy demand. Two complementary type of actions are required for grids: buildouts, which can take up to 10 years of development in Europe; and modernisation of existing assets, representing an opportunity to deploy new technologies to enhance existing grid infrastructure in a shorter timeframe. The grid system requires decisive action to achieve EU climate goals, ensure stability amid increasing renewables, and unlock cost-saving potential through greater interconnection among Member States.

Key take-aways

- Currently, only ~11 million of the 17.8 million kilometers required by 2040 is built. To reach the target by 2040, distribution buildout must be increased by 3x, and transmission grids face a tougher challenge of increasing build-rate by 20x.
- The EU has a good foundation of existing asset base and manufacturing capacity and capability on which to build an improved grid system. The main challenge lies in planning and setting targets for buildouts, resulting in slow permitting processes that add lag time to the construction of infrastructure assets.
- Moving forward, the EU must create a conducive ecosystem for grid buildout by shifting the investment paradigm through prioritisation of grid optimisation before enhancement and expansion, as well as looking at total project expense rather than only capital expenses.
- Addressing ownership issues in grid infrastructure development requires improvements in planning processes and coordination. A more holistic, forward-looking, and collaborative approach to European grid infrastructure planning, supported by legislated targets, should integrate decarbonisation plans, renewable electricity generation, flexibility solutions, and interconnection expansion.

POWER GRIDS

STRENGTHENING THE BACKBONE OF THE EU'S DECARBONISATION EFFORTS

STRATEGIC OBJECTIVES FOR EUROPE

- Grids are critical to **reach 2030 renewables targets** and **2050 net-zero ambitions** and manage a surging **renewable power market** by proactively avoiding curtailment issues.
- Accelerating the buildout rate and modernising the grid will require **doubling the current annual investment in grid infrastructure, delivering significant economic benefits to the EU economy.**
- Europe needs to maintain its position as a **global leader for cable manufacturing.**
- Future-proofing the power grid is essential for the **EU to remain a globally competitive place to do business** with the oncoming steep electrification rate of industry and transport.

CURRENT PROGRESS OF GRID EXPANSION IN THE EU

OFF-TRACK — ON-TRACK

STATUS: OFF-TRACK The EU is home to the biggest connected synchronous grid globally but is facing an unprecedented challenge to meet the EU's increasing power demand. The current annual investment into grid buildout and modernisation needs to double to meet the EU's energy transition power needs.

10.8 MILLION KMS BUILT
OUT OF
17.8 MILLION KMS REQUIRED

ANNUAL GRID BUILDOUT (KM)

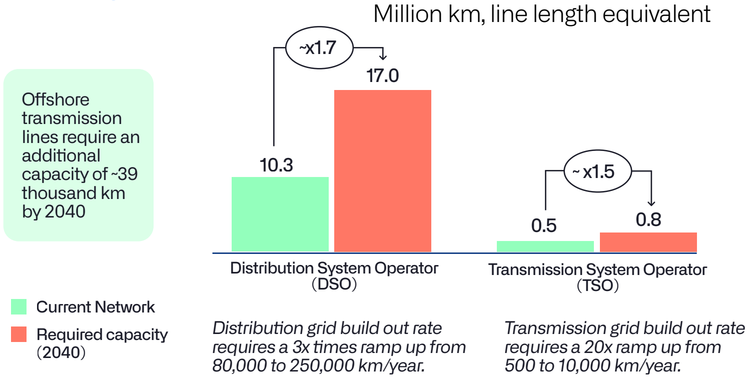
	Current (2022)		Needed (2025-40)
Distribution	80,000	x 3	250,000
Transmission	500	x 20	10,000

STEEP GRID BUILDOUT IS REQUIRED TO MEET POWER DEMANDS BY 2040 — MODERNISATION CAN FAST-TRACK

Innovative grid technologies have the potential to speed up realisation of required grid expansion by:

- 8 years (from 2040 to 2032) for the transmission grid.
- 7 years (2040 to 2033) for the distribution grid.[1]

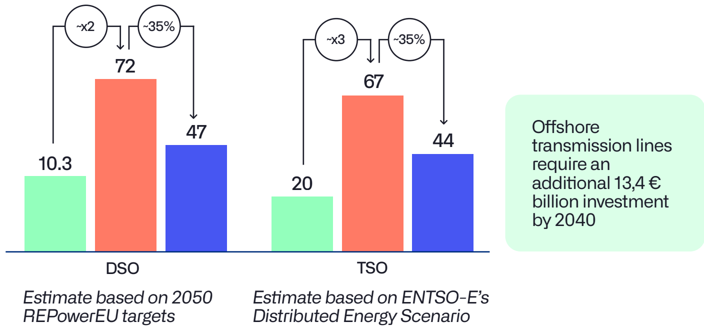
EU grid size requirements for distribution and transmission
Million km, line length equivalent



CURRENT ANNUAL GRID INVESTMENT NEEDS TO ROUGHLY DOUBLE TO MEET GRID EXPANSION TARGETS

- The nominal cost of building underground power lines is ~7x higher than building above ground for both transmission and distribution lines.[3]
Capital expenditures (CAPEX) range from €5-12.5 million per kilometer for underground lines and €0.7-1.8 million per kilometer for overhead lines[4] (lower bounds are distribution, upper bounds are transmission).

Annual grid investments required in the EU between 2025-2040
€ Billion



Notes: 1. Estimate sourced from Prospects for Innovative Grid Technologies (CurrENT 2024), assumes 10-20% capacity improvement on existing and all newly built grid assets by deployment of Innovative Grid Technologies, does not include the deployment costs for innovative grid technologies themselves | 2. Assumption that 64% of investment is done in DSO grid, 36% in TSO grid | 3. Averaged over France, Germany, Spain, Italy, Denmark, Netherlands, UK, between 2015-2022; | 4. Averaged over Germany, based on 500km projects with MW capacities of 25/250/2500 for wires at kV levels of ~70/~230/~500, excluding substation costs | Sources: Analysis by Systemiq undertaken for Breakthrough Energy and Cleantech for Europe; Building Grids faster: the backbone of the energy transition (ETC,2024); Grids for Speed (Eurelectric, 2024).

POWER GRIDS

STRENGTHENING THE BACKBONE OF THE EU'S DECARBONISATION EFFORTS

ENABLERS – WHAT IS GOING WELL

HIGHLY RELIABLE AND FUNCTIONAL GRID

The EU grid is the largest synchronous connected grid worldwide with high reliability (averaging 32% less outage time versus USA). Current regulations have enabled Distribution System Operators (DSO) to jointly invest €33 billion annually from 2019-2023, a positive starting point for meeting grid transition needs.

LEADING GRID CABLE MANUFACTURING SUPPLY

Three of the largest Western grid cable suppliers are EU-based and have historically supplied the buildout of new grid infrastructure in the EU. This manufacturing capacity, scaled to the required size, could enable the domestic supply of the EU grid transition.

INCREASED POLICY AWARENESS ON GRID

Partially driven by increased renewable electricity deployment targets, policies and initiatives such as the Action Plan for Grids, the recent Draghi report, and Green Industrial Deal pay attention to accelerating smart grid capacity buildout and investments to meet EU decarbonisation goals.

BARRIERS – WHAT IS NOT GOING WELL

LACK OF FORWARD-LOOKING PLANNING AND LEGISLATED TARGETS

EU power grid policies lack an integral, long-term vision and legislated output-based targets to ensure collaboration and alignment across key roadmaps and stakeholders, such as national decarbonisation, grid flexibility, and interconnection capacity targets, renewable power generation siting as well as DSO and Transmission System Operator (TSO) network planning.

FINANCING / INCENTIVE SCHEMES NOT FIT FOR GRID TRANSITION

Current regulatory and remuneration frameworks are not fit for purpose, mainly having CAPEX-driven decision-making approach to incrementally build out the power grid, as opposed to OPEX or cost-saving. Innovative grid technologies also have limited access to EU funding streams, especially for first-of-a-kind projects or large-scale grid infrastructure that require de-risking.

PERMITTING & COMPLIANCE PROCESSES RESULTING IN BACKLOG AND LIMITED PACE OF EXPANSION

Transmission deployment can take up to 10 years, much longer than actual construction times (~1-2 years) due to planning and permitting. Compliance processes and tests required for innovative technology (e.g., Long Duration Energy Storage assets) need to act as de-risking mechanism to avoid 'death by pilot' without real scale-ups.

ACTION AGENDA – WHAT NEEDS TO BE DONE

1. **Implement an integral strategic vision and targets for coordinated EU grid buildout and modernisation.** Coordinate between national grid regulators and operators to co-develop holistic, forward-looking European grid infrastructure planning across national decarbonisation plans, renewable electricity generation and siting, as well as flexibility and interconnections buildout. Additionally, develop legislated, output-based targets that stimulate both new grid buildouts and modernisation simultaneously to ensure all stakeholders working on the EU grid are aligned beyond 2030.

2. **Reform investment paradigm and financing structures to stimulate investment in a future-proof grid.** Reform the existing investment approach to enable anticipatory investment ahead of need (e.g., expanding planning cycles for operators, removing operators' investment cap, and stimulating benefit sharing cost reduction to end customers) and prioritise Total Cost of Expense (Capital + Operational Expense). Additionally, make EU funding more accessible to innovative technologies (e.g., through the EU Innovation Fund) and derisking facilities for grid buildout and modernisation (e.g., participatory investments, public first loss guarantees) to spur private investment.

3. **Address slow permitting, compliance processes that limits pace of deployment.** Develop regulatory and legislative reform to address barriers (e.g., slow permitting and compliance processes, lack of resources) for TSO & DSO grid buildouts and modernisation. Consider setting prioritisation for grid investment opportunities principles to prioritise grid optimisation before grid enhancement before grid expansion.

4. **Provide financial incentives to de-risk and speed up adoption of new technologies by system operators.** Accelerate the rate of implementing innovation, for instance through lump-sum innovation funding or covering Weighted Average Cost of Capital (WACC) premiums, regulatory sandboxes, as well as the transfer of best-practices and standards across Member States (e.g. through EU Innovation Fund, EIT Knowledge-Sharing platforms).

«The grid is facing an unprecedented task in supporting Europe's ambitious energy transition, and innovative grid technologies are essential to meeting this challenge. By setting smart, output-based targets, we can ensure that the grid buildout and modernisation efforts are impactful and aligned with Europe's long-term sustainability goals.»

Layla Sawyer, Secretary General, **CurrENT**