For a *Twin Transition Investing* Strategy

February 2025

How to read this report

The document is structured into two main areas: **Energy Transition**, within which the topics covered include *Clean Energy Production, Energy Storage and Distribution, Energy Efficiency, Circular Economy and Carbon Capture, Low Carbon Transportation*, and **Digital Transition**, within which the topics covered include Higher Computing Power, Enhancing Wireless Transmission, and Increasing Fiber Connectivity.
Each section follows a consistent analytical framework structured around three key pillars:

1. Market Drivers

This section examines the factors driving growth in each sector, structured into two core subsections:

- **Regulatory Framework:** Provides an overview of relevant policies, regulations, and incentives shaping sectoral developments.
- **Key Technologies: E**xplores the most significant technologies, assessing their maturity levels, growth potential, and market impact.

This framework enables a comprehensive understanding of both the regulatory landscape, which influences investment decisions, and the technological innovations that drive sectoral transformation.

2. Market Development & Investment Opportunities

This section offers a clear perspective on market size, growth trajectories, and key investment opportunities. Rather than relying on proprietary forecasts, our analysis is built on a comparative assessment of available market projections, integrating insights from the most reliable sources. The focus is on validating trends through a systematic review of data from institutions and industry analysts, providing a structured and evidence-based view of growth dynamics.

3. Twin Transition Potential

Each section also examines the intersection of energy and digital transitions, emphasizing how the integration of energy and digital technologies can accelerate decarbonization and enable new business models. This part of the analysis shows how digitalization enhances energy system efficiency, optimizes operational performance, and strengthens infrastructure resilience, fostering a more sustainable and competitive ecosystem.

Summary

Introduction

“Uncertainty is an uncomfortable position, but certainty is an absurd one.”

- Voltaire

Today, these words carry profound relevance in a world marked by swift advancements in technology, shifting market dynamics, and evolving geopolitical landscapes that continually test the adaptability of businesses and policymakers.

As we embarked on this research effort, we were acutely aware of the numerous variables and uncertainties at play in the energy and digital sectors, as well as the inherent challenges in producing an analysis that would be clear, reliable, and ultimately useful.

To achieve this goal, we assembled a dedicated research team that operated with a dual approach:
a) Gathering and analyzing data and insights from the most reputable and up-to-date sources, including scientific/academic publications and industry/consulting reports.
b) Conducting interviews with sector experts to validate the conclusions reached through desk research and, more importantly, to explore potential scenarios beyond the simple extrapolation of existing trends.

This report offers a comprehensive overview of the current state of the energy and digital sectors, emphasizing their convergence within the concept of the Twin Transition. It serves as the first in a series, providing a broad perspective on these industries and their underlying trends. Future reports will delve deeper into specific sectors, technologies, or innovations, offering targeted analyses to guide strategic decision-making in these rapidly evolving fields.

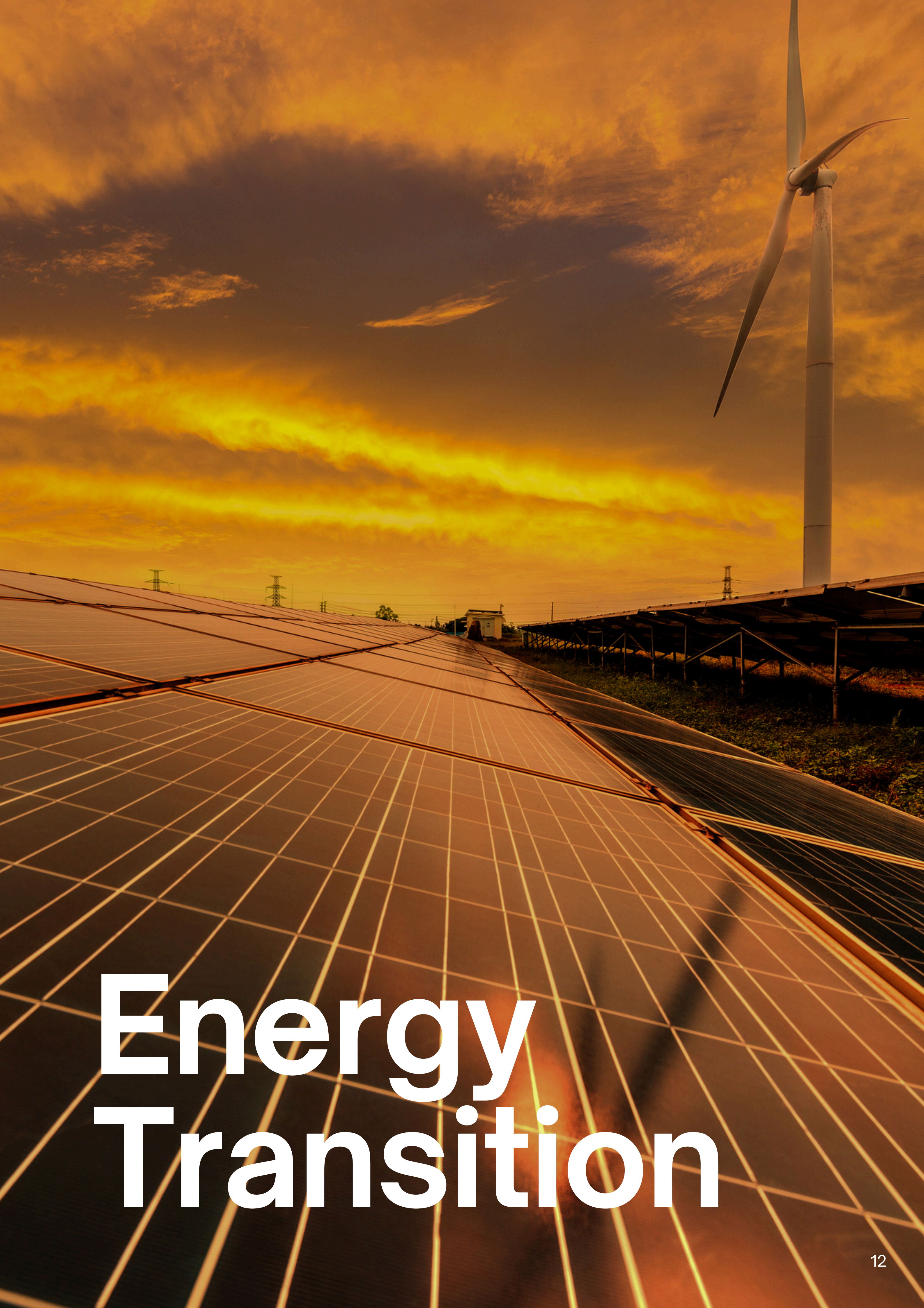
Carlo Alberto Pratesi
President of EIIS

Energy transition

The Energy Transition is the shift from fossil fuels to renewable and sustainable energy sources, with the goal of reducing greenhouse gas emissions, improving energy efficiency, and promoting the electrification of key sectors.

Digital transition

The Digital Transition is the shift from traditional processes to digital technologies, aiming to enhance efficiency, foster innovation, and enable the digitalization of key sectors through the integration of advanced tools and systems.



Energy Transition

Clean Energy Production

Renewable energies

The global renewable energy market is undergoing rapid expansion, driven by the urgent need to transition to a low-carbon economy. Renewable energy sources such as solar PV, wind, and hydropower are at the core of this transformation. Greenfield investments, which involve building new projects from scratch, and brownfield investments, focusing on upgrading and optimizing existing assets, present significant opportunities to diversify investment portfolios and ensure sustainable long-term growth.
The global energy transition is accelerating, driven by urgent climate targets, declining costs of renewable technologies, and increasing demand for clean energy. Renewable energy projects —particularly solar PV, wind, and hydropower—are expected to dominate new energy capacity additions globally. Data from IEA (2024)[1] shows that global energy investment is set to exceed USD 3 trillion for the first time in 2024, with USD 2 trillion going to clean energy technologies and infrastructure surpassing spending on oil, gas, and coal for the first time.

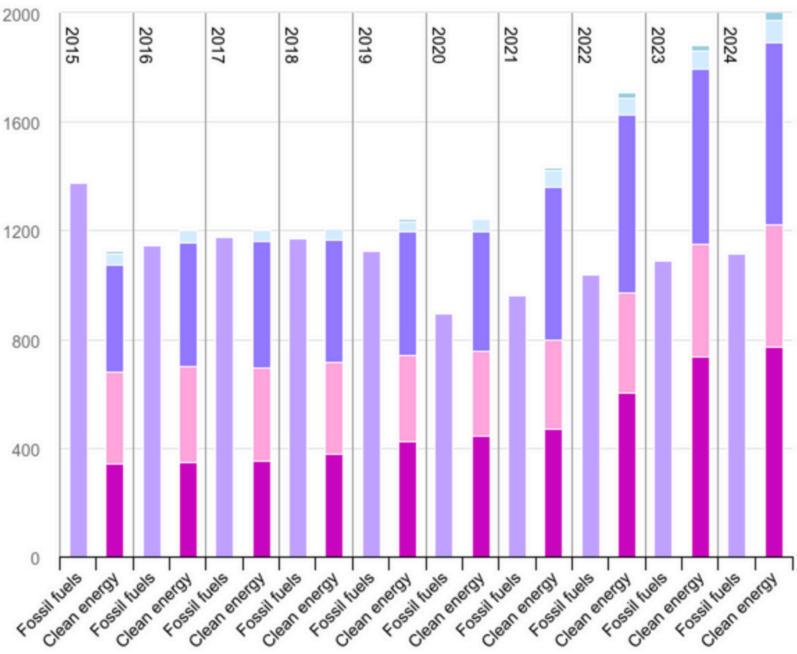


Fig. 1 - Global investment in clean energy and fossil fuels, 2015-2024

Source: IEA (2024), World Energy Investment 2024, IEA, Paris

[1] IEA (2024), World Energy Investment 2024, IEA, Paris

https://www.iea.org/reports/world-energy-investment-2024

Market Drivers - Regulatory Framework

- EU Green Deal and Fit for 55 Package: The EU has set ambitious targets to reduce greenhouse gas emissions by 55% by 2030, mandating significant growth in renewable energy capacity. Renewable Energy Directive (RED III) aims to achieve at least 42.5% renewable energy in the EU's total energy mix by 2030.
- Global Renewable Energy Policies: Countries worldwide are ramping up commitments to clean energy through subsidies, tax incentives, and auctions for renewable projects. The International Energy Agency (IEA) forecasts global renewable capacity to grow by 107 GW annually through 2030.
- NationalSupportMechanisms:KeymarketslikeGermany,Italy,andFranceoffer feed-in tariffs, tax credits, and grants for renewable energy projects, creating a favorable investment environment for greenfield and brownfield projects.
- Corporate Decarbonization Pledges: Private companies increasingly procure renewable energy via Power Purchase Agreements (PPAs), providing long-term revenue stability for renewable projects.

Key Technologies

Solar Photovoltaic (PV)

The growth of renewable energy installations has been primarily driven by solar photovoltaic technology. China alone added nearly 100 GW of solar PV capacity in 2022, nearly 70% more than in 2021, and is on track to add 150 GW in 2023. The European Union also experienced significant growth in solar PV installations, increasing by nearly 50% compared to 2021, stemming from the push to increase investments in renewable energy and as a response to cuts in Russian gas supplies.

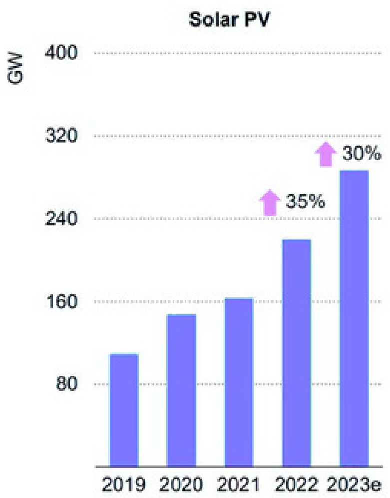


Fig. 2 - Annual Capacity Increases for Solar Photovoltaic

Source: "Critical Minerals Market Review 2023", International Energy Agency, 2023

- **Market Growth:**
  Solar PV is a leader in renewable energy investment, with forecasts indicating daily investments exceeding $1 billion in 2023.
- **Cost Reductions:**
  The cost of solar panels has dropped significantly, enabling broader adoption and improved economic viability.
- **Flexibility and Scalability:**
  Solar projects can be developed at various scales, from residential rooftop installations to large utility-scale solar farms, catering to diverse market needs.

Expert Insight:
The Solar Revolution – A European Perspective

Developed with insights from Alberto Dalla Riva, Senior Lead Business Developer at Ørsted

Solar energy is driving a transformative revolution in global energy systems, with 60-70% of newly installed power capacity worldwide coming from solar (BloombergNEF). This surge positions solar as a cornerstone of the fourth industrial revolution, providing unprecedented access to affordable and potentially free electricity. Advances in technology, coupled with the abundant availability of rooftops and minimal land use requirements (just 1% of agricultural land), highlight the enormous potential for scaling solar to terawatt levels.

Key Trends and Regional Dynamics:

- **Technological Competitiveness:** Even without further innovation, existing solar technology can sustain exponential growth. The primary barriers lie in storage and distribution, not generation capacity.
- **European Leadership:** Germany, the Netherlands, and Poland are standout markets in Europe, showcasing robust deployment strategies. Southern European countries like Italy and Spain also remain critical players due to high solar irradiance and supportive policies.
- **Future Proofing in Northern Europe:** Countries with less sunlight, such as Denmark, are adopting ambitious solar strategies, underlining that solar's economic competitiveness transcends geography.

The dominance of Chinese manufacturing in solar panels remains a challenge for European industries. However, this does not hinder solar's growth trajectory, making it a pivotal area for investment and innovation in Europe.

Wind Energy

Wind capacity did not grow as much as PV in the last years due to the sector being exposed to bottlenecks and scheduling delays. However, onshore wind capacity is expected to rebound by 70% in 2023, as delayed projects will be initiated.

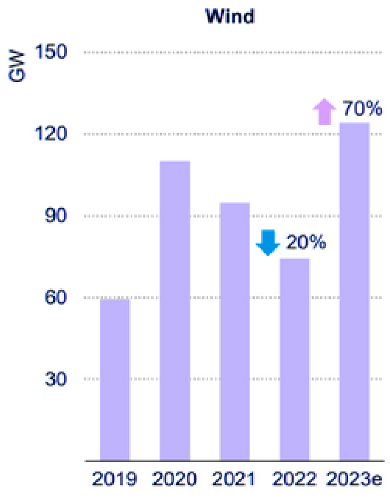


Fig. 3 - Global Annual Capacity Increases for Wind Energy

Source: "Critical Minerals Market Review 2023", International Energy Agency, 2023

- **Cost Efficiency:**
  Wind energy costs have decreased substantially, primarily due to innovations such as longer rotor blades, which enhance energy output.

- **Competitive Returns:**
  Investments in wind energy can yield high returns, with projects often benefiting from favorable long-term power purchase agreements (PPAs).

- **Diverse Applications:**
  Both onshore and offshore wind projects can be strategically located to maximize energy generation based on regional wind patterns.

Expert Insight:
Europe’s Wind Industry: Challenges and Strategic Choices

Developed with insights from Alberto Dalla Riva, Senior Lead Business Developer at Ørsted

Europe is striving to maintain its leadership in the wind industry. The sector is facing financial and production challenges (*Vestas* and *Siemens Gamesa* still provide much of the European supply but are in crisis), while China is expanding beyond its domestic market, increasing competitive pressure on European manufacturers.
EU policy is therefore at a crossroads:

- Support European industry to avoid dependence on China, as happened in the solar sector.
- Leave room for Chinese players and reduce costs, but lose technological autonomy.

Offshore wind is more capital-intensive than solar, making it particularly vulnerable to rising interest rates and supply chain disruptions. The key challenges slowing down its expansion include:

- The war in Ukraine, which has driven up raw material and logistics costs.
- Rising interest rates, making long-term investments more expensive.
- Extended development timelines: an offshore wind farm can take 8-10 years, at least 2 years longer than onshore projects.

Despite these challenges, offshore wind remains a crucial technology for the energy transition, but accelerating its growth will require:

- Reducing permitting times to speed up project execution. One of the major bottlenecks, especially for offshore projects, is lengthy permitting processes. In Italy, onshore wind projects take 5-6 years to get approval, while offshore projects can take up to 7 years between approval and construction. Streamlining bureaucratic processes would make wind energy more competitive with other renewables.
- Balancing public and private investment to mitigate the impact of rising interest rates and ensure financial sustainability for long-term projects.

- Driving innovation through repowering, which involves upgrading existing wind farms with more efficient technology to maximize output without requiring new large-scale developments.

Hydropower

Hydropower has long been a cornerstone of renewable energy, providing a substantial share of global electricity generation. It is currently the largest source of renewable electricity, accounting for approximately 16% of total global electricity generation and around 60% of all renewable power.[2] This technology harnesses the energy of flowing or falling water to generate electricity, making it both a reliable and efficient energy source.

The global hydropower capacity reached over 1,300 GW in 2022, with significant installations in countries such as China, Brazil, and Canada. China remains the world leader in hydropower production, contributing nearly 35% of global capacity.[3] In recent years, investments in hydropower have surged, driven by the need for clean energy solutions that can provide stable baseload power to complement intermittent sources like solar and wind. As countries strive to meet their climate goals and transition away from fossil fuels, hydropower offers a critical means of ensuring grid stability and energy security.[4]

- **Stable Energy Source**
  Hydropower provides a reliable and consistent source of energy, contributing to grid stability and energy security.

- **Environmental Benefits:**
  Modern hydropower projects are increasingly designed to minimize ecological impacts, making them attractive from both an investment and sustainability perspective.

- **Long Lifespan:**
  Hydropower facilities typically have long operational lifespans, providing stable returns over extended periods.

Electric Grids

The deployment of clean energy technologies must accelerate rapidly to meet climate goals. In the Net Zero Emissions by 2050 (NZE) scenario, renewables are expected to account for over 60% of energy production (up from 30% today), and electricity demand is projected to increase by 25%, representing nearly 30% of total final consumption (up from 20% today). This clearly anticipates a significant increase in electric transmission infrastructure. Such rapid growth poses considerable challenges to supply chains. In the NZE scenario, the annual use of metals for energy transmission lines, distribution grids, and transformers is expected to increase by about 50% from 2022 to 2030 compared to today.

The copper used for grids and transformers in 2022-2030 will correspond to nearly 20% of global copperproduction in 2030.

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[2] International Energy Agency (IEA). (2023). Renewable Energy Market Update. Retrieved from IEA Website.

[3] World Hydropower Report. (2022). 2022 World Hydropower Report. International Hydropower Association. Retrieved from IHA Website.

[4] International Renewable Energy Agency (IRENA). (2023). Renewable Power Generation Costs in 2023. Retrieved from IRENA Website.

Expert Insight:
Geothermal energy - Opportunities and technological advances

Developed with insights from Nicola Armaroli, Research Director at CNR and Ernesto Ciorra, Innovation and Sustainability Expert

Geothermal energy is a critical renewable option, offering consistent and sustainable power generation. Recent innovations, such as Enhanced Geothermal Systems (EGS), have expanded the potential of geothermal energy. Unlike traditional systems that rely on natural hydrothermal reservoirs, EGS technology enables the extraction of heat from deeper, less permeable rock formations, significantly broadening the geographical applicability of geothermal projects. Current technological advancements, such as enhanced geothermal systems (EGS), are expanding its viability, making it an increasingly essential component in today's energy transition strategies.

Expert Insight:
Revamping Mini Hydro Assets – A Strategic opportunity

Developed with insights from Ernesto Ciorra, Innovation and Sustainability Expert

Mini hydro, defined as hydropower systems with a capacity of up to 10 MW, has proven to be a reliable and sustainable source of energy, particularly in decentralized and remote regions.
By upgrading turbines, generators, and control systems, energy output can improve by 10–30%, boosting revenue and sustainability. Improved performance translates directly into higher revenues, making this an attractive asset optimization strategy.
Revamping existing mini hydro infrastructure is significantly more cost-effective than developing new hydro projects, as it leverages existing assets like dams, reservoirs, and water channels. This approach reduces permitting complexities and environmental impacts, accelerating project timelines.

Market development and Investment Opportunities

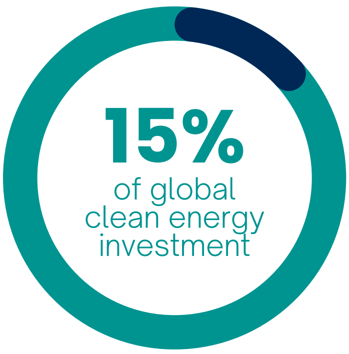
Solar energy is at the forefront of the global shift towards renewables, driven by significant investment and technological advancements. In 2023, the daily investment in solar energy surpassed $1 billion, totaling $380 billion for the year, marking a major milestone as solar investment outpaced spending on oil extraction for the first time. The cost of solar panels has decreased by 30% over the past two years, making it an increasingly attractive option for energy investors. In addition, the prices of crucial materials for energy transitions, particularly metals used in batteries, have seen substantial declines, further boosting the appeal of solar power.

Looking ahead, solar photovoltaic (PV) technology investment is expected to surpass $500 billion in 2024, overtaking all other energy generation sources combined. Although the rapid growth in the solar sector may slow slightly due to falling PV module prices, solar energy remains integral to the transformation of the power sector. In fact, in 2023, each dollar invested in wind and solar PV technologies produced 2.5 times more energy output than a similar investment in these technologies a decade ago. This highlights the increasing efficiency and competitiveness of renewable energy, especially solar.

The sharp decline in costs for renewable energy technologies over the past decade has been particularly notable for solar and wind power. Solar electricity generation costs have fallen by an impressive 83% since 2010, driven largely by increased demand, technological innovation, and heightened competition within the industry. This trend is evident in two key areas: residential rooftop solar installations and large-scale solar farms built by electric utilities as they move away from coal-powered plants.

Wind energy has followed a similar trajectory, with costs dropping by 85% over the same period. One of the key innovations driving this cost reduction is the development of longer rotor blades for both onshore and offshore wind turbines, allowing for significantly increased energy output.

On a macroeconomic level, there is an unequal distribution of investments between advanced countries and emerging or developing economies. While advanced economies seem capable of increasing investments in clean energy to meet climate targets, developing nations will need to triple or even quintuple their energy investments to align with climate action plans and zero-emission scenarios. This challenge is compounded by the difficulties low-income consumers and businesses face in dealing with the high initial costs of developing clean energy technologies, as well as the lack of robust policy frameworks and institutional capacity in many of these countries. In particular, emerging and developing economies are projected to exceed $300 billion in clean energy spending for the first time, driven by countries like India and Brazil. However, this represents only 15% of global clean energy investment, which is far below the necessary levels to meet the growing energy demand in these regions. A key obstacle is the high cost of capital, which is hindering the development of new clean energy projects in many of these countries.



$300 billion
clean energy

Expert Insight:
Recyclability in Renewable Energy

Developed with insights from Nicola Armaroli, Research Director at CNR

Renewable energy technologies, while critical for decarbonization, face challenges in end-of-life management. Solar panels, wind turbines, and batteries often rely on materials like rare earth metals, which require sustainable recycling solutions. Emerging innovations are improving the recyclability of these components:

- **Solar Panels:** Recycling can recover up to 95% of valuable materials, including silicon and silver.
- **Wind Turbines:** Blade recycling technologies are advancing, turning composites into raw materials for construction or new blades.
- **Batteries:** Recycling initiatives recover lithium, cobalt, and nickel, reducing dependency on mining.

Prioritizing recyclability strengthens the circular economy, minimizes waste, and aligns with EU sustainability policies.

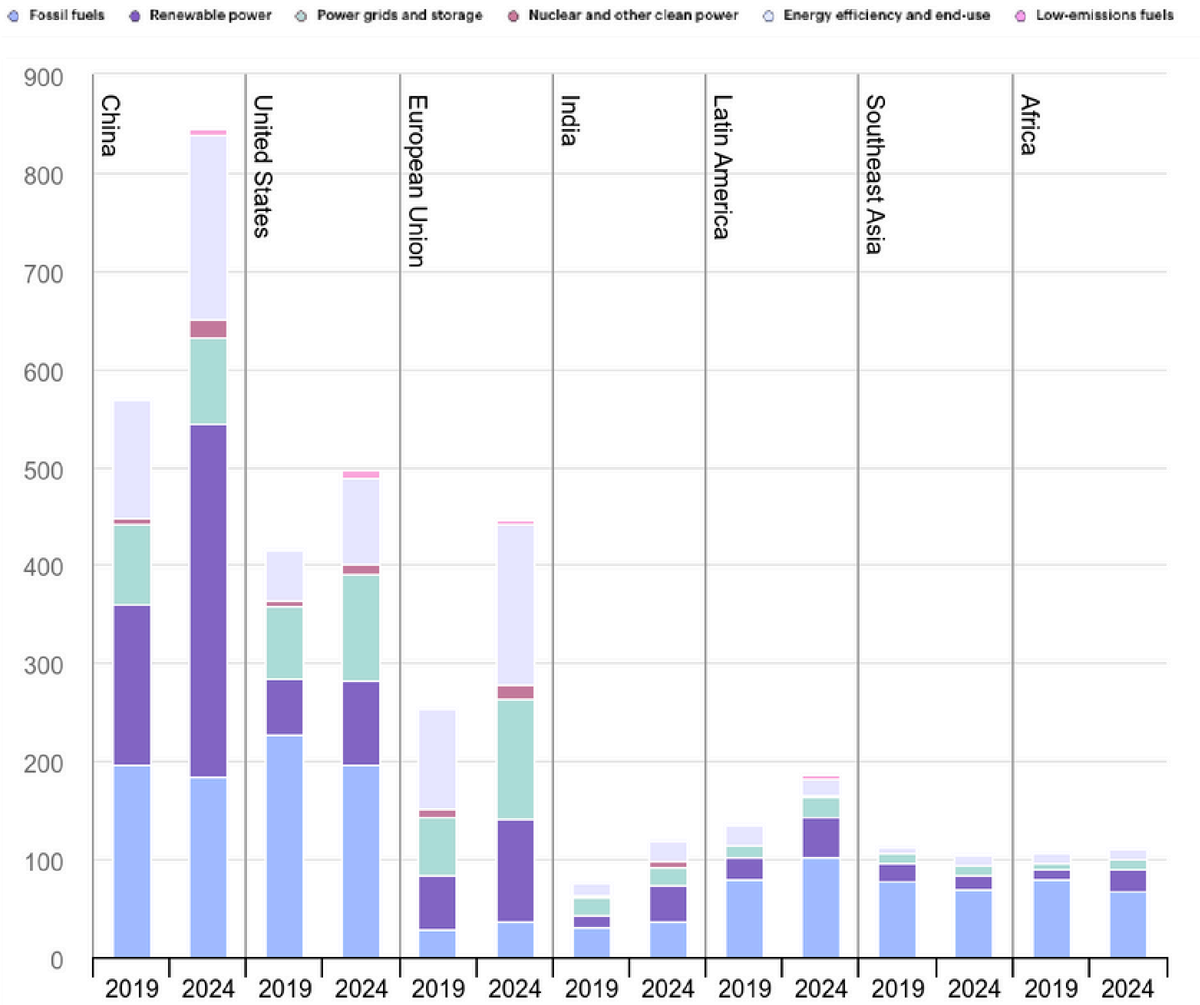


Fig. 4 - Annual investment in clean energy by selected country and region, 2019 and 2024
Source: IEA (2024)

For investors, the renewable energy sector presents a wealth of opportunities. These could include:

- Pure-play clean tech firms specializing in renewable energy technology or production.
- Electric utilities transitioning from fossil fuels to cleaner energy sources.
- Oil and gas companies investing in carbon capture or diversifying into renewable energy.

Electric Grids

- **Greenfield:**
  Investment in large-scale solar farms, especially in Southern Europe where solar irradiation is highest. Projects in Spain, Italy, and Greece benefit from robust regulatory support.
- **Brownfield:**
  Retrofitting existing solar facilities with advanced tracking systems and bifacial panels to enhance efficiency.

Wind Power Market Development

- **Greenfield:**
  Offshore wind presents unparalleled growth potential. The North Sea and Baltic Sea are prime regions for large-scale offshore projects with government-backed subsidies and auctions.

- **Brownfield:**
  Opportunities lie in upgrading aging onshore wind farms across Europe, particularly in Germany and Denmark, where early projects are reaching the end of their lifecycle.

Hydropower Market Development

- **Greenfield:**
  Limited new large-scale opportunities due to environmental concerns but potential for small-scale hydropower projects, particularly in the Alpine and Balkan regions.

- **Brownfield:**
  Modernizing existing facilities to incorporate advanced turbines and digital monitoring systems, thereby increasing output and efficiency.

Despite the compelling opportunities, investing in renewable energy infrastructure is not without challenges:

- **Capital Costs:**
  Upfront capital requirements for developing renewable energy projects can be significant. High interest rates may impact financing conditions and overall project feasibility.

- **Regulatory Risks:**
  Navigating complex regulatory environments can delay project approvals and add to development costs. Investors must stay informed about policy changes and market dynamics.

- **Supply Chain Constraints:**
  Recent global disruptions have highlighted vulnerabilities in supply chains, which can impact project timelines and cost structures. Investors should consider companies with robust supply chain strategies.

- **Market Volatility:**
  The renewable energy sector is subject to market fluctuations driven by technological advancements, competition, and policy shifts. A diversified approach can mitigate these risks.

While the potential for growth in the renewable energy sector is strong, investments are not without risks. The sector’s expansion depends on ongoing technological advancements, substantial private investment, and continued policy support from governments worldwide. As solar and wind energy continue to gain ground, particularly in developed markets, the energy landscape is evolving rapidly, offering both challenges and opportunities for investors looking to be part of the energy transition.

Twin transition potential

Renewables drive decarbonization and digital innovation, positioning energy systems as a foundation for a sustainable and tech-enabled future.

Green Transition Potential

- Significant GHG reduction by replacing fossil fuels, contributing to 90% of electricity generation by 2050 under net-zero targets (IEA, 2023).
- Enhances energy independence and scales across utility and decentralized solutions.
- Renewable investments, combined with battery storage solutions, enable grid stability and efficient utilization of intermittent energy sources, further reducing reliance on fossil fuels.

Digital Transition

- Renewables are a key enabler of smart grid technologies, which rely on real-time data for efficient energy distribution. Smart grids enhance renewable energy integration by managing variable supply and demand.
- Digital tools such as IoT sensors and AI-based analytics improve the efficiency and predictive maintenance of renewable energy systems, optimizing energy output and reducing downtime.
- Real-time monitoring of renewable systems supports informed decision-making for energy producers and consumers, driving efficiency and sustainability.

Flexibility Solutions

The intermittent nature of renewable energy sources and the variability of electricity consumption are creating an increasing demand for flexible solutions, such as reducing demand peaks, quickly adjusting production, and maintaining energy reserves to stabilize the grid. These solutions can help manage periods of high demand and minimize unnecessary investments in energy production and distribution. Addressing this need requires increasing flexibility in energy consumption and improving the coordination between electricity supply and demand[5]

Energy Communities

Energy communities offer a promising solution, (increased use of renewable sources and a smarter, more coordinated integration into power systems) but face significant legal and bureaucratic challenges, particularly in Europe and Italy, which may slow their growth compared to initial projections.

The concept of "Energy Communities" (EC) has gained considerable momentum worldwide. According to the World Resources Institute, the United States is making significant investments in energy communities in regions that have traditionally relied on fossil fuels. Approximately 64 million people live in areas classified as energy communities, which are spread across 46 states. Historically dependent on the fossil fuel industry, these communities are now benefiting from the Inflation Reduction Act, which provides funding to support their transition towards renewable energy source[6].

In Africa, energy communities are expanding, particularly as a means to address the lack of access to electricity in rural areas. A recent study of five African countries highlighted how ECs can improve access to renewable energy for vulnerable populations. Nevertheless, one of the most significant obstacles remains the restricted local involvement and ownership of these initiatives[7].

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[5]European Environment Agency and EU Agency for the Cooperation of Energy Regulators (2023). Flexibility solutions to support a decarbonised and secure EU electricity system. [Available at: https://www.acer.europa.eu]

[6]Shrestha, R., Rajpurohit, S., & Saha, D. (2023, July 31). Redefining America’s ‘Energy Communities’ Can Boost Clean Energy Investments. World Resources Institute. https://www.wri.org/insights/redefining-americas-energy-communities

[7]Atinsia, M. A., Adu-Kankam, K. O., & Diawuo, F. A. (2023). Renewable Energy Communities in Africa: A Case Study of Five Selected Countries. In L. M. Camarinha-Matos & F. Ferrada (Eds.), Technological Innovation for Connected Cyber Physical Spaces: Proceedings of the 14th IFIP WG 5.5/SOCOLNET Doctoral Conference on Computing, Electrical and Industrial Systems, DoCEIS 2023, Caparica, Portugal, July 5–7, 2023 (pp. 52-64). Springer.

Market Drivers - Regulatory Framework

European Directives:
The concept of renewable energy communities was formally introduced in Europe under Directive (EU) 2018/2001 on Renewable Energy (REDII).
A Renewable Energy Community (REC) is defined as a legal entity that is characterized by open and voluntary participation, autonomous governance, and control by its shareholders or members, who must reside in close proximity to the renewable energy projects.

The EU's Renewable Energy Directive (RED II) and the Electricity Market Directive explicitly encourage the establishment of energy communities by providing a legal framework for collective energy generation and self-consumption. The EU Green Deal provides substantial funding opportunities through mechanisms such as the Innovation Fund and Just Transition Fund, accelerating investment in community-driven renewable energy.

National-Level Policies:
Italy: Italy is emerging as a leader in energy communities, with a national framework offering incentives for energy sharing projects, particularly in rural areas.
The National Recovery and Resilience Plan (PNRR) allocates €2.2 billion for renewable energy and energy community projects.

Germany: The Energiewende framework supports citizen-driven renewable initiatives through subsidies and regulatory support.

Spain: Spain's Self-Consumption Law simplifies grid access for energy-sharing initiatives and waives charges for renewable self-consumption projects.

Currently, there are over 3,500 active communities across the continent.[8]

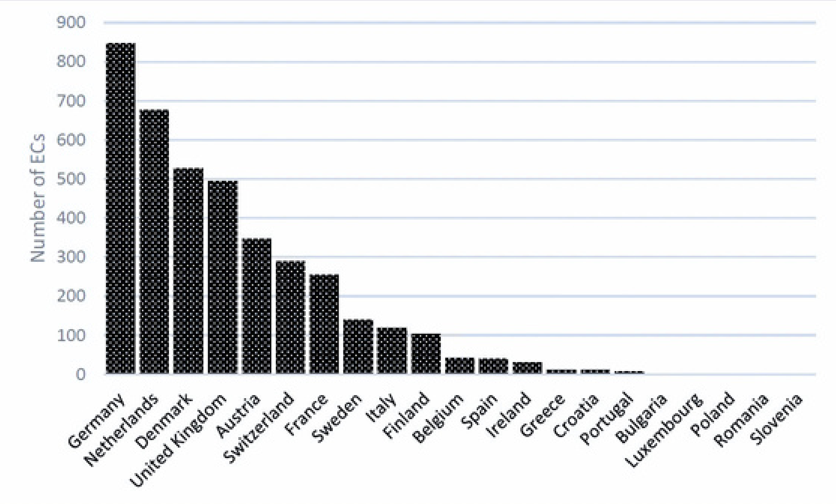

Fig. 5 - Deployment of energy communities in the European Union
Source: Koltunov et al. (2023)

[8]European Commission. (n.d.). Energy communities repository products. Energy. Retrieved October 17, 2024, from
https://energy.ec.europa.eu/topics/markets-and-consumers/energy-consumers-and prosumers/energy-communiti es/energy-communities-repository-products_en

The spread of energy communities varies significantly across European countries. Germany, the Netherlands, and Denmark are leading the movement, while countries such as Italy and Spain are still in the early stages of development.
In Eastern European countries like Poland, Slovenia, and Bulgaria, energy communities remain relatively rare.[9]

In Europe, most renewable energy communities take the form of cooperatives, community interest companies, or non-profit organizations. From a technological standpoint, these communities leverage a variety of renewable energy solutions, including photovoltaic and solar thermal systems, wind turbines, biomass and biogas production, small-scale hydropower plants, and, in some cases, fleets of electric vehicles.[10]
This diversification allows communities to optimize local resource use, reduce dependence on centralized grids, and actively contribute to the decarbonization of the European energy system. Policies governing energy communities differ globally and nationally, shaped by existing legislation, energy infrastructure, and local market conditions. These regulatory differences can significantly influence the technical design of energy communities.[11]
For example, in some countries like Germany, there are specific requirements regarding the local production of renewable energy, whereas in others, such as Italy, energy communities must be connected to the same substation. These technical and regulatory constraints impact not only community design but also the economic opportunities available to members. Nevertheless, community-based energy systems are attracting growing attention from policymakers and professionals as promising models for the transition to a low-carbon society.

Business Models

Energy communities can adopt various business models, each tailored to the specific characteristics of local energy resources, stakeholders, and regulatory frameworks.

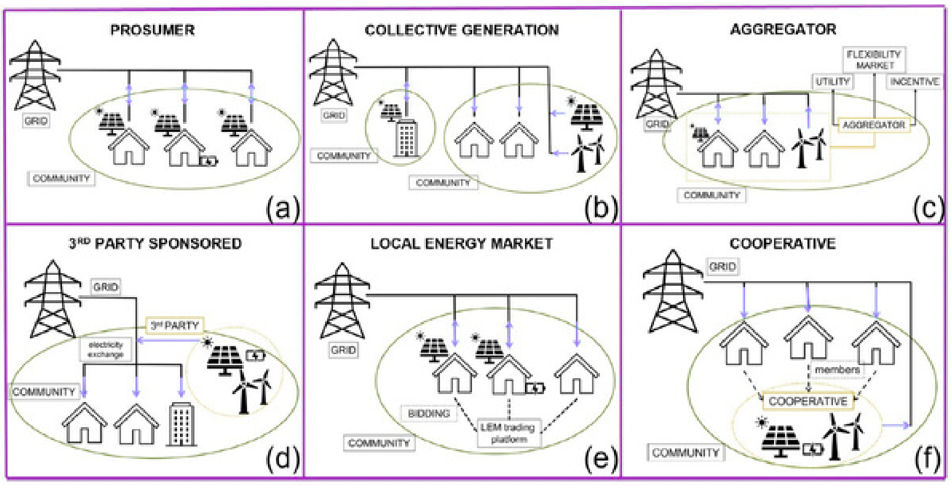

Fig. 6 - Business Model Schematic Representation
Source: Barabino et al. (2023)

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[9] D. Spasova, S. Braungardt, The EU Policy Framework for Energy Communities, Vol. 484, Elsevier Inc., 2022,pp. 25–42.

[10] Barabino, E., Fioriti, D., Guerrazzi, E., Mariuzzo, I., Poli, D., Raugi, M., Razaei, E., & Thomopulos, D. (2023). Energy Communities: A review on trends, energy system modelling, business models, and optimisation objectives. Sustainable Energy, Grids and Networks, 36, 101187

[11] Koltunov, M.; Pezzutto, S.; Bisello, A.; Lettner, G.; Hiesl, A.; van Sark,W.; Louwen, A.;Wilczynski, E. Mapping of Energy Communities in Europe: Status Quo and Review of Existing Classifications. Sustainability 2023, 15, 8201.

a. **Prosumer Model**
This model envisions users producing renewable energy (e.g., rooftop solar panels) to meet their own needs, with any surplus shared with the community, thus reducing reliance on the central grid. Prosumers both consume and produce energy, contributing to the community's energy self-sufficiency.

b. **Collective Generation**
Energy is collectively produced through centralized installations (e.g., solar panels on shared buildings). Participants benefit from lower energy bills through the use of generated energy, with any excess sold to the market or redistributed.

c. **Aggregator Model**
An aggregator consolidates producers and consumers within the community to optimize energy management. They can negotiate better terms with suppliers and access flexibility markets, balancing supply and demand among community members.

d. **External Sponsors**
Communities created by external sponsors (e.g., public entities, utilities, or ESCOs) retain ownership of the installations and manage governance. The community benefits from access to green energy and reduced prices.

e. **Local Energy Markets (LEM)**
Members trade energy through peer-to-peer (P2P) platforms, buying and selling at agreed prices. This system allows higher revenues from surplus sales and more competitive prices for consumers.

f. **Energy Cooperatives**
In energy cooperatives, members act as shareholders, sharing ownership of the installations. Revenues from energy production can be reinvested in new projects or redistributed as dividends, fostering collective participation and local development.

Some examples

Some notable examples of energy communities in Europe include:

1. **Schönau, Germany:**
Following the Chernobyl disaster, residents of Schönau, led by Ursula Sladek, successfully took control of their local electricity grid, forming the ElektrizitätsWerke Schönau (EWS) cooperative. Today, EWS provides clean energy to over 185,000 people and supports numerous renewable projects across Germany.

2. **Ecopower, Belgium:**
Founded in 1991 in Flanders, Ecopower brings together over 67,000 members who co-own renewable energy installations. In 2022, the cooperative saved nearly 61,000 tons of CO_2 and maintained the lowest energy bills in Belgium, even during the energy crisis.

3. **Magliano Alpi, Italy:**
Established in the small town of Magliano Alpi, Italy's first renewable energy community focuses on solar energy production and was a pioneering initiative under EU directives supporting decentralized energy.

Key Technologies

Solar Photovoltaic (PV)

Solar PV forms the backbone of energy communities, given its scalability and cost-effectiveness. Technological advancements such as bifacial panels and microinverters further enhance efficiency.to cuts in Russian gas supplies.

Battery Energy Storage Systems (BESS)

Storage solutions enable energy communities to manage variability in renewable generation, ensure grid stability, and optimize self-consumption.

Smart Grid Infrastructure

Digital technologies like smart meters, blockchain-based energy trading platforms, and AI-driven grid optimization play a pivotal role in enabling seamless energy sharing and management.

Electric Vehicle Integration

Community energy systems increasingly incorporate EV charging infrastructure, aligning with the twin goals of renewable energy adoption and sustainable mobility.

Market development and Investment Opportunities

The economic management of energy communities relies on various pricing models and the distribution of benefits among members. Common pricing models include fixed pricing, which involves a constant rate regardless of grid conditions or time; time-of-use pricing, where rates vary by the hour to encourage energy use during off-peak times; and dynamic pricing, which fluctuates in real-time based on demand, grid congestion, or market conditions, promoting more efficient resource use. Earnings can come from government incentives or feed-in tariffs for generated energy. In fact, energy communities are benefiting from growing political support across Europe, with targeted measures designed to encourage and facilitate their development. These include feed-in premiums (FIP), which provide an additional premium on renewable energy sold to the market, promoting investment in clean technologies. Other tools include quota obligations, requiring utilities to purchase a certain percentage of renewable energy, and renewable energy certificates, which allow ECs to monetize the environmental value of their production.
Many governments are also introducing favorable tax regimes for ECs, improving their profitability, and offering public grants or low-interest loans to overcome the initial financial barriers that often hinder the creation of new energy communities.[12] The distribution of economic benefits may follow different principles: equal distribution, where all participants receive the same share, or distribution based on individual contributions, where those who generate more energy or invest more in infrastructure receive a proportionate share.

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[12] Koltunov, M.; Pezzutto, S.; Bisello, A.; Lettner, G.; Hiesl, A.; van Sark,W.; Louwen, A.;Wilczynski, E. Mapping of Energy Communities in Europe: Status Quo and Review of Existing Classifications. Sustainability 2023, 15, 8201.

In other cases, ownership of the installations might be considered when determining benefits, while external investors or stakeholders might also be allocated a portion of the gains.[13] From an economic perspective, energy communities are proving to be powerful drivers of local value creation. A study in France revealed that for every euro invested in an energy community project, €2.57 in value is returned to the region over 20 years.[14] This translates into tangible savings on energy bills for community members and a significant mobilization of private capital for the energy transition. The future prospects for energy communities are bright. Estimates suggest that by 2030, energy communities could own about 17% of installed wind capacity and 21% of solar capacity in Europe. Even more impressive, by 2050, nearly half of EU households are expected to be involved in renewable energy production.[15] While the economic models and incentives play a crucial role in the success of energy communities, their contribution goes beyond financial benefits. A key strength of energy communities lies in their ability to create more flexible and resilient energy systems. By managing supply and demand locally, they not only optimize energy use but also reduce the strain on centralized grids. This opens the door to more advanced solutions, such as Virtual Power Plants (VPPs), which further enhance system flexibility and sustainability.[16]

Twin transition potential

Energy communities are at the forefront of Europe's twin transition, addressing both the green and digital transformation simultaneously.
These communities not only reduce environmental impact but also embrace innovative technologies to build sustainable, resilient energy systems.
Energy communities prioritize the use of renewable energy sources like solar, wind, and biogas.
By decentralizing energy production, they directly reduce CO2 emissions associated with fossil fuel consumption. Community-driven initiatives also lower methane emissions by integrating waste-to-energy projects, leveraging organic waste streams to produce clean energy. Moreover, localized energy systems enhance resilience against climate change impacts, such as extreme weather events, by reducing reliance on centralized, vulnerable grids. Energy communities embrace advanced technologies to manage energy production, storage, and distribution efficiently.

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[13] Barabino, E., Fioriti, D., Guerrazzi, E., Mariuzzo, I., Poli, D., Raugi, M., Razaei, E., & Thomopulos, D. (2023). Energy Communities: A review on trends, energy system modelling, business models, and optimisation objectives. Sustainable Energy, Grids and Networks, 36, 101187.

[14] Energie Partagée. Les Retombées Economiques Locales des Projets Citoyens; Énergie Partagée Association:Paris, France, 2019.

[15] European Commission. Energy D-G for Clean Energy for All Europeans; European Comission: Brussels, Belgium, 2019.

[16] S. Adams, D. Brown, J.P. Cárdenas Álvarez, R. Chitchyan, M.J. Fell, U.J.J. Hahnel, K. Hojckova, C. Johnson, L. Klein, M. Montakhabi, K. Say, A. Singh, N. Watson, Social and economic value in emerging decentralized energy business models: A critical review, Energies 14 (23) (2021) 7864

- **Smart Infrastructure Deployment:**
  Advanced technologies like IoT-enabled sensors, blockchain for energy trading, and AI-driven energy management optimize consumption patterns, ensuring efficiency and transparency. Smart meters and real-time monitoring systems empower community members to manage their energy use, reduce waste, and optimize costs.

- **Decentralized Energy Trading:**
  Digital platforms allow peer-to-peer energy trading within the community, creating a democratized and transparent energy market. These systems also ensure equitable distribution of financial and energy benefits among participants.

- **Interoperability and Connectivity:**
  Integration with broader smart grid networks ensures that surplus energy generated by communities is efficiently redirected to meet regional demands, balancing energy flows across the grid.

Virtual Power Plants

In recent years, Virtual Power Plants (VPPs) have become increasingly important as an innovative solution for managing Distributed Energy Resources (DERs), addressing the growing need for a more flexible and sustainable energy system.
VPPs operate as business models designed to generate revenue through participation in energy markets, the optimization of distributed resources, and the reduction of costs associated with energy demand peaks. These platforms aggregate, optimize, and control diverse energy resources, such as photovoltaic systems, wind turbines, energy storage devices, and flexible loads, to deliver services both to the power grid and energy markets.[17]
Unlike traditional plants, VPPs are virtual, coordinating resources to function as a unified power plant without physical interconnections.[18]
Their core strength lies in operational flexibility. By aggregating resources across technologies and locations, VPPs use sophisticated algorithms to optimize supply and demand peaks, stabilizing the grid while reducing CO2 emissions. This capability positions VPPs as key players in the energy market, providing advantages over isolated resources.[19]
VPPs manage various distributed resources, including smart buildings, electric vehicles, energy storage devices, and renewable generation sources. By optimizing the combined production, storage, and consumption, VPPs improve system efficiency and grid reliability.[20]

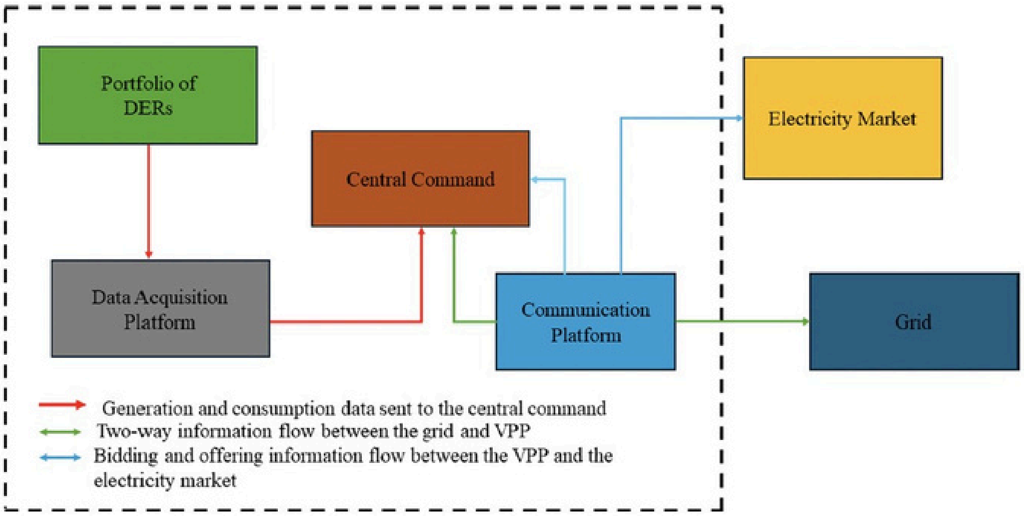


Fig. 7 - Architecture of a VPP Source: Abdelkader et al. (2024)

[17]Ruan, G. et al. (2024) 'Data-driven energy management of virtual power plants: A review', Advances in Applied Energy. Elsevier Ltd. Available at: https://doi.org/10.1016/j.adapen.2024.100170.

[18]Abdelkader, S., Amissah, J. and Abdel-Rahim, O. (2024) 'Virtual power plants: an in-depth analysis of their advancements and importance as crucial players in modern power systems', Energy, Sustainability and Society. BioMed Central Ltd. Available at: https://doi.org/10.1186/s13705-024-00483-y.

[19]Gao, H. et al. (2024) 'Review of virtual power plant operations: Resource coordination and multidimensional interaction', Applied Energy, 357. Available at: https://doi.org/10.1016/j.apenergy.2023.122284; Ruan, G. et al. (2024) 'Data-driven energy management of virtual power plants: A review', Advances in Applied Energy. Elsevier Ltd. Available at: https://doi.org/10.1016/j.adapen.2024.100170.

[20]Ullah, Z., Arshad, A. and Nekahi, A. (2024) 'Virtual Power Plants: Challenges, Opportunities, and Profitability Assessment in Current Energy Markets', Electricity, 5(2), pp. 370–384. Available at: https://doi.org/10.3390/electricity5020019.

One of the primary advantages of VPPs is their seamless integration into energy markets. VPPs actively participate in short-term markets, such as day-ahead trading, and in ancillary service markets by providing frequency regulation, load balancing, and demand management services.[21] This capability allows them to compete with traditional power plants, offering greater flexibility and responsiveness.[22] Additionally, VPPs can participate in demand response programs, reducing energy consumption during peak demand periods and contributing to grid stability.[23] This participation offers significant economic benefits by lowering operational costs, improving the efficiency of distributed resources, and generating revenue from the provision of ancillary services.

Market Drivers - Regulatory framework

- **European Green Deal and Renewable Integration:**
  EU policies, including the Fit for55 package and REPowerEU plan, prioritize renewable energy adoption and grid modernization. VPPs are pivotal in achieving these goals by enabling flexible, real-time energy management across distributed networks.
- **Energy Markets Liberalization:**
  Regulations facilitating market access for decentralized energy producers, such as the EU's Clean Energy Package, encourage the growth of VPPs by allowing aggregated DERs to participate in energy trading and balancing markets.
- **Capacity Mechanisms and Demand Response:**
  EU member states are incentivizing VPP deployment through capacity market reforms and demand response schemes. In Germany, subsidies for smart energy infrastructure include VPP development to support grid balancing.
- **Carbon Pricing:**
  The EU Emissions Trading System (ETS) creates financial incentives for cleaner energy solutions. VPPs, by integrating low-carbon and renewable energy sources, stand to benefit from these mechanisms.

Key Technologies

- **Advanced IoT and AI Platforms:**
  VPPs rely on Internet of Things (IoT) sensors and Artificial Intelligence (AI) algorithms to monitor, forecast, and optimize DER performance in real-time.
- **Battery Energy Storage Systems (BESS):**
  Batteries are a cornerstone of VPPs, ensuring energy is stored and dispatched efficiently to balance supply and demand, particularly for intermittent renewables like wind and solar.
- **Blockchain Technology:**
  Emerging blockchain solutions enhance transparency in energy transactions and facilitate secure, decentralized peer-to-peer trading within VPP networks.

[21] Bell, K. and Gill, S. (2018) 'Delivering a highly distributed electricity system: Technical, regulatory and policychallenges', Energy Policy, 113, pp. 765–777. Available at: https://doi.org/10.1016/j.enpol.2017.11.039.

[22] Yang, Z., Liu, J., Baskaran, S. et al (2010). Enabling renewable energy—and the future grid—with advanced electricity storage. JOM 62, 14–23 . https://doi.org/10.1007/s11837-010-0129-0

[23] Ullah, Z., Arshad and Hassanin, H. (2022) 'Modeling, Optimization, and Analysis of a Virtual Power Plant Demand Response Mechanism for the Internal Electricity Market Considering the Uncertainty of Renewable Energy Sources', Energies, 15(14). Available at: https://doi.org/10.3390/en15145296.

- **Smart Meters and Edge Computing:**
  Real-time energy data collection and processing via smart meters and edge devices allow precise control over energy assets, improving grid stability and resource optimization.

Market development and Investment Opportunities

Investments in Virtual Power Plants (VPPs) represent one of the key opportunities for the future of the energy sector. VPPs enable the aggregation, optimization, and management of distributed resources such as renewable energy and storage systems, offering a significant competitive advantage over isolated resources. This optimization capability reduces operational costs, improves overall energy system efficiency, and stabilizes the grid during demand peaks, thereby maximizing revenues from energy markets.

As early as 2019, a study conducted by Navigant Research clearly highlighted this trend.

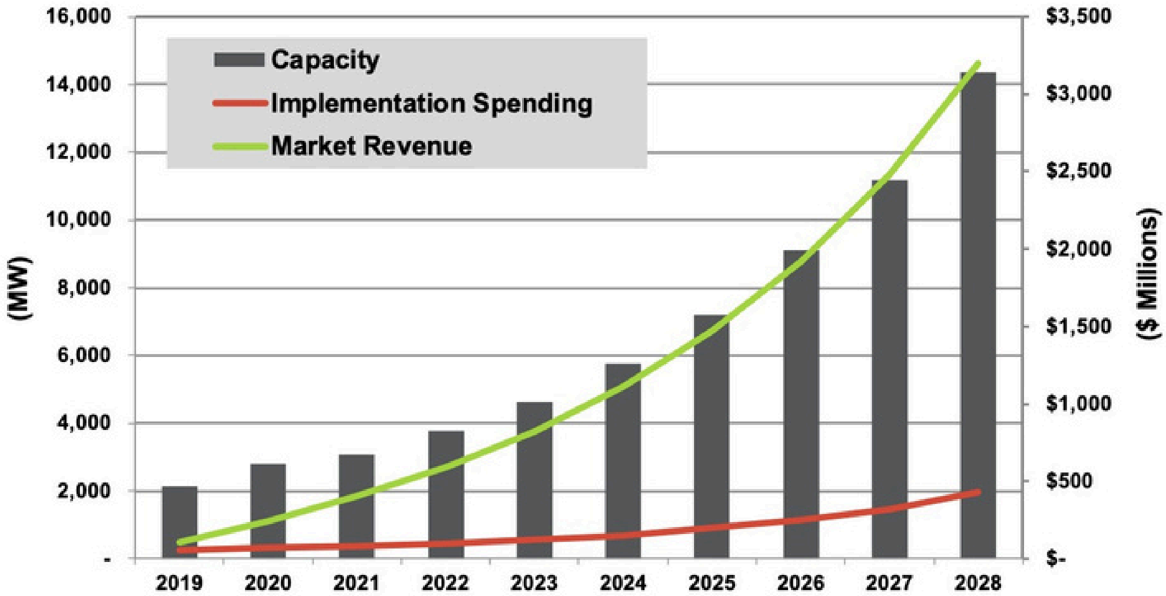


Fig. 8 - Annual Total VPP Capacity, Implementation Spending and Market Revenues, Europe: 2019-2028 Source: Navigant Research

The graph shows a significant growth in installed VPP capacity (measured in MW), steadily increasing from 2019 to 2028. At the same time, market revenues associated with VPPs follow a sharp upward trajectory, rising from moderate levels in 2020 to a substantial increase by 2028, underscoring the economic potential of VPPs. In contrast, implementation costs remain relatively stable, suggesting that once the initial investment phases are overcome, VPPs can generate increasing revenues with relatively modest additional investment. Most recently, MIT Technology Review estimated current U.S. VPP capacity at 30-60 GW, covering 4-8% of peak electricity demand, with a goal to expand to 80-160 GW by 2030, potentially replacing 80-160 fossil fuel plants.[24]

[24] MIT Technology Review. (2024, February 7). How virtual power plants are shaping tomorrow's energy system. Retrieved from https://www.technologyreview.com/2024/02/07/1087836/how-virtual-power-plants-are-shaping-tomorrows-energy-system/

In recent years in fact, investments in VPPs have grown significantly, driven by the demand for flexible solutions in renewable energy management and the need to enhance grid reliability. According to market forecasts, the VPP sector is expected to grow from $6.47 billion in 2022 to approximately $16.90 billion by 2030. This approach not only contributes to grid stability but also generates new revenue streams through the provision of flexibility services such as frequency regulation and load balancing.[25]

Investments in these technologies not only enhance the resilience of the energy system but also provide significant economic returns, positioning VPPs as a strategic asset for the future of global energy markets.

Noteworthy examples of VPP implementations include:

- Statkraft in Norway, the world's largest VPP, with a capacity of 10 GW sourced from over 1,000 aggregated resources;[26]
- Tesla's project in South Australia, which aims to connect 4,000 to 50,000 homes, potentially making it the largest VPP in the world.[27]
- In Italy, a prominent example is EGO, which manages 1.6 GW of renewable and cogenerated energy across more than 1,500 production sites. Recently acquired by Shell, EGO represents a significant step in the expansion of VPPs across Europe.[28]

Europe is leading VPP deployment globally, with strong growth in Germany, the UK, and Scandinavia. Regulatory support, coupled with a focus on grid reliability amidst increasing renewable penetration, is accelerating market expansion. The EU estimates the contribution of DERs to electricity consumption will exceed 30% by 2030, underscoring the potential for VPP aggregation. High penetration of residential solar PVs and EV charging stations in countries like the Netherlands and Norway present lucrative markets for VPP operators. VPPs provide value through multiple revenue streams:

- **Energy arbitrage:**
  Buying and storing energy during off-peak periods for resale during high demand.

- **Capacity markets:**
  Participating in grid stabilization services.

- **Carbon offsets:**
  Leveraging clean energy integration to benefit from carbon credit markets.

[25] Skyquest team. (2023). Global virtual power plant market insights. Available from https://www.skyquestt.com/report/virtual-power-plant-market

[26] Tranninger, J. (2020). Statkraft's virtual power plant participates in UK's balancing mechanism. Available from https://www.statkraft.com/newsroom/news-and-stories/2020/vpp-balancing-services/

[27] Tesla team. (2023). What is South Australia's virtual power plant. Available from https://www.tesla.com/en_au/sa-virtual-power-plant

[28] 28Shell. (2023). Shell completa l'acquisizione della società di gestione dell'energia EGO Srl. Available from https://www.shell.it/media-centre/2023/shell-completa-l-acquisizione-della-societa-di-gestione-dellenergia-ego-srl.html

Highlights

- **Key Investment Areas**
  Energy communities and Virtual Power Plants (VPPs) offer scalable, decentralized energy solutions, enhancing local renewable energy integration and grid stability.
- **High Return Potential**
  The VPP market is expected to grow to $16.90 billion by 2030, driven by participation in energy and flexibility markets. Investments in VPPs enable revenue generation through ancillary services like frequency regulation and load balancing.
- **Sustainability and Resilience**
  VPPs and energy communities improve the resilience of energy systems, optimizing resource use to manage peak demand and reduce CO2 emissions, contributing to the decarbonization of energy production.
- **Government Support**
  European Policies incentivize investment in energy communities and VPPs, promoting renewable energy growth and increasing the profitability of these models.
- **Decentralized Energy Models**
  Business models like prosumers, aggregators, and local energy markets promote stakeholder engagement, resource efficiency, and cost reduction, offering financial sustainability while fostering energy self-sufficiency.

Twin transition potential

The integration of VPPs aligns with the EU’s twin transition agenda, promoting digital transformation while advancing environmental sustainability.

- **Decarbonization:**
  VPPs directly support the energy transition by enabling higher renewable energy adoption and reducing dependency on fossil fuel-based power plants.
- **Digitalization:**
  By leveraging IoT, AI, and blockchain, VPPs exemplify the digital innovation needed to transform Europe’s energy infrastructure.
- **Resilience and Flexibility:**
  VPPs enhance energy system resilience by decentralizing power generation and enabling adaptive responses to grid demands. This flexibility also improves energy security, a critical EU focus amid geopolitical energy supply risks.

Energy storage and distribution

Energy storage and distribution

Clean and smart grids

TModern, smart, and expanded electricity grids are essential for a successful energy transition. As the world moves towards net-zero emissions, enhanced grid infrastructure will form the backbone of low-carbon economies, enabling the integration of renewable energy and electrification across multiple sectors. However, current investments in grid expansion and digitalization fall short of what is necessary. To meet global energy and climate goals, substantial investments in building, upgrading, and modernizing grids are required, creating an urgent need for capital.[29]

Clean and smart grids represent the next generation of electricity networks, designed to integrate digital technologies and advanced infrastructure for efficient energy management. These grids enable the seamless incorporation of renewable energy sources, enhance energy efficiency, and provide consumers with greater control over their energy usage.

Key characteristics are:

- **Intelligent Monitoring and Control:**
  Use of digital sensors, IoT devices, and real-time data analytics to monitor energy flows and optimize grid operations.
- **Integration of Renewables:**
  Facilitation of variable energy sources like wind and solar, ensuring stability and reliability despite intermittent generation.
- **Two-Way Communication:**
  Supports bidirectional energy flow, enabling distributed energy resources (DERs), such as rooftop solar panels and battery storage, to participate actively in the grid.
- **Enhanced Reliability:**
  Reduction in power outages through predictive maintenance and rapid fault detection.
- **Consumer-Centric Design:**
  Empowering end users with smart meters and dynamic pricing models to manage their energy consumption effectively.

[29] IEA (2023), Electricity Grids and Secure Energy Transitions, IEA, Paris https://www.iea.org/reports/electricity-grids-and-secure-energy-transitions

Market Drivers - Regulatory framework

EU Digitalization and Cybersecurity Directives:
Policies like the NIS2 Directive ensure smart grid resilience by addressing cybersecurity challenges, an essential consideration for investment in grid digitalization.

National Grid Modernization Initiatives:
Countries like Germany, France, and Italy are introducing subsidies and incentives for grid upgrades, focusing on digital technologies and integration of electric vehicles (EVs).

Key Technologies

Advanced Metering Infrastructure (AMI):

Smart meters form the backbone of clean grids, enabling real-time data collection, two-way communication, and precise energy management.

Supervisory Control and Data Acquisition (SCADA) Systems

These systems allow utilities to monitor and control grid operations remotely, improving efficiency and reliability.

Energy Storage Systems (ESS)

Batteries and other storage solutions help balancesupply and demand, critical for integrating variable renewable energy sources like wind and solar.

IoT and Big Data Analytics

IoT devices and analytics platforms enable predictive maintenance, grid optimization, and customer-centric services.

Artificial Intelligence (AI) and Machine Learning

AI applications include demand forecasting, fault detection, and grid balancing, making grids smarter and more adaptive.

Blockchain for Energy Transactions

Blockchain technology facilitates peer-to-peer energy trading and enhances transparency in grid operations.

Expert Insight:
Green Hydrogen: Expectations vs. Reality

Developed with insights from Nicola Armaroli, Research Director at CNR, and Alberto Dalla Riva, Senior Lead Business Developer at Ørsted

Hydrogen is not growing as expected, mainly due to the high cost of electrolysers and the lack of significant price reductions. The sector's expectations are much lower than they were three years ago. The main challenge is the high cost of green hydrogen, which is 3-4 times more expensive than alternative energy sources.
Additionally, it is uncertain how much of Europe's industrial demand will persist, given that countries like Oman, Egypt, and Morocco can produce hydrogen at significantly lower costs. Another critical issue is the role of hydrogen in industrial heating. Too expensive compared to natural gas, fuel cells have not been widely adopted. Meanwhile, more competitive solutions such as electric boilers and heat pumps are emerging and could replace much of the industrial demand without switching to hydrogen.

Green hydrogen remains a key element in the decarbonisation of hard-to-abate sectors, but its widespread use in the short term seems increasingly unrealistic. Europe faces a challenge: should it continue to invest in hydrogen or focus on more immediate and cost-effective electrified solutions?

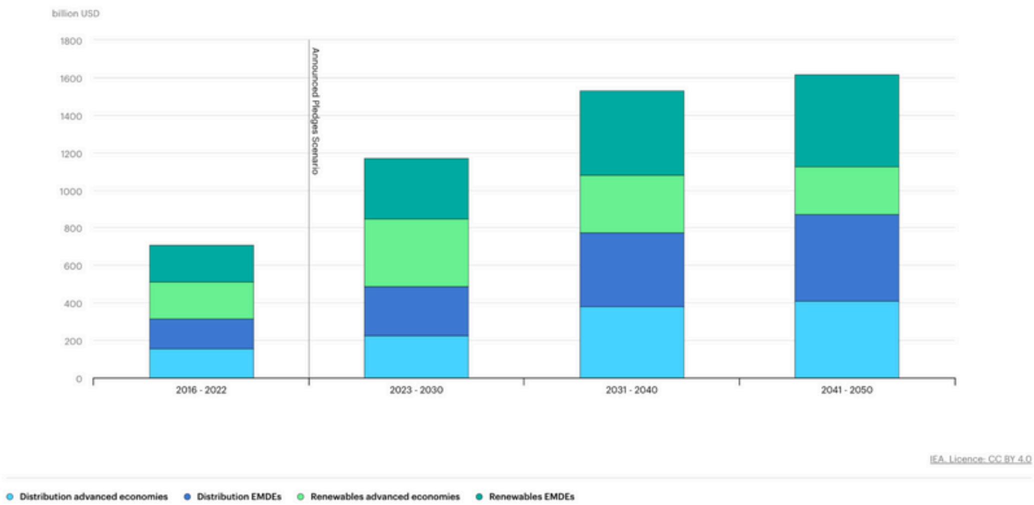
Market development and Investment Opportunities

Achieving the net-zero pathway requires doubling global grid investments to over USD 750 billion per year by 2030, focused on digitalisation and modernising distribution grids. Current investments remain static at around USD 330 billion, with around 75% of the investments allocated to the distribution grids to expand, strengthen, and digitalise technologies, highlighting a significant opportunity for private capital to bridge this gap.[30]

Concerningly, emerging and developing economies, excluding China, have seen a decline in grid investment in recent years, despite robust electricity demand growth and energy access needs. Advanced economies have seen steady growth in grid investment, but the pace needs to step up to enable rapid clean energy transitions. Investment continues to rise in all regions beyond 2030.

Fig. 9 - Average annual investment in grids and renewables by regional grouping in the Announced Pledges Scenario, 2011-2050

Source: IEA (2023), Electricity Grids and Secure Energy Transitions, IEA, Paris

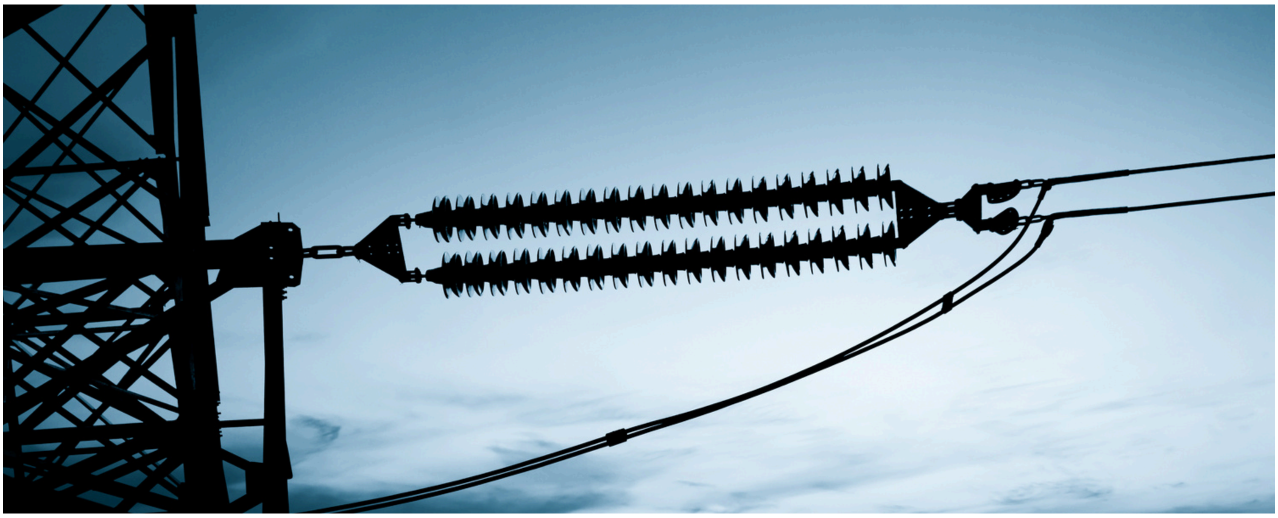


Indeed, at least 3,000 GW of renewable projects are currently queued for grid connection, equivalent to five times the wind and solar capacity added in 2022. Without increased investment, grids risk becoming the bottleneck in the clean energy transition. Delayed investment would increase cumulative CO_2 emissions by 58 gigatonnes by 2050, putting the 1.5 °C climate goal out of reach and leading to reliance on fossil fuels, with increased coal and gas imports.

[30] IEA (2023), Unlocking Smart Grid Opportunities in Emerging Markets and Developing Economies, IEA, Paris
https://www.iea.org/reports/electricity-grids-and-secure-energy-transitions

The push for clean and smart grids is driven by global trends:

- **Rapid electrification:**
  Electricity demand is expected to grow 20% faster in the coming decade, driven by increased use in sectors like transportation, heating, cooling, and hydrogen production.
- **Renewable integration:**
  To reach net-zero emissions, renewable energy's share must increase significantly, with wind and solar PV accounting for almost 90% of the rise in power capacity by 2050.
- **Digitalisation and Grid Flexibility:**
  The shift toward renewable power sources requires flexible, resilient grids that can manage variability. Digitalisation will be essential for ensuring reliability, efficiency, and integration of distributed resources like rooftop solar.



As electricity grids advance in the global energy transition, digital infrastructure is taking on a pivotal role in both distribution and transmission. Digital grid investments grew by approximately 7% in 2022, driven by the increasing importance of smart meters, automation, and data-driven management systems. The focus on digital solutions is critical to optimising grid reliability, resilience, and flexibility, particularly as renewable energy integration and electric vehicle (EV) adoption accelerate. For investors, digital infrastructure in electricity grids offers promising returns and is fundamental to the sustainable energy transition.[31]

In the distribution sector, digitalisation has become a primary focus, receiving around 75% of digital grid funding. Investments are particularly directed toward smart meters, sensors, and Distributed Energy Management Systems (DERMS). These tools are pivotal in enabling effective management of distributed energy resources, from small-scale renewable plants to electric vehicle (EV) chargers and battery storage systems. By integrating flexible resources. into grid management, distribution system operators can sidestep costly physical grid reinforcements, achieving operational savings and improved grid stability.

[31] IEA (2023), Investment in digital infrastructure in transmission and distribution electricity grids, 2015-2022, IEA,Paris
https://www.iea.org/data-and-statistics/charts/investment-indigitalinfrastructure-in-transmission-and-distribution- electricity-grids-2015-2022

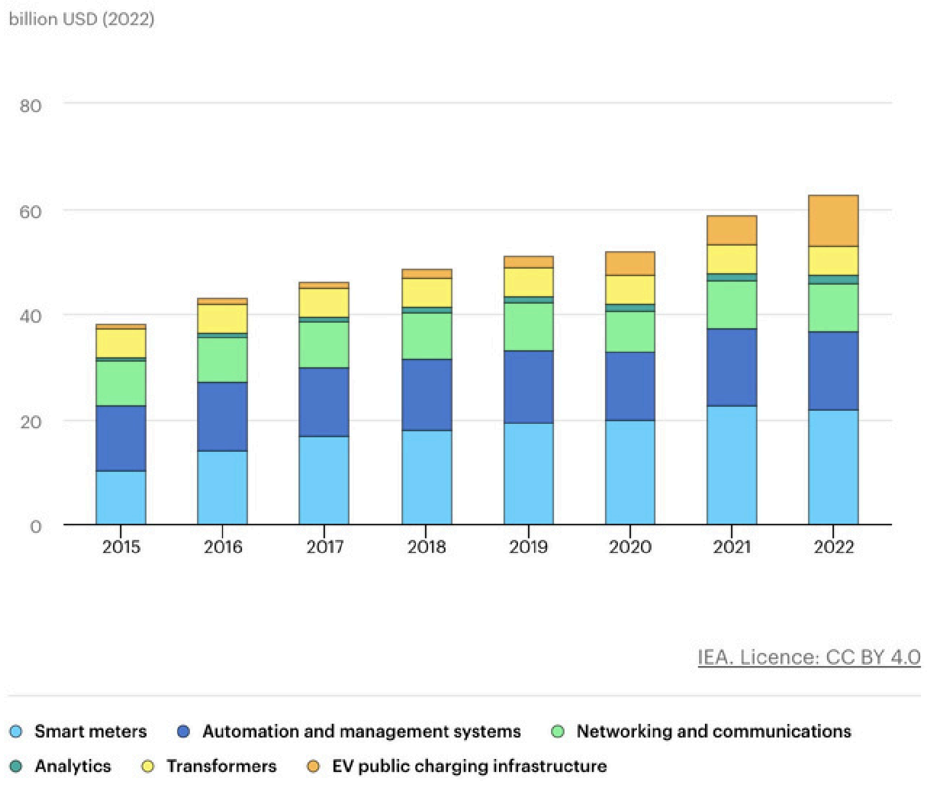
The rapid expansion of EV infrastructure has further underscored the value of digital grid investments. Investment in EV charging infrastructure alone grew by over 75% in 2022, reflecting rising global EV adoption and the demand for effective grid integration. Smart grid technologies provide critical visibility and control over EV charging operations, balancing loads to prevent bottlenecks and maintain energy stability. This integration not only enhances the efficiency of EV charging infrastructure but also creates a steady revenue stream through demand response capabilities, benefiting both grid operators and consumers.

In transmission, digitalisation efforts focus on automating substations, digitising power transformers, and implementing Flexible Alternating-Current Transmission Systems (FACTS). Advanced tools like phasor measurement units and sensors have allowed for faster, more efficient grid operations, crucial for optimising energy flows and managing fluctuations associated with renewable energy integration. For investors, digital transmission technologies represent a strong value proposition, as they help reduce the likelihood of outages, optimise energy distribution, and facilitate the scaling up of renewable energy sources.

Resilience is another critical aspect of smart grids, increasingly supported by predictive analytics and disaster prevention technologies. Emerging solutions, including Spark Prevention Units and satellite-based geographic information systems, help prevent fires and mitigate climate-related risks by monitoring grid assets in vulnerable areas. Predictive analytics reduce maintenance costs and protect grid infrastructure from environmental damage, securing long-term returns by preserving asset integrity and ensuring continuous service.

Fig. 10 - Investment in digital infrastructure in transmission and distribution electricity grids, 2015 -2022

Source: EA (2023), Investment in digital infrastructure in transmission and distribution electricity grids, 2015-2022, IEA, Paris



Twin transition potential

The development of clean and smart grids aligns with the EU's twin transition agenda, emphasizing the synergy between digital innovation and environmental sustainability.

- **Digitalization Benefits:**
  Smart grids integrate IoT, AI, and big data technologies, modernizing energy infrastructure and enabling consumer-centric services like dynamic pricing and energy efficiency programs.
- **Decarbonization Impact:**
  - By facilitating renewable energy integration, clean grids reduce reliance on fossil fuels, lowering greenhouse gas emissions.
  - Grid flexibility minimizes energy waste and enhances overall efficiency.
- **Resilience and Energy Security:**
  - Advanced grids improve resilience against disruptions, crucial amid geopolitical energy challenges.
  - They also support decentralized energy production, reducing dependence on centralized generation.
- **Consumer Empowerment:**
  Smart grids allow consumers to participate actively in energy markets, offering them control over energy usage and costs through smart technologies.

Energy Storage

There is a growing need for solutions that ensure power grid reliability and facilitate renewable energy integration. Among these, energy storage represents a key resource, enabling the accumulation of energy generated from intermittent sources such as solar and wind power, and allowing its flexible deployment to balance supply and demand.
Storage systems have strategic implications across multiple fronts: in power grid stability, they support continuous energy supply, which is essential for decarbonized infrastructure. In the transport sector, they enable increasing electrification, crucial for reducing environmental impact. Industry and residential sectors also benefit from storage, optimizing self-consumption and promoting energy self-sufficiency.[32]

The energy storage landscape encompasses various technologies, each with distinct characteristics and applications:[33]

Mechanical Storage:
In pumped hydroelectric systems, water is pumped into a reservoir when energy is abundant and later released to generate electricity when needed. However, this is feasible only in areas with suitable geographical formations.

Chemical Storage:
Batteries, particularly lithium-ion systems, excel at storing large amounts of energy in compact spaces. Their versatility enables deployment across a wide range of applications, from large-scale grid systems to residential installations and electric vehicles.
While lithium-ion batteries dominate the Battery Energy Storage Systems (BESS) market due to their proven performance, the technology landscape includes several alternatives: flow batteries offer extended duration capabilities, lead-acid batteries provide cost-effective solutions for specific applications, and various advanced chemistries are under development.

Thermal Storage:
This technology stores energy in the form of heat, utilizing materials such as molten salts. It is particularly effective when combined with concentrated solar power plants, where heat collected during daylight hours can be released at night.

[32] IRENA (2024), Renewable power generation costs in 2023, International Renewable Energy Agency, Abu Dhabi.

[33] IRENA (2020), Electricity Storage Valuation Framework: Assessing system value and ensuring project viability, International Renewable Energy Agency, Abu Dhabi.

Expert Insight:

Thermal Storage and Heat Pumps – Key innovations for decarbonizing Hard-to-Abate Sectors

Developed with insights from Nicola Armaroli, Research Director at CNR and Ernesto Ciorra, Innovation and Sustainability Expert

Thermal storage and heat pumps are emerging as critical technologies for decarbonizing industries that are traditionally challenging to transition to sustainable energy, such as ceramics, brewing, and other heat-intensive sectors.

Thermal Storage for High-Temperature Applications
Thermal storage systems capable of operating up to 600°C are transformative for industries requiring consistent high-temperature heat. These systems enable the decoupling of energy generation from energy use, improving efficiency and facilitating the integration of renewable energy sources.

Heat Pumps and Electrification of Heating
Heating accounts for 35% of primary energy consumption in Europe, making it a crucial focus area for decarbonization. Heat pumps, which can efficiently convert electricity into heat, are key to electrifying heating systems.

Battery Energy Storage Systems (BESS)

In particular, Battery Energy Storage Systems (BESS) provide rapid and flexible response capabilities for addressing the challenges inherent in an energy sector increasingly dependent on intermittent generation sources, specifically solar and wind power.[34]
Primary technical applications and operational characteristics are:[35]

Grid Stabilization and Supply-Demand Fluctuation Response: Increasing penetration of variable renewable sources introduces significant supply fluctuations, necessitating sophisticated demand balancing mechanisms to maintain service continuity and power quality parameters. These systems demonstrate near-instantaneous energy storage and discharge capabilities, facilitating supply-demand equilibrium through real-time frequency variation response.
This frequency regulation functionality is critical for grid stability in high-renewable-penetration scenarios where generation exhibits weather dependency.

Intermittent Renewable Energy Optimization: The temporal storage and scheduled discharge capabilities of BESS are fundamental for managing variable renewable generation.
During peak production periods—characterized by high solar irradiance or optimal wind conditions—excess generation is accumulated for subsequent deployment during low-production intervals, thereby ensuring consistent supply parameters.

Electric Mobility and Vehicle-to-Grid (V2G) Integration: In electric mobility applications, storage systems facilitate both vehicle propulsion and bidirectional grid interaction through V2G protocols. This technology enables the transformation of electric vehicles into distributed mobile storage units capable of grid supply during peak demand periods, optimizing distribution efficiency without additional generation infrastructure requirements.

Off-Grid Applications and Microgrid Integration: In geographically isolated contexts where grid connectivity is impractical or unfeasible, BESS enable autonomous microgrid deployment. These systems integrate local renewable generation with advanced storage capabilities, ensuring supply continuity. Standard operational protocols maintain consistent power delivery to local infrastructure, while storage systems provide demand management during generation shortfalls. This configuration enhances system resilience, minimizes fossil fuel dependency, and optimizes energy security in isolated regions.

[34]SolarPower Europe (2024): European Market Outlook for Battery Storage 2024-2028.
[35]IEA (2023), Batteries and Secure Energy Transitions, IEA, Paris.

Market Drivers - Regulatory Framework

The growing share of intermittent renewable energy sources has necessitated solutions like BESS to balance supply and demand in real-time. Indeed, upgrades to aging infrastructure require flexible technologies like BESS to ensure stable and efficient grid operations.
BESS improves resilience against power outages and ensures continuous energy supply during peak demand or grid disruptions. Furthermore, lithium-ion battery costs have dropped significantly, making BESS increasingly attractive for utility-scale, commercial, and residential applications.
Finally, Distributed Energy Resources (DERs), including rooftop solar and community energy projects, have created demand for localized storage solutions.

European Union

- **Energy Storage Directive:**
  Provides a framework for integrating storage technologies into the energy market by removing barriers such as double taxation and grid access restrictions.
- **Clean Energy for All Europeans Package:**
  Encourages energy storage to support renewable energy deployment and ensure grid flexibility.
- **EU Battery Regulation (2023):**
  Promotes sustainability in battery production, recycling, and ethical material sourcing.

Italy

- **National Recovery and Resilience Plan (PNRR):**
  Invests in BESS to facilitate renewable integration and grid modernization, supported by significant EU funding.
- **ARERA Guidelines:**
  Incentivize storage adoption by enabling flexible tariffs and fostering participation in ancillary service markets.
- **Regulatory Decree 199/2021:**
  Implements EU energy directives to promote renewable energy and storage technologies.

Key Technologies

Lithium-Ion Batteries:

Dominant technology due to high energy density, efficiency, and declining costs.
Widely used in utility-scale, commercial, and residential applications.

Flow Batteries:

Emerging for long-duration storage. Offers scalability and greater cycle life compared to lithium-ion but with higher initial costs.

Solid-State Batteries:

Promising next-generation technology with improved safety, energy density, and lifecycle, though currently in the R&D phase.

Hybrid Systems:

Combines BESS with other technologies (e.g., hydrogen storage or thermal energy storage) for enhanced system flexibility and efficiency.

Advanced Software and AI:

Optimizes battery performance, extends lifespan, and enables smart integration with the grid through real-time monitoring and predictive analytics.

Expert Insight:
The Future of Batteries: Growth and Innovation

Developed with insights from Nicola Armaroli, Research Director at CNR, and Alberto Dalla Riva, Senior Lead Business Developer at Ørsted

The battery industry is experiencing a strong accelerating phase, driven by the Chinese industry, but with significant expansion (in terms of installation) also occurring in Australia, the US, and recently in Europe. An attempt was made to establish battery gigafactories in Europe, but intense competition from Chinese manufacturers led to the bankruptcy of *Northvolt* (which had raised, since 2016, almost $15 billion in funding).
The current dominance of lithium-ion batteries could be challenged in the medium to long term by emerging technologies such as sodium batteries, which offer lower costs and greater material availability. Flow batteries could also play a key role in the future. Battery storage capacity has grown from a few megawatts before 2020 to 150-170 GW worldwide in 2023, overtaking pumped hydro. Falling production costs have accelerated this transition, with China already reaching the costs projected for 2040.
One of the key issues is the availability of lithium, which is crucial for today's batteries. However, alternative solutions are emerging:

- LFP (Lithium Iron Phosphate) batteries, which eliminate cobalt and reduce the environmental and social problems associated with mining.
- Lithium-free sodium batteries, which could become dominant by 2030 due to their cost effectiveness and lower environmental impact.
- Recycling and partial replacement: recent studies suggest that with proper recycling management, net-zero lithium extraction could be achieved by 2035.

Market development and Investment Opportunities

The BESS market segmentation comprises three primary categories[36]:

- **Utility-scale (front-of-the-meter)**
  represents the largest and fastest-growing segment, projecting a 29% annual growth rate through 2030. Utility-scale installed capacity is expected to reach 450-620 GWh by 2030, potentially constituting up to 90% of the market.

[36] SolarPower Europe (2024): European Market Outlook for Battery Storage 2024-2028.

- **Commercial and Industrial (C&I)**
  projects a 13% annual growth rate through 2030.
  Commercial users report up to 80% reduction in energy costs, particularly in regions with high demand charges.
- **Residential**
  segment, while smallest in scale with a targeted installed capacity of approximately 20 GWh by 2030, presents significant opportunities for innovation and market differentiation.

BESS project profitability relies on simultaneous revenue generation from multiple sources, a practice known as revenue stacking. Primary revenue streams include:[37]

- **Energy Arbitrage**
  Energy arbitrage capitalizes on intraday electricity price differentials. Systems accumulate energy during low-demand periods (characterized by lower prices) and discharge during high-demand periods, when market prices peak. This optimization strategy maximizes returns during peak pricing periods, enhancing overall project economics.
- **Frequency Regulation**
  Power grids require stable frequency maintenance (e.g., 50 Hz in European networks). BESS provide millisecond-response capabilities to frequency fluctuations, injecting or absorbing power to maintain stability. Grid operators compensate for this essential service, particularly valuable in systems with high penetration of variable renewable sources.
- **Peak Shaving**
  Peak shaving involves strategic demand peak reduction. BESS temporarily satisfy demand during maximum load periods, reducing strain on primary grid infrastructure. This service delivers cost avoidance benefits to commercial entities, particularly in regions with demand-based tariff structures.
- **Renewable Curtailment Minimization**
  During periods of peak renewable generation (wind or solar), excess production may require curtailment due to grid capacity constraints. BESS capture this surplus energy, preventing waste, and enable strategic deployment during periods of higher demand or reduced renewable generation.

A utility-scale BESS project can optimize revenue through simultaneous deployment of these strategies: accumulating energy during low-demand periods for arbitrage opportunities, providing continuous frequency regulation services, implementing afternoon peak shaving, and, when integrated with solar or wind facilities, storing excess generation to prevent curtailment.

In 2023, investments in Battery Energy Storage Systems (BESS) reached approximately USD 40 billion, representing a fivefold increase from 2018 levels.[38]

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[37] McKinsey & Company (2023), Enabling Renewable Energy with Battery Energy Storage Systems, McKinsey & Company, August 2023.
[38] IEA (2023), Batteries and Secure Energy Transitions, IEA, Paris.

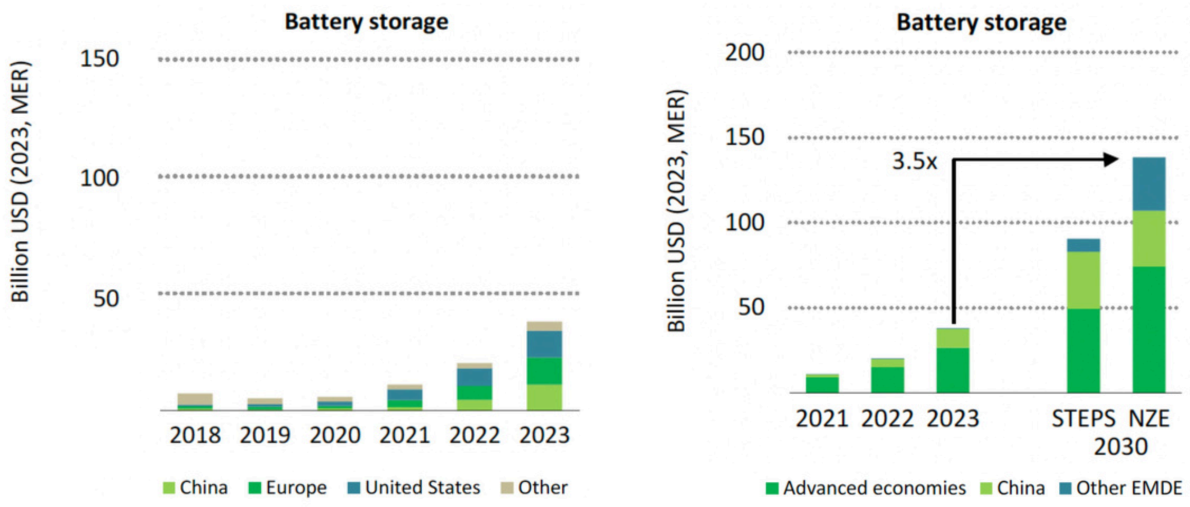

Fig. 11 - Global investment in battery storage, 2018-2023

Source: IEA (2023), Batteries and Secure Energy Transitions, IEA, Paris.

This growth trajectory is evidenced in an expanding market where energy storage projects now constitute a fundamental component for grid stability and renewable energy integration. However, investment distribution exhibits significant geographical concentration: China, Europe, and the United States account for over 90% of total expenditure. This investment disparity primarily stems from variations in capital costs and policy incentive frameworks.
Advanced economies benefit from favorable financing conditions and incentive mechanisms that effectively mitigate investment risks, whereas emerging markets typically face double the capital costs for BESS projects.[39]

Total battery expenditure across all applications is projected to increase substantially in the coming years, with estimates indicating approximately USD 800 billion by 2030, representing a considerable increase from current levels. According to Solar Power Europe's report, investment allocation is expected to shift in favor of emerging markets and developing countries outside China, with annual expenditure potentially reaching USD 30 billion for battery storage by 2030.[40]

However, several risks impede the expansion of battery storage expenditure, particularly in emerging markets and developing nations. Macroeconomic and country-specific factors contribute significantly to the elevated cost of capital for clean energy projects. Investors express concerns regarding the robustness of legal frameworks and contract stability in certain jurisdictions, as well as high inflation, currency fluctuations, and currency convertibility. In the long term, addressing investor concerns will necessitate implementing a series of measures to stabilize the economic and financial environment in emerging markets. These efforts must encompass strengthening national institutions to ensure political stability and legal reliability; reducing inflation, which is essential for maintaining currency stability; and developing local capital markets to facilitate more accessible domestic financing.[41]

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[39] IEA (2023), Batteries and Secure Energy Transitions, IEA, Paris.

[40] SolarPower Europe (2024): European Market Outlook for Battery Storage 2024-2028.

[41] 41SolarPower Europe (2024), European Market Outlook for Battery Storage 2024-2028, SolarPower Europe; and McKinsey & Company (2023), Enabling Renewable Energy with Battery Energy Storage Systems, McKinsey & Company, August 2023.

Within this context, 2024 is expected to witness a significant reorganization in the ranking of principal European markets for battery storage:

1. **Italy:**
   Currently the second-largest annual market in 2023, Italy is projected to surpass Germany in 2024, ascending to the primary position due to growth in the large-scale segment. The Italian market is estimated to add 7.7 GWh of BESS capacity, doubling installed volumes compared to 2023 and capturing 34% of total annually constructed capacity in Europe.

2. **United Kingdom:**
   The UK, an established leader in large-scale battery deployment, is projected to marginally surpass Germany in 2024, returning to the second position after a two-year absence, achieving a 70% year-over-year growth with 4.5 GWh of capacity additions.

3. **Germany:**
   Despite dropping two positions to third place in 2024, Germany maintains the highest expansion potential: the German BESS market is projected to deploy 4.4 GWh, accounting for 20% of total European installations.

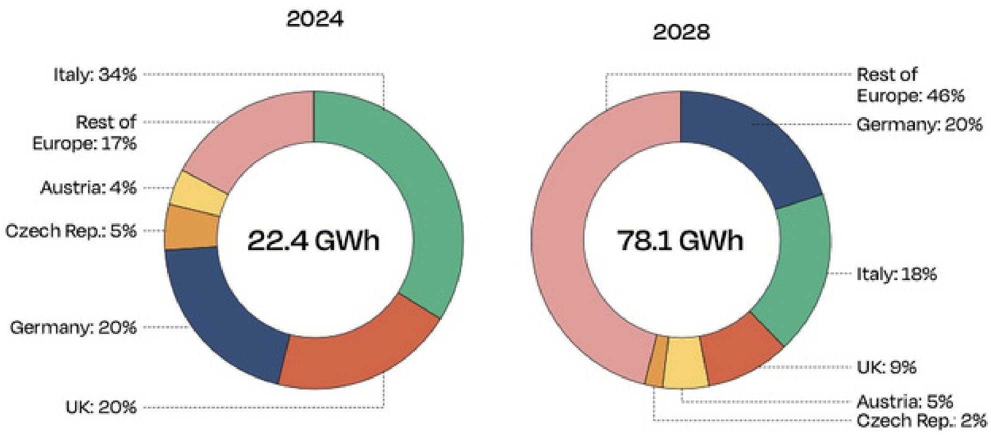

Fig. 13 - Europe Top 5 Markets 2024-2028

Source: SolarPower Europe (2024): European Market Outlook for Battery Storage 2024-2028.

Twin transition potential

The integration of BESS supports decarbonization, improves grid resilience, and enables innovative energy solutions, making it a cornerstone of the twin transition. BESS sits at the intersection of the energy and digital transitions, providing high potential for dual transformation:

- **Energy Transition:**
  Facilitates the shift from fossil fuels to renewables by ensuring reliability and reducing dependence on traditional energy sources.

- **Digital Transformation:**
  Leverages advanced technologies like AI and IoT for enhanced grid management, predictive maintenance, and optimal energy utilization.

Power-to-X (PtX)

Power-to-X (PtX) technologies represent a transformative opportunity within the renewable energy sector. By converting surplus renewable electricity into other energy carriers, such as hydrogen, ammonia, and synthetic fuels, PtX enables the storage, transfer, and utilization of green energy across various sectors. These technologies offer flexibility and versatility essential for sectors like transportation, heavy industry, and agriculture, where direct electrification may be challenging. As a critical component in the energy transition, PtX systems present substantial growth potential and promising investment opportunities. While PtX technologies hold significant potential, several barriers exist:

- **High capital expenditure:**
  Electrolyser and synthesis plant setup costs remain high, requiring substantial capital investment and supportive policies.
- **Energy conversion losses:**
  Efficiency losses in converting electricity to other forms of energy mean PtX technologies may require continued innovations to optimize.
- **Infrastructure adaptation:**
  Many PtX fuels require dedicated infrastructure for storage, transport, and end-use, which can be costly and may face regulatory hurdles.

Power-to-X technologies offer a robust approach to addressing the intermittent nature of renewable energy while enabling decarbonization across various sectors. For investors, PtX provides a diversified portfolio of opportunities, ranging from green hydrogen and ammonia production to synthetic fuels and sustainable food production. With strong growth projections and critical roles in decarbonizing hard-to-abate sectors, PtX technologies are positioned as attractive, long-term investments within the clean energy space.

Market drivers

Global and regional commitments to net-zero emissions are accelerating demand for PtX technologies as key enablers for reducing reliance on fossil fuels. Increasing renewable energy capacity has led to periods of surplus electricity. PtX provides a flexible means to convert this surplus into storable and usable forms of energy, reducing curtailment. PtX offers low-carbon alternatives for industries like steel, chemicals, and aviation, sectors that are otherwise difficult to electrify directly. By producing green hydrogen, synthetic fuels, and other energy carriers, PtX reduces reliance on imported fossil fuels, enhancing energy independence. Improvements in electrolysis efficiency, scaling of renewable capacity, and supportive policy frameworks are driving down costs, making PtX increasingly economically viable. Finally, PtX supports circular economy principles by enabling carbon capture and utilization (CCU) processes to produce sustainable fuels and chemicals.

Regulatory Framework

European Union:

- **Renewable Energy Directive II (RED II):**
  Sets binding targets for renewable energy use and promotes green hydrogen and synthetic fuel production.
- **Fit for 55 Package:**
  Introduces incentives for hydrogen and PtX adoption in transport, industry, and heating, including quotas for renewable fuels of non-biological origin (RFNBOs).
- **EU Hydrogen Strategy (2020):**
  Envisions the deployment of 40 GW of electrolyzers to produce green hydrogen by 2030, supporting PtX markets.

Italy:

- **National Hydrogen Strategy:**
  Sets binding targets for renewable energy use and promotes green hydrogen and synthetic fuel production.
- **Fit for 55 Package:**
  Identifies PtX technologies, particularly green hydrogen, as critical to decarbonizing industry and transport. Includes incentives for renewable energy integration and electrolyzer deployment.
- **PNRR Initiatives:**
  Allocates €3 billion for hydrogen infrastructure, including production, distribution, and utilization projects.

Key technologies

Power-to-Hydrogen (P2H2)

- **Overview:**
  Power-to-Hydrogen uses electrolysis to convert renewable electricity into green hydrogen, a clean fuel suitable for transportation, industry, and electricity generation. Green hydrogen production is expected to reach significant capacity by 2030, driven by demand for decarbonized fuel alternatives.

- **Data:**
  The global green hydrogen market is projected to grow at a compound annual growth rate (CAGR) of 54.7%, potentially reaching $89 billion by 2030 (Allied Market Research, 2022).[42] A BCG analysis [43] estimates a potential CAGR of 24% for the green hydrogen and hydrogen derivatives market, for example. This projection assumes that society embraces green hydrogen as part of its effort to restrict the rise in global average temperature to below 2°C above preindustrial levels.

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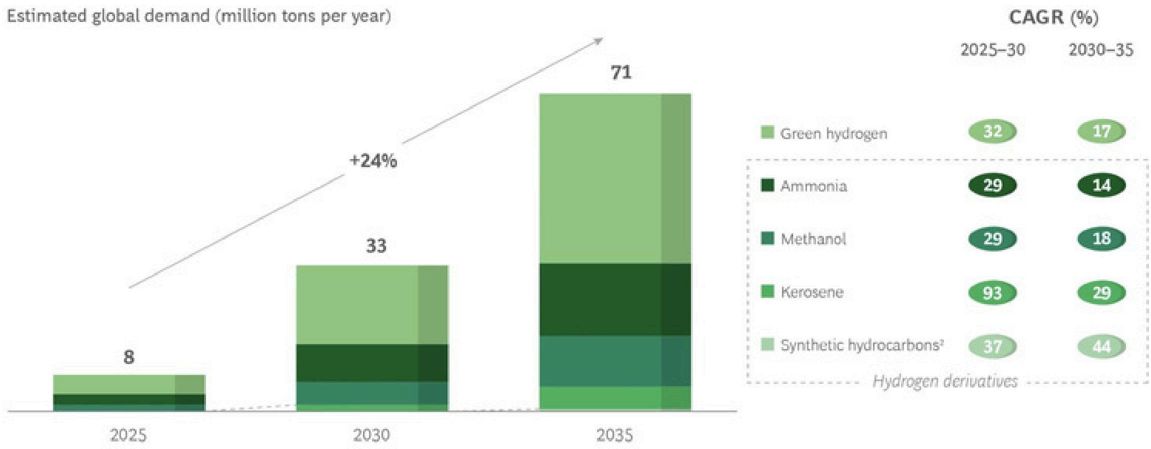
[42] Allied Market Research. (2022). Green Hydrogen Market Report.
[43] BCG (2023), Five Strategies for Optimizing Power-to-X Projects - https://www.bcg.com/publications/2023/five-strategies-for-optimizing-ptx-projects

The market for green hydrogen and hydrogen derivatives is estimated to have a potential CAGR of 24% through 2035[1]



Sources: BCG global hydrogen demand model (November 2022); BCG analysis.

[1]Hydrogen-derivative fuels are normalized to hydrogen equivalent. BCG's demand model assumes that society embraces green hydrogen to restrict the rise in global average temperature to below 2°C above preindustrial levels.

[2]Includes methanol converted to other end products.

Electrolyser capacity, integral to green hydrogen production, is anticipated to increase from 0.3 GW in 2020 to 300 GW by 2030 (BloombergNEF, 2022).[44]

Investment opportunities:
The scaling up of electrolyser production facilities, infrastructure for hydrogen storage and transport, and retrofitting industrial facilities to use green hydrogen are key areas for investors.

Power-to-Ammonia (P2A)

Overview:
Power-to-Ammonia converts renewable electricity into ammonia, often via hydrogen as an intermediary. Ammonia serves as a zero-carbon fuel for ships and a sustainable fertilizer, vital for reducing emissions in agriculture and heavy transport.

Data:
NH3 market is projected to experience a growth trajectory exceeding 4% Compound Annual Growth Rate (CAGR) from 2021 to 2031.[45] This growth is driven by the maritime industry's move towards low-emission fuel options[46] and the agricultural sector's need for sustainable fertilizers.

Investment Opportunities:
Potential investments include developing ammonia production facilities close to renewable energy sources, building port infrastructure to accommodate ammonia-fueled vessels, and advancing storage systems to handle the unique properties of ammonia safely.

44 BloombergNEF. (2022). Electrolyser Market Outlook.

45 Neelam Bora, Akhilesh Kumar Singh, Priti Pal, Uttam Kumar Sahoo, Dibyakanta Seth, Dheeraj Rathore, Sudipa Bhadra, Surajbhan Sevda, Veluswamy Venkatramanan, Shiv Prasad, Anoop Singh, Rupam Kataki, Prakash Kumar Sarangi, Green ammonia production: Process technologies and challenges, Fuel, Volume 369, 2024, https://doi.org/10.1016/j.fuel.2024.131808.

46 Mallouppas, G., Ioannou, C., & Yfantis, E. A. (2022). A review of the latest trends in the use of green ammonia as an energy carrier in maritime industry. Energies, 15(4), 1453.

- **Overview:**
  Power-to-Methane involves converting hydrogen and captured CO_2 into methane, providing a renewable alternative to natural gas. This synthetic methane can be transported and stored within existing gas infrastructure, making it suitable for power plants, heating, and industry.

- **Data:**
  IAs natural gas decarbonization intensifies, the power-to-methane market is expected to expand, with projections indicating that renewable methane could account for up to 10% of gas grid energy by 2030 and 14% by 2040.[47] Moreover, the IEA estimates that in 2040 overall production costs for biomethane will be 25% lower than today. The assumed average costs for biomethane production are 60 euros/MWh for anaerobic digestion and 40 euros/MWh for thermal gasification. In both cases, fixed costs would account for less than 40%.[48]

- **Investment opportunities:**
  Key areas include methane synthesis plants, CO_2 capture technologies, and grid adaptations to incorporate synthetic methane. Key advantages of PtM are: (1) It allows converting power into a commodity that can be used to reduce CO2 emissions in other sectors; (2) It uses existing infrastructure; (3) When considered as storage option, it has a high energy density (CH4 has >1000 kWh/m3 while hydrogen has 270 kWh/m3 and pumped hydro storage has 0.7 kWh/m3) and over 1000 TWh of storage capacity already deployed and operating; (4) It is suitable for long term and large scale storage.[49] P2M technology could be a promising storage solution in an electricity system that relies heavily on weather-dependent renewable electricity generation. However, in order to realize the theoretical potential, the application of the technology requires significant scaling.[50]

[47] ACER/CEER, Annual Report on the Results of Monitoring the Internal Electricity and Natural Gas Markets in 2021 Decarbonised Gases and Hydrogen volume, October 2022

[48] IEA (2020), Outlook for biogas and biomethane: Prospects for organic growth, IEA, Paris https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth

[49] Herib Blanco, Wouter Nijs, Johannes Ruf, André Faaij,Potential of Power-to-Methane in the EU energy transition to a low carbon system using cost optimization, Applied Energy, Volume 232, 2018, https://doi.org/10.1016/j.apenergy.2018.08.027

[50] Gábor Pintér, The development of global power-to-methane potentials between 2000 and 2020: A comparative overview of international projects, Applied Energy, Volume 353, Part A,2024, https://doi.org/10.1016/j.apenergy.2023.122094

Power-to-Liquids (P2L)

- **Overview:**
  Power-to-Liquids technology converts renewable electricity into liquid fuels, such as synthetic kerosene and diesel, useful for sectors that are hard to electrify, such as aviation and heavy-duty road transport.
- **Data:**
  The sustainable aviation fuel (SAF) industry is still in its infancy: in 2024, production capacity will not exceed 1.5 million metric tons (Mt), barely 0.5 percent of total jet fuel needs, according to International Air Transport Association estimates.[51] However, demand is expected to rise, due to regulation and voluntary airline commitments. The estimated global demand from mandated SAF is around 4.5 million Mt in 2030.[52]
- **Investment Opportunities:**
  Investing in SAF production facilities, distribution networks for liquid fuels, and partnerships with airlines could be viable paths for investors looking to support decarbonization in aviation.

Power-to-Food (P2F)

- **Overview:**
  Power-to-Food technologies leverage renewable energy to produce food, primarily through aquaculture and indoor farming systems. PtX enables the use of renewable hydrogen and other chemicals to synthesize nutrients and energy inputs for plant or animal food production.
- **Data:**
  The vertical farming and aquaculture sectors, closely tied to P2F, are predicted to grow at a CAGR of 20-25%, reaching $15 billion by 2030, as demand for sustainable and localized food production rises (Grand View Research, 2023).
- **Investment Opportunities:**
  IInvestments in controlled environment agriculture (CEA) systems, aquaponics, and nutrient synthesis technologies are areas of focus within the P2F sector.

[51] IATA (2024) SAF Production to Triple in 2024 but More Opportunities for Diversification Needed https://www.iata.org/en/pressroom/2024-releases/2024-06-02-03/

[52] McKinsey & Company, How the aviation industry could help scale sustainable fuel production, July 22, 2024 https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/how-the-aviation-industry-could-help-scale-sustainable-fuel-production

Market development and Investment Opportunities

The concept of "Power-to-X" (PtX) was introduced in Germany in the early 2010s as a versatile approach to address the limitations of electrical energy storage. PtX refers to technologies that convert surplus renewable electricity into alternative fuels, which can then be used for stationary energy production or in the transportation sector. This approach is especially valuable for mitigating renewable energy intermittency issues and enhancing the storage potential of renewable power. In this report, we delve into the foundational and emerging PtX technologies, including Power-to-Hydrogen (PtH), Power-to-Methanol (PtM), and Power-to-Ammonia (PtA), with an emphasis on their investment potential. Power-to-Hydrogen is widely regarded as the backbone of the PtX concept. Hydrogen production via electrolysis uses water as a feedstock and is powered by renewable energy sources, making it a geographically versatile and environmentally sustainable fuel option. On a weight basis, hydrogen has a high energy density, making it an efficient choice for both stationary power generation and transportation.[53] When used in fuel cells or combustion systems, hydrogen emits only water, which has garnered significant interest from academia, corporations, and governments alike as a clean energy solution (Sterner and Specht, 2021.[54])

In a study for the Danish Energy Agency, are analysed the global market potential and technology readiness for Power-to-X and carbon capture utilisation and storage (CCUS). In this study, the global market potential of Power-to-X is estimated to reach 601-2,319 billion EUR by 2035.[55]

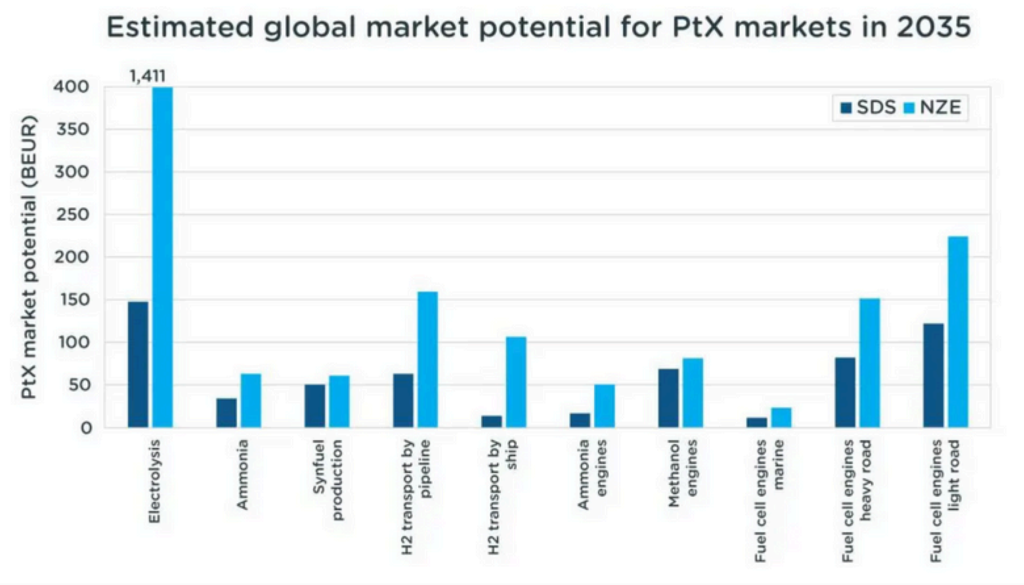


Fig. 14 - Potential for PtX markets

The global market for potential for Power-to-X has been estimated according to IEA's Sustainable Development Scenario (SDS), and IEA's Net Zero Emissions scenario (NZE). Source: Ramboll 2021 -Study for the Danish Energy Agency in 2021.

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53 Palys, M. J., & Daoutidis, P. (2022). Power-to-X: A review and perspective. Computers & Chemical Engineering, 165, 107948.

54 Sterner, M., & Specht, M. (2021). Power-to-gas and power-to-X—The history and results of developing a new storage concept. Energies, 14(20), 6594.

55 Ramboll (2021), Prospects for the global green hydrogen and Power-to-X markets, Accessed 2024-https://www.ramboll.com/net-zero-explorers/from-potential-to-profit

Twin transition potential

Power-to-X is pivotal for achieving net-zero targets while fostering the integration of renewable energy into a digitally enabled circular energy ecosystem.

Italy:

- Converts surplus renewable electricity into fuels like hydrogen, ammonia, or synthetic gas, enabling decarbonization of hard-to-abate sectors (e.g., steel, chemicals, aviation).
- Reduces dependence on fossil fuels, promoting circular resource use and storage of renewable energy.
- Green hydrogen, a key Power-to-X product, is projected to replace 25% of global energy demand by 2050 (IRENA, 2023).

Digital Transition:

- Utilizes AI and IoT for dynamic optimization of energy conversion, storage, and reconversion processes.
- Digital platforms enhance real-time monitoring, enabling sector coupling between power and transport, industry, and heating.

Energy efficiency

Energy efficiency

Energy Service Companies(ESCOs)

New financing mechanisms are vital to delivering the investment opportunity for the energy transition. Most energy efficiency investments continue to be self-financed, for example through homeowners' personal savings or companies' own balance sheets. These types of finance are unlikely to deliver the required investment growth on their own. To build confidence and capacity to encourage wider investment, policies are needed that support alternative finance mechanisms and business models such as energy service companies (ESCOs), green banks and green bonds. These mechanisms are growing, with the ESCO market increasing by 8% to nearly USD 29 billion in 2017 and green bonds issued primarily for energy efficiency tripling.[56]

In this context, Energy Service Companies (ESCOs) are emerging as essential players in the energy efficiency landscape, offering turn-key solutions that guarantee energy savings while aligning their compensation with achieved efficiencies.

Market Drivers - Regulatory Framework

European Framework

- **Energy Efficiency Directive (2012/27/EU):**
  Introduced in 2012, this directive provides a robust framework to enhance energy efficiency across the EU. It specifically supports ESCOs by promoting Energy Performance Contracts (EPCs) and obligates member states to eliminate regulatory and administrative barriers that hinder the development of energy services.

- **Energy Performance of Buildings Directive (2010/31/EU):**
  Adopted in 2010 and subsequently updated, this directive sets minimum energy efficiency standards for buildings. It highlights the critical role ESCOs play in delivering building energy upgrades and achieving EU energy targets.

- **Clean Energy for All Europeans Package (2019):**
  This package of directives and regulations aims to accelerate the EU's transition to a low-carbon economy. It includes measures to promote energy efficiency, renewable energy, and smart energy systems. ESCOs benefit directly from the focus on energy performance, as the package encourages market-based solutions and performance contracting to meet energy savings targets.

- **European Energy Certificate System (EECS):**
  Established in 2001, the EECS facilitates the issuance, transfer, and cancellation of energy certificates across member states. By standardizing renewable energy certifications, it supports transparency and market integration.

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[56] IEA (2018), Energy Efficiency 2018, IEA, Paris https://www.iea.org/reports/energy-efficiency-2018

- **European Skills, Competences, Qualifications and Occupations (ESCO):**
  Launched in 2013, this initiative indirectly benefits Energy Service Companies by promoting workforce mobility and harmonizing skills and qualifications across the EU, ensuring that the expertise required for energy efficiency projects is readily available.

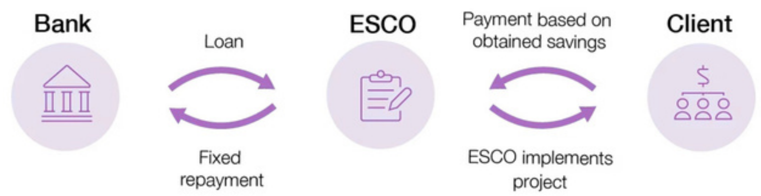
Italian Framework

- **UNI CEI 11352:2014 Certification:**
  Introduced in 2014, this certification is mandatory for Italian ESCOs, verifying their ability to deliver energy efficiency services in line with European Standard EN 15900. It is a prerequisite for accessing the White Certificates (TEE) scheme and conducting mandatory energy audits under Legislative Decree 102/2014.
- **White Certificates (TEE):**
  First implemented in 2001, this scheme incentivizes energy efficiency by awarding tradable certificates to ESCOs based on verified energy savings. It is a cornerstone of Italy's energy efficiency initiatives.
- **Conto Termico:**
  Launched in 2013, this program provides financial incentives for energy efficiency projects and the adoption of renewable energy systems. ESCOs often act as facilitators, managing the implementation of these projects and securing financial support for their clients.

Key technologies

Worldwide, ESCOs typically utilize three main types of contracts in their operations:

- **Shared savings contracts**



- **Shared savings contracts**

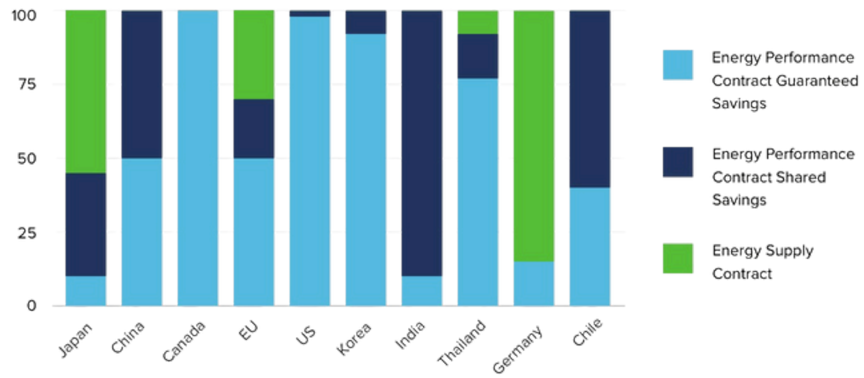
Source: IEA, 2018

* **Fee-for-service contracts**

The first two categories are commonly referred to as energy performance contracting (EPC) and represent the primary business models that set ESCOs apart from other service providers in implementing energy efficiency measures. In shared savings contracts, an ESCO not only offers technical assistance for energy efficiency projects and their execution but is also accountable for the initial financing of the project. As a result, the ESCO assumes both the performance and financial risks associated with the project. In contrast, guaranteed savings contracts place the responsibility for financing the energy efficiency project on the facility owner rather than the ESCO. In these agreements, the ESCO guarantees the facility owner a specific percentage of the energy savings achieved. Fee-for-service contracts involve the ESCO providing defined energy efficiency services for an agreed-upon fee. The facility owner finances the energy efficiency project and retains all cost savings. In this case, the ESCO does not need to guarantee a certain level of energy savings and will not receive a share of the savings generated by the project. Therefore, this type of contract is not based on performance. Data from the IEA shows that different countries adopt various approaches to ESCO market design. For instance, in China, a leading global market for ESCOs, both guaranteed savings and shared savings models are equally prevalent, each accounting for 50 percent of the market share. In Canada, the USA, and South Korea, the guaranteed savings model is the most common, while in India and Chile, the shared savings model holds the largest market share. The Japanese and EU member states' markets exhibit a balanced structure, with all contract types being actively utilized.

Fig.15. Global ESCO Structure of Revenues by Contract Type in 2020 (%)

Source: IEA, 2018



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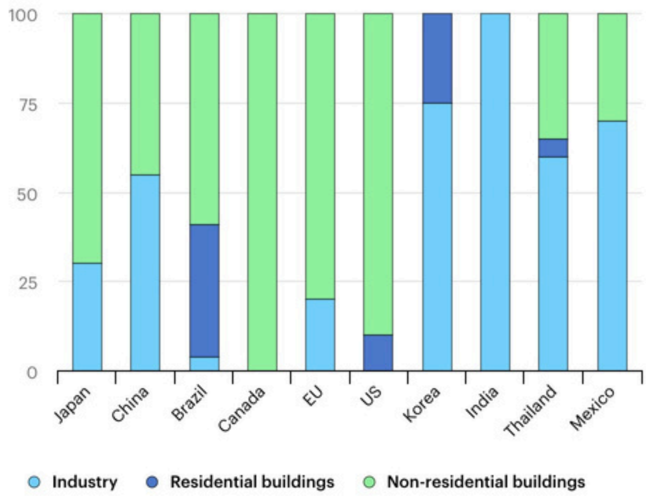
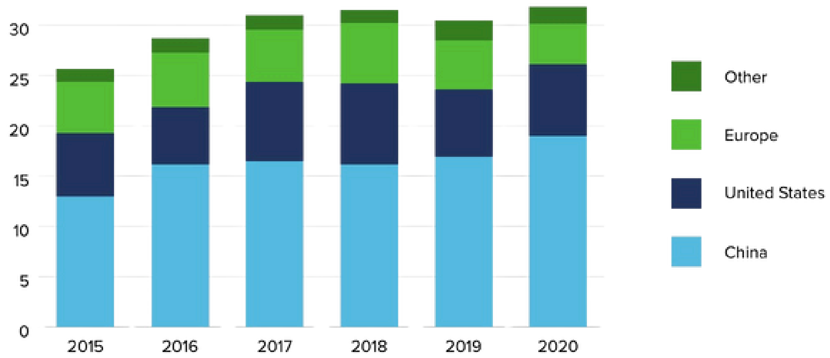


Market development and Investment Opportunities

ESCOs represent a strong value proposition for investors, especially in sectors and regions focused on sustainability and energy cost reductions. With energy demands rising and regulations increasingly favoring sustainable practices, ESCOs deliver a compelling model for scalable, risk-mitigated investment in the energy efficiency market. The global ESCO market as a whole increased by around 6 percent in 2020 to USD 33 billion. Regulatory pressures, rising energy costs, and increased demand for sustainable energy solutions support this growth.

Fig. 17. Global ESCO Market Size in 2015-2020 (USD Billions)

Source: IEA, 2018



This expansion was primarily focused in China, where investments increased by 12% despite the challenges posed by the pandemic. Other significant ESCO markets, such as those in the United States, Europe, and emerging economies,[57] either saw no growth or experienced declines. In 2020, the global ESCO market faced substantial disruptions due to physical lockdown measures. In Middle Eastern nations like Saudi Arabia and the United Arab Emirates, there was a growing recognition of the importance of efficient ventilation and cooling systems, which contributed positively to business operations. Europe represented 14 percent of the global ESCP market in 2020, while the United States accounted for 20 percent. From 2015 to 2020, Chinese energy service companies witnessed considerable growth, with China's share of global ESCO service sales rising from 52 to 59 percent over this six-year span. The Chinese ESCO association EMCA noted that these companies quickly adapted by utilizing online tools and remote controls to maintain client engagement and ensure strong business continuity. In 2020, Chinese ESCOs seized the opportunity to revamp their business models by incorporating more smart tools and technologies. Additionally, a crucial factor that bolstered the Chinese market was the introduction of new tax incentives by the Chinese government in May 2020, aimed at promoting the growth and innovation of ESCO businesses.[58]

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[57] IEA (2018), Energy Service Companies (ESCOs), IEA, Paris https://www.iea.org/reports/energy-service-companies-escos-2

[58] UNPD (2023), An Overview of the Best Practices of ESCO Market Design and Recommendations for Ukraine.

Energy savings insurance can further reduce risk associated with ESCO projects The ESCO market is not immune to the issue of uncertainty associated with the performance of efficiency projects, which inhibits greater levels of third-party finance. To reduce this uncertainty, a small number of financial institutions and private companies are now offering energy savings insurance (ESI). Two types of ESI are being offered, technical and credit. Technical insurance covers the ESCO or technology provider if promised energy savings are not achieved, assuming the technical risk associated with the efficiency project.

Fig.18. Technical Risk Insurance
Source: IEA, 2018

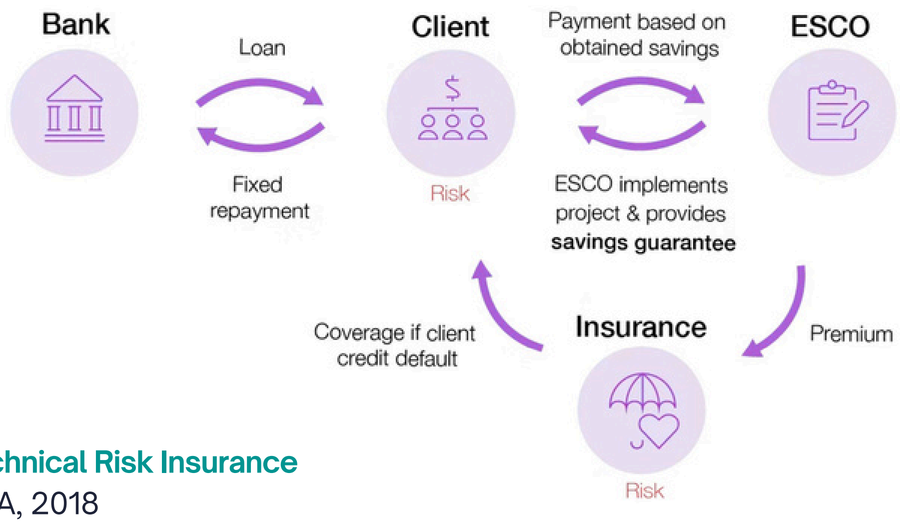

Fig.19. Technical Risk Insurance
Source: IEA, 2018

The Italian ESCO market

The Italian ESCO market is regarded as one of the largest and most developed in Europe, valued at €3.7 billion in 2018. Of this revenue, 35% came from energy performance contract (EPC) services, 42% from energy efficiency (EE) and consulting projects, and 23% from the sale of white certificates. [58] The adoption of EPCs in EE investments is significant in the commercial and office sectors, though it remains low in the residential sector. In public administration, only about 35% of the sector's EE investments were implemented through EPCs. While there are around 1,500 registered ESCOs, only 340 can be classified as genuine ESCOs. The majority of these are small and medium-sized enterprises (SMEs) and typically include energy supply companies, utilities, facility management firms, and energy auditors. They employ various technologies, such as active and passive systems, heating and cooling systems, air conditioning, street lighting, cogeneration, and automation and control systems. Italy is home to numerous ESCO associations that promote energy efficiency, including AssoEsco, Federesco, and FIRE. Key drivers for implementing EE measures in Italy have included regulatory support schemes, particularly the white certificates program, which was introduced in 2001 and became applicable to ESCOs in 2004, allowing end-users and ESCOs to obtain white certificates based on the levels of energy efficiency they achieved. Other support schemes that have contributed to the market's growth in recent years include the "Conto Termico" program, which encourages EE investments and thermal energy production from renewable sources for both public administration and private individuals, tax incentives for EE investments in buildings, and the introduction of D.Lgs 102/2014, which mandates that large companies undergo mandatory audits by ESCOs. Despite these advancements, significant barriers to the development of the ESCO market in Italy remain. According to a 2018 survey by the JRC, the primary challenges include a lack of appropriate financing options and insufficient trust from potential clients. Additional obstacles faced by ESCOs consist of ambiguities in the legislative framework, the small scale of projects coupled with high transaction costs, long and complicated procedures—especially in the public sector due to the nature of EPC contracts—and a shortage of resources and skills at the local authority level.

The ESCO model presents a high-potential investment avenue for companies interested in capitalizing on the growing demand for energy efficiency. By offering risk-mitigated, performance-guaranteed solutions, ESCOs align their financial success with energy savings, making them attractive to clients and investors alike. As energy efficiency gains momentum globally, investing in ESCOs can deliver consistent returns while supporting the broader shift toward sustainable energy practices.

[59] IEA (2018), Energy Service Companies (ESCOs), IEA, Paris
https://www.iea.org/reports/energy-service-companies-escos-2

Twin Transition Potential

The twin transition, characterized by the integration of digitalization and sustainability, represents a critical opportunity for Energy Service Companies (ESCOs) to advance energy efficiency and sustainability objectives. Through the adoption of advanced digital technologies, such as the Internet of Things (IoT), artificial intelligence (AI), and blockchain, ESCOs can significantly enhance energy management systems. These technologies enable real-time monitoring and control of energy consumption, predictive maintenance, and seamless integration of renewable energy sources, thus improving overall system efficiency and reducing operational costs for clients.

The European Commission highlights the critical role of digitalization in transforming energy systems into more intelligent, reliable, and sustainable infrastructures. For ESCOs, this translates into actionable insights that drive measurable efficiency improvements and cost reductions. Furthermore, digital tools allow ESCOs to offer value-added services, such as real-time performance tracking and enhanced client transparency, fostering stronger stakeholder trust.

Public Lighting

Public lighting represents a fundamental element of urban infrastructure, directly influencing safety, community well-being, and the aesthetic quality of public spaces. Despite its importance, it remains one of the largest contributors to municipal energy consumption. Globally, approximately 636 million streetlights are installed, with public lighting accounting for 19% of cities' total electricity use. In the European context, this figure rises significantly, with public lighting constituting between 40% and 60% of total municipal energy expenditure, highlighting the urgent need for energy-efficient interventions60. Traditional public lighting systems, predominantly based on high-intensity discharge (HID) lamps, are highly inefficient, characterized by excessive energy consumption and frequent maintenance needs. This inefficiency not only contributes to unnecessary operational costs but also exacerbates greenhouse gas emissions. With urban areas accounting for more than 70% of global energy demand and contributing significantly to climate change, the modernization of public lighting systems emerges as a critical component of sustainable urban development strategies.[60]

The transition to energy-efficient public lighting systems is underpinned by:

Energy Savings Potential

The adoption of light-emitting diode (LED) technologies and adaptive lighting systems presents an unparalleled opportunity to reduce energy consumption in public lighting. LED systems are approximately 50-70% more efficient than traditional discharge lamps, and their extended lifespan of 15-20 years significantly reduces maintenance costs, offering long-term financial benefits for municipalities. Additionally, adaptive lighting technologies, which adjust light intensity based on environmental parameters such as traffic patterns and weather conditions, provide further energy savings of 30-50%.[61]

Alignment with Urban Sustainability Goals

As cities strive to meet ambitious climate targets such as those outlined in the European Green Deal and the Fit for 55 package, public lighting modernization has emerged as a critical pathway for achieving these objectives. Modern systems align with broader urban sustainability strategies by reducing the carbon footprint of municipal operations and enhancing urban livability.[62]

Economic and Environmental Incentives

Large-scale adoption of LED and smart lighting technologies can significantly reduce global energy demand. Projections suggest that widespread implementation could prevent the construction of over 1,250 power plants, translating into billions of tons of CO_2 emission reductions globally. These systems also generate substantial financial savings through reduced energy expenditure, creating an attractive proposition for public and privateinvestors alike.[63]

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60 Gallerand, M., et al. (2022). PROSPECT+ Learning Handbook: Public lighting module. European Union Horizon 2020 Programme.

61 LightingEurope (2022). Annual report 2022.

62 Gallerand, M., et al. (2022).

63 Gallerand, M., et al. (2022). PROSPECT+ Learning Handbook: Public lighting module. European Union Horizon 2020 Programme.

Market Drivers - Regulatory framework

European Union

The European Union has established a robust regulatory framework to incentivize the transition to energy-efficient public lighting systems:

- **Energy Efficiency Directive (EED) [2012/27/EU]:**
  introduced in 2012 and revised in 2018, this directive mandates the modernization of public lighting infrastructure, prioritizing energy-efficient and low-carbon solutions. It also sets energy-saving targets for member states and encourages the use of innovative financing models, such as Energy Performance Contracts (EPCs).
- **Clean Energy for All Europeans Package:**
  adopted in 2021, this initiative aims to reduce greenhouse gas emissions by 55% by 2030 compared to 1990 levels. It provides financial mechanisms, including the European Regional Development Fund (ERDF), to support municipalities in implementing energy-efficient public lighting projects.
- **Ecodesign Directive [2009/125/EC]:**
  introduced in 2009 and updated multiple times, this directive establishes stringent standards for the design, production, and lifecycle efficiency of lighting products. It promotes the adoption of sustainable technologies by phasing out inefficient lighting solutions, including halogen lamps, and supports the transition to LED technologies.

Italian Initiatives:

Italy has taken proactive measures to modernize its public lighting systems:

- Regional programs in Lombardy and Emilia-Romagna encourage the deployment of adaptive lighting systems and the integration of renewable energy sources into public lighting infrastructure. These initiatives align with Italy's broader National Integrated Energy and Climate Plan (PNIEC), first published in 2019, which emphasizes energy efficiency and sustainability in urban planning.

Key technologies

LED Lighting Systems

LED systems are the cornerstone of energy-efficient public lighting. Their high luminous efficacy and extended operational life make them a cost-effective solution for municipalities.

Adaptive Lighting Technologies

These systems utilize sensors and IoT-enabled technologies to dynamically adjust light intensity based on real-time conditions such as pedestrian and vehicular traffic. This not only optimizes energy use but also ensures that safety standards are upheld during low-demand periods. Remote monitoring capabilities further enhance system efficiency by enabling predictive maintenance and minimizing downtime.

Solar-Powered Street Lights:

Solar lighting systems offer a decentralized, off-grid solution for remote or underserved areas. These systems are particularly effective in reducing dependence on centralized energy grids and aligning with renewable energy targets.

Market development and Investment Opportunities

The global market for smart public lighting systems is poised for significant growth, with projections indicating an increase from USD 2.41 billion in 2022 to USD 8.23 billion by 2029 [64] However, the high upfront costs associated with transitioning to advanced lighting systems remain a key barrier. To address this, municipalities across Europe are leveraging innovative financing mechanisms:

1 **Energy Performance Contracts (EPCs):**
EPCs allow municipalities to implement lighting upgrades without initial capital investment. Costs are recovered through the energy savings generated by the new systems.[65]

2 **Public-Private Partnerships (PPPs):**
PPPs enable collaboration between public authorities and private entities, facilitating the financing, construction, and management of modern lighting infrastructure.[66]

3 **Grants and Subsidies:**
National and EU-level funding mechanisms, such as the ERDF and the Cohesion Fund, provide significant financial support for public lighting modernization projects.[67]

Examples of successful implementation include Germany's IKK Energetische Stadtsanierung program, which provides low-interest loans for LED installations, and Milan's deployment of adaptive lighting technologies, demonstrating energy savings of up to 60%.[68]

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64 Fortune Business Insights. (2024). Smart street lighting market size, share & COVID-19 impact analysis, by communication technology (NB-IoT, powerline communication, radio frequency, others), by application (environmental monitoring, traffic optimization, smart parking, others), by end-user (commercial, residential, industrial), and regional forecasts, 2022-2029.

65 Gallerand, M., et al. (2022).

66 Novikova, A., Stelmakh, K., Emmrich, J., Stamo, I., & Hessling, M. (2017). Guidelines on finding a suitable financing model for public lighting investment: Deliverable D.T2.3.4. Report of the EU funded project "INTERREG Central Europe CE452 Dynamic Light."

67 Novikova, A., Stelmakh, K., Emmrich, J., Stamo, I., & Hessling, M. (2017).

68 Novikova, A., Stamo, I., Stelmakh, K., & Hessling, M. (2017); Gallerand, A., Heemann, J., Matosovic, M. D., Prsancova, D., & Anders, C. (2022).

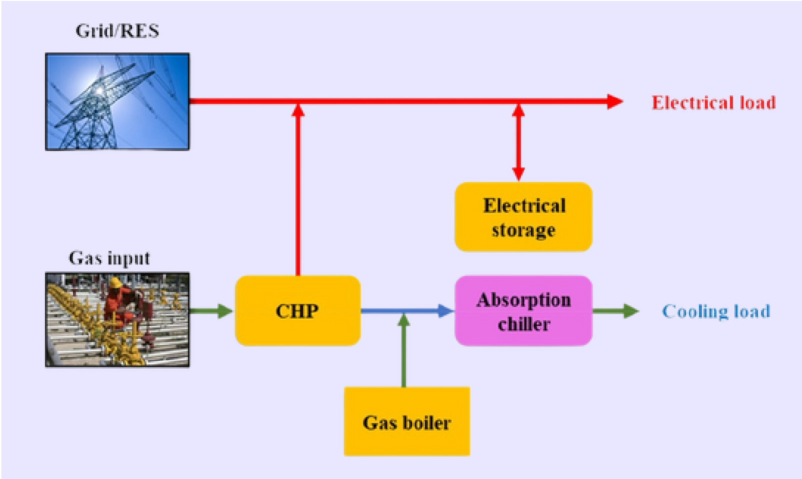
Twin Transition Potential

- **Decarbonization:**
  Replacing traditional systems with LEDs can significantly reduce CO_2 emissions. For example, projects in London, Paris, and Milan have cut emissions by over 70%, showcasing the transformative potential of energy-efficient lighting.
- **Circular Economy:**
  The use of recyclable materials and renewable energy sources aligns with broader circular economy principles.
- **IoT and Smart Systems:**
  Adaptive lighting systems integrate seamlessly with smart city frameworks, enabling real-time adjustments, predictive maintenance, and remote monitoring.
- **Grid Optimization:**
  These systems reduce energy peaks and stabilize demand, contributing to overall grid resilience.

Cogeneration and Trigeneration

Cogeneration (CHP - Combined Heat and Power) and trigeneration (CCHP - Combined Cooling, Heating, and Power) systems are pivotal technologies for improving energy efficiency and reducing greenhouse gas emissions. These systems simultaneously produce electricity, heat, and cooling, optimizing the use of primary energy and significantly reducing losses.[69]

Fig. 20. Cogeneration output
Source: Alabi et al., 2022



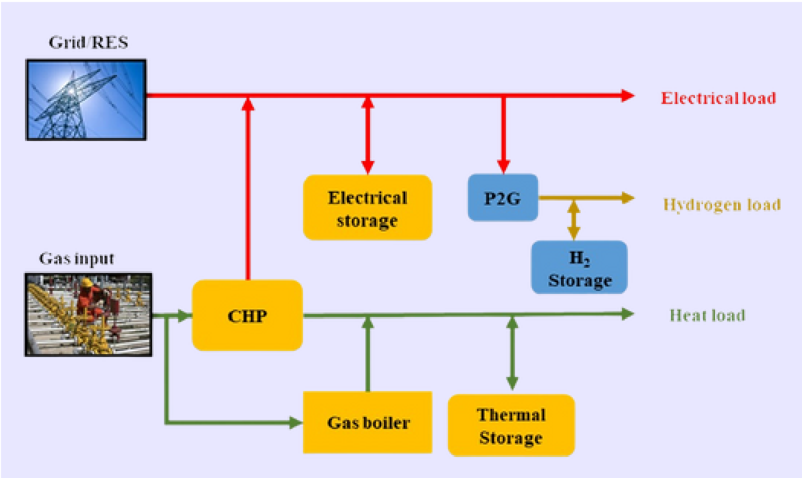


Fig. 21. Trigeneration output
Source: Alabi et al., 2022

Globally, greenhouse gas emissions from electricity production represent 73% of total emissions, with only 33% of primary energy converted into useful energy. CHP and CCHP address this inefficiency by recovering waste heat, achieving overall efficiencies exceeding 80-93%, compared to 30-40% for conventional power plants.[70]

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[69] Alabi, T. M., Aghimien, E. I., Agbajor, F. D., Yang, Z., Lu, L., Adeoye, A. R., & Gopaluni, B. (2022). A review on the integrated optimization techniques and machine learning approaches for modeling, prediction, and decision making on integrated energy systems. Renewable Energy, 194, 822–849.

[70] González, C., Chung-Camargo, K., & Chen, M. (2023). Advances in cogeneration and trigeneration systems: A review on conventional and bio-inspired approaches. Proceedings of the LACCEI International Multi-Conference for Engineering, Education, and Technology.

The urgency of decarbonization and the rising demand for energy-efficient solutions are key drivers for cogeneration and trigeneration systems. Globally, electricity and heat production account for 73% of greenhouse gas emissions, underscoring the need for more efficient technologies. Cogeneration addresses this challenge by optimizing energy use, recovering waste heat, and reducing emissions.

In Europe, the annual energy savings from cogeneration reach 356 TWh, equivalent to the consumption of 23 million households. Urban areas with high-density populations, as well as industries such as chemicals, ceramics, and food processing, benefit significantly from these systems. For instance, in Italy, CHP adoption in the paper and pulp sector has improved energy efficiency by 20-30% while ensuring compliance with EU regulations.[71]

These technologies are also central to achieving European Union decarbonization goals, as outlined in the Green Deal and the Fit for 55 package. By integrating renewable energy sources such as biogas, hydrogen, and biomass, CHP and CCHP contribute to reducing fossil fuel dependency while supporting the EU's carbon neutrality objectives.

Market Drivers - Regulatory framework

European Union

The European Union has established a robust regulatory framework to incentivize the transition to energy-efficient public lighting systems:

- **Renewable Energy Directive II (RED II) [2018/2001/EU]:**
  adopted in 2018, this directive mandates the integration of high-efficiency combined heat and power (CHP) systems in energy networks and promotes the adoption of renewable energy.
- **Energy Efficiency Directive (EED) [2012/27/EU]:**
  introduced in 2012 and revised in 2018, this directive prioritizes the use of cogeneration to reduce primary energy consumption and enhance energy efficiency.
- **Fit for 55 (2021):**
  launched in 2021, this package provides financial mechanisms such as the European Regional Development Fund (ERDF) and the Cohesion Fund to support cogeneration projects and achieve the EU's 55% emissions reduction target by 2030.

National Policies (Italy):

- **PNIEC (2019):**
  Italy's National Integrated Energy and Climate Plan (PNIEC), published in 2019, supports CHP and CCHP adoption through grants, subsidies, and tax incentives to foster energy efficiency and decarbonization.

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[71] COGEN Europe. (2024). The role of cogeneration in Europe's energy transition: Enabling an efficient pathway to net zero. Policy Priorities 2024-2029.

Key Technologies

Combined Heat and Power (CHP):

- Recovers waste heat from electricity generation to produce heat, achieving efficiencies above 80%.
- Widely adopted in industries such as paper, chemicals, and ceramics.

Trigeneration (CCHP):

- Extends CHP benefits by adding cooling capabilities through absorption chillers.
- Offers overall efficiencies between 80% and 93%.
- Suitable for urban areas, hospitals, shopping centers, and other facilities with year-round climate control needs.

Hybrid and Renewable Systems:

- Integrates renewable energy sources, including solar, biogas, and hydrogen, into CHP and CCHP systems to enhance sustainability.
- Biogas-powered trigeneration systems achieve efficiencies of up to 64%, with increasing adoption in industrial and agricultural settings.
- Innovations like CO_2 capture and storage technologies further improve environmental performance.

Market development and Investment Opportunities

The growth of cogeneration (CHP) and trigeneration (CCHP) markets is supported by significant investments in infrastructure and technological innovation aimed at overcoming structural challenges, such as dependence on fossil fuels, CO2 emission regulations, and the volatility of gas prices. In Europe, cogeneration accounts for approximately 19% of total electricity generation, with Germany, Poland, and Italy leading the market.[72]

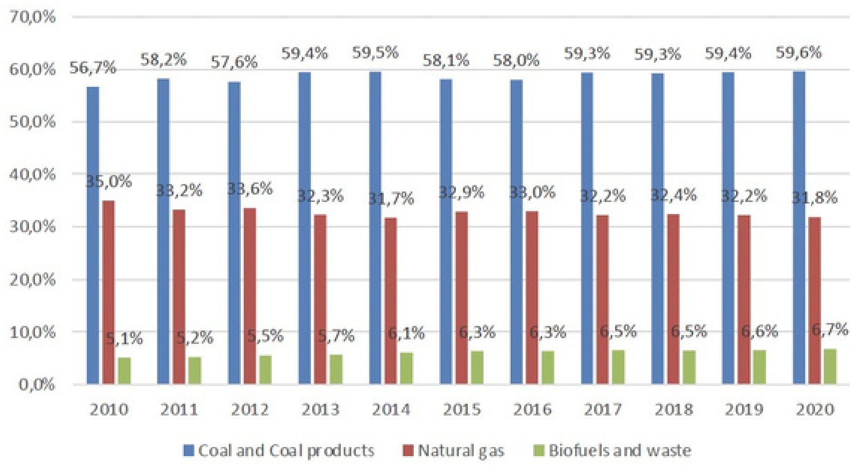

Fig. 22. CHP main fuel use

Source: Cogen World Coalition, 2023

Key technologies include gas and steam turbines, primarily powered by natural gas and coal, though the adoption of biofuels and waste is gradually increasing. Countries like the Netherlands and Denmark demonstrate significant uptake of gas-based cogeneration, which contributes nearly one-fifth of their total energy production, while the UK achieves around 11%.[73]

Investment opportunities in the cogeneration (CHP) and trigeneration (CCHP) markets are increasingly focused on sustainable technologies such as fuel cells, micro-CHP systems, and the growing use of biofuels and hydrogen, particularly for localized and residential applications.[74] Demand for small-scale units (<10 MW), commonly utilized in district heating and commercial projects, is rising.

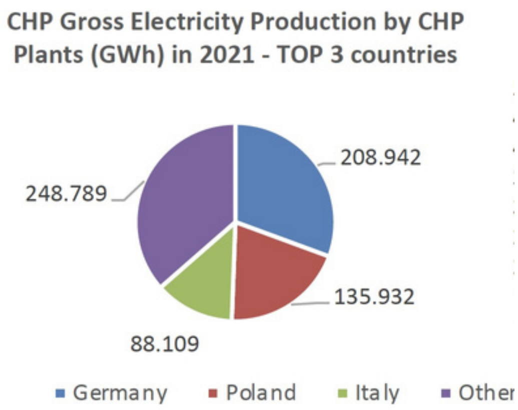

Fig. 23 CHP Gross Electricity Production by CHP Plants (GWh) in 2021 - TOP 3 countries

Source: Cogen World Coalition, 2023

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[72] Cogen World Coalition. (2023). Global Cogeneration Market Overview (2nd ed.)

[73] Powerline article: Powerline. (2021, February 4). Promising technology. Retrieved from https://powerline.net.in/2021/02/04/promising-technology/

[74] COGEN Europe. (2024).

However, large-capacity systems remain dominant in industrial sectors like refineries, chemical manufacturing, and food processing, where they continue to meet the high energy demands of these industries.[75] Despite growing interest in innovative solutions like hydrogen, economic and infrastructural barriers currently constrain its large-scale adoption in the short to medium term. Europe's CHP sector continues to rely heavily on natural gas and coal, with only modest growth in the adoption of biofuels and waste. The transition from coal to cleaner energy sources is slow, and while gas plays a significant role due to its lower emissions compared to coal and oil, the future share of fossil gas in CHP is expected to decline. Stricter emission standards further complicate the business case for gas-fired CHP systems, creating additional challenges for market players.

At the same time, trigeneration is becoming increasingly widespread, offering the potential to reduce primary energy demand by up to 70% and greenhouse gas emissions by up to 30%. This is particularly relevant in urban and district contexts, where heat recovery and the integration of multi-energy systems are key to decarbonizing the power sector and achieving global climate goals.[76]

Twin Transition Potential

Environmental Transition

By recovering waste heat from industrial and power generation processes, these systems minimize energy losses while displacing traditional, less efficient heating and cooling solutions. For instance:

- The integration of renewable energy sources such as biogas, biomass, and hydrogen into CHP and CCHP systems enables a direct reduction in greenhouse gas emissions. This is particularly critical in meeting European Union targets under the Fit for 55 package, which mandates a 55% reduction in emissions by 2030.
- Trigeneration, with its capability to provide cooling through absorption chillers, supports the shift toward sustainable cooling solutions in response to the growing demand for climate control, particularly in high-density urban areas and industrial facilities.

Environmental Transition

By recovering waste heat from industrial and power generation processes, these systems minimize energy losses while displacing traditional, less efficient heating and cooling solutions. For instance:

- **IoT and Smart Monitoring:**
  embedded IoT sensors enable real-time performance monitoring, predictive maintenance, and optimized fuel management. These capabilities ensure high operational reliability and adaptiveness to fluctuating energy demands.
- **AI and Machine Learning:**
  advanced analytics algorithms analyze operational data to forecast demand, optimize resource allocation, and dynamically adjust outputs. These tools are particularly effective in integrating variable renewable energy sources, enhancing grid stability and efficiency.
- **Energy Management Systems (EMS):**
  modern EMS tools in CHP and CCHP systems enable precise coordination of electricity, heating, and cooling outputs, aligning production with grid requirements and minimizing peak demand costs.

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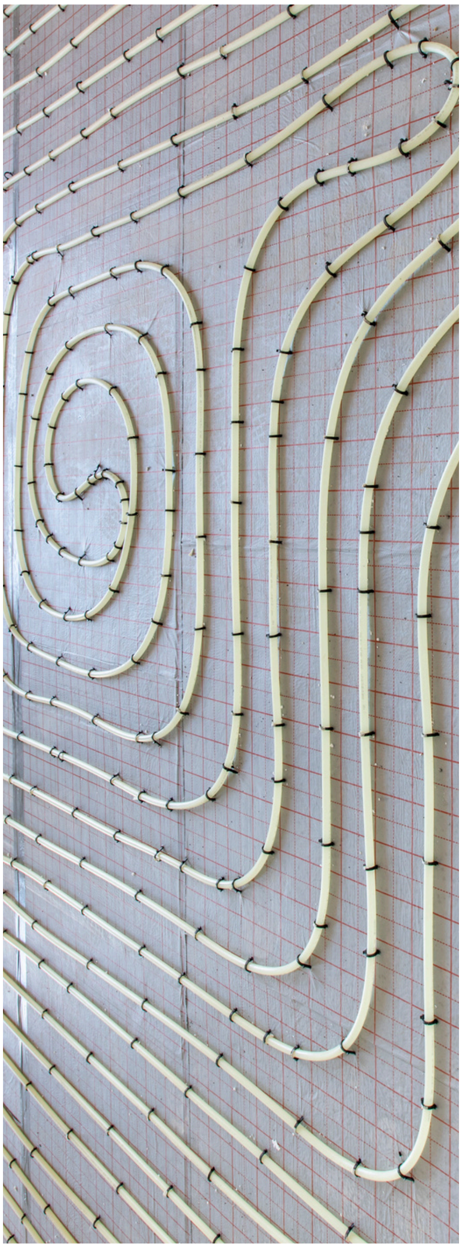
[75] Cogen World Coalition. (2023).

[76] International Institute for Energy Conservation (IIEC). Tri-generation factsheet.

District Heating Systems

District heating (DH) systems are poised to play a transformative role in Europe's energy transition. Currently, heating and cooling account for 42% of the EU's final energy consumption, with 75% still reliant on fossil fuels. The decarbonization of district heating systems presents a unique opportunity to reduce greenhouse gas emissions, improve energy efficiency, and promote the integration of renewable energy sources.[77] Recent data indicate that district heating meets approximately 12.5% of Europe's total heat demand. This share is expected to rise to 50% by 2050, driven by advancements in fourth-generation district heating (4GDH) systems and increasing urban demand for sustainable heating solutions. Globally, district heating demand is projected to grow modestly by 4% over the next six years. However, the integration of renewable energy in DH systems is anticipated to expand by over 40%, with Europe playing a key role in this transition.[78]

In Italy, the potential for district heating is particularly notable in cities such as Milan, Turin, and Bologna, where pilot projects demonstrate the feasibility of integrating renewable heat sources and waste heat recovery. Meanwhile, unserved urban areas, particularly in central and southern Italy, represent untapped opportunities for expanding these networks.[79] Despite its potential, district heating faces significant barriers, including outdated infrastructure, high distribution losses, and dependency on fossil fuels. Many European networks are over 40 years old, with energy losses exceeding 15% in some cases. Transitioning to advanced 4GDH systems is crucial to overcome these challenges.[80]



[77] Malcher, X., & Gonzalez-Salazar, M. (2024). Strategies for decarbonizing European district heating: Evaluation of their effectiveness in Sweden, France, Germany, and Poland. Energy, 306, 132457.

[78] Euroheat & Power. (2023). Fit for 2050: Unleashing the potential of efficient district heating and cooling to decarbonise Europe; Auvinen, K., Meriläinen, T., Saikku, L., Hyysalo, S., & Juntunen, J. K. (2023). Accelerating transition toward district heating-system decarbonization by policy co-design with key investors: Opportunities and challenges. Sustainability: Science, Practice and Policy, 19(1)

[79] Lettenbichler, S., Corscadden, J., & Krasatsenka, A. (2023). Advancing district heating & cooling solutions and uptake in European cities. European Commission, Directorate-General for Energy.

[80] Malcher, X., & Gonzalez-Salazar, M. (2024).

Market Drivers - Regulatory framework

European Policies:

- Fit for 55: aims for 100% renewable heating by 2050, mandating phased reductions in fossil fuel reliance by 2030.
- **Renewable Energy Directive II (RED II) [2018/2001/EU]:**
  requires a 1.3% annual increase in renewable energy integration for heating and cooling networks.
- **Energy Efficiency Directive (EED) [2012/27/EU]:**
  lencourages member states to modernize DH systems, prioritizing low-temperature networks and renewable energy adoption.

National Policies:

- **Italy's Integrated National Energy and Climate Plan (PNIEC):**
  from 2019, prioritizes DH network expansion and modernization, allocating €1.5 billion for infrastructure upgrades.

Key technologies

Fourth-Generation District Heating (4GDH):

- Operates at lower temperatures (50-60°C), reducing distribution losses by up to 50%.
- Enables efficient integration of renewable energy sources such as solar thermal and geothermal heat.
- Promotes the use of pre-insulated piping and advanced control systems.

Digitalization and Smart Systems:

- IoT-enabled sensors provide real-time data for monitoring and optimization.
- Predictive maintenance reduces operational costs and improves reliability.

Combined Heat and Power (CHP) and Trigeneration (CCHP):

- High-efficiency systems capable of achieving 90% overall efficiency by generating heat, cooling, and electricity simultaneously.
- Trigeneration systems enhance year-round efficiency, adapting to seasonal demand variations.

Heat Pumps and Thermal Storage:

- Advanced heat pumps utilize low-temperature waste heat from industrial processes.
- Thermal storage systems decouple heat production from demand, providing flexibility during peak periods.

Market development and Investment Opportunities

The modernisation and expansion of district heating networks in Europe is estimated to require an investment of €144 billion by 2030. These investments are designed to integrate renewable energy sources, improve system efficiency, and extend networks into underserved areas. In Italy, recent studies have indicated that the adoption of fourth-generation district heating (4GDH) systems could result in a reduction of CO_2 emissions by up to 30% compared to conventional systems, which would align with the nation's broader climate goals.[81]

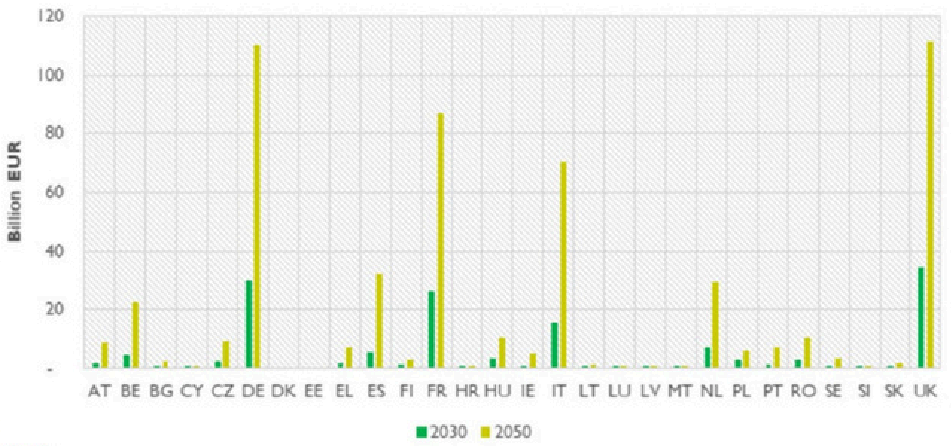


Fig.24. District heating investments needed by 2030 and 2050
Source: Euroheat & Power, 2023

The modernisation of infrastructure in Europe is supported by substantial financial resources, including European funds such as the European Regional Development Fund (ERDF) and the Cohesion Fund, as well as innovative models such as public-private partnerships (PPPs). Furthermore, countries such as Germany and Poland provide additional incentives for district heating projects through the implementation of tax benefits and the issuance of green energy certificates.[82]

Nevertheless, the transition to low-emission systems necessitates the implementation of targeted support strategies, including the provision of subsidies for renewable energy sources and investments in infrastructure to facilitate the shift to clean technologies. The co-design and co-creation of policies with key stakeholders, including investors and governments, can enhance the quality and effectiveness of policy decisions, thereby promoting socially and technically acceptable solutions.[83]

[81] Lettenbichler, S., Corscadden, J., & Krasatsenka, A. (2023). Advancing district heating & cooling solutions and uptake in European cities. European Commission, Directorate-General for Energy.

[82] Malcher, X., & Gonzalez-Salazar, M. (2024).

[83] Auvinen, K. et al. (2023). Accelerating transition toward district heating-system decarbonization by policy co-design with key investors: Opportunities and challenges. Sustainability: Science, Practice and Policy, 19(1), 2256622.

Despite their potential, district heating systems encounter considerable obstacles. These include:

- High initial costs and restricted access to financing.
- Outdated infrastructure that necessitates modernisation.
- The presence of regulatory obstacles that impede the uptake of innovative technologies.

The existing literature indicates that policymakers can address these challenges through a mixed-policy approach that incorporates the following measures:

1 **Financial incentives:**
subsidies for renewable energy sources, tax benefits, and green certificates.

2 **Support for R&D:**
the advancement of innovative business models and cutting-edge technologies.

3 **Multi-level collaborations:**
the involvement of governments, industry, and research through co-design processes.

Policy co-design, in particular, enables the direct involvement of stakeholders in the identification of socially acceptable and technically sustainable solutions.[84] For instance, the utilisation of iterative and reflective methodologies permits the incorporation of a multiplicity of perspectives, thereby enhancing the efficacy and implementability of policies.

[84] Tan, J., Wu, Q., & Zhang, M. (2022). Strategic investment for district heating systems participating in energy and reserve markets using heat flexibility. Electrical Power and Energy Systems, 137, 107933; Auvinen, K. et al. (2023).

Twin Transition Potential

District heating systems are uniquely positioned at the intersection of the green and digital transitions, offering scalable solutions for urban sustainability.

Environmental Transition

- **Energy security and decarbonization:**
  - Expanding district heating systems to meet 20% of Europe's heating demand by 2030 could save approximately 24 billion cubic meters of gas.
  - Contribute significantly to achieving climate goals and reducing reliance on fossil fuels.

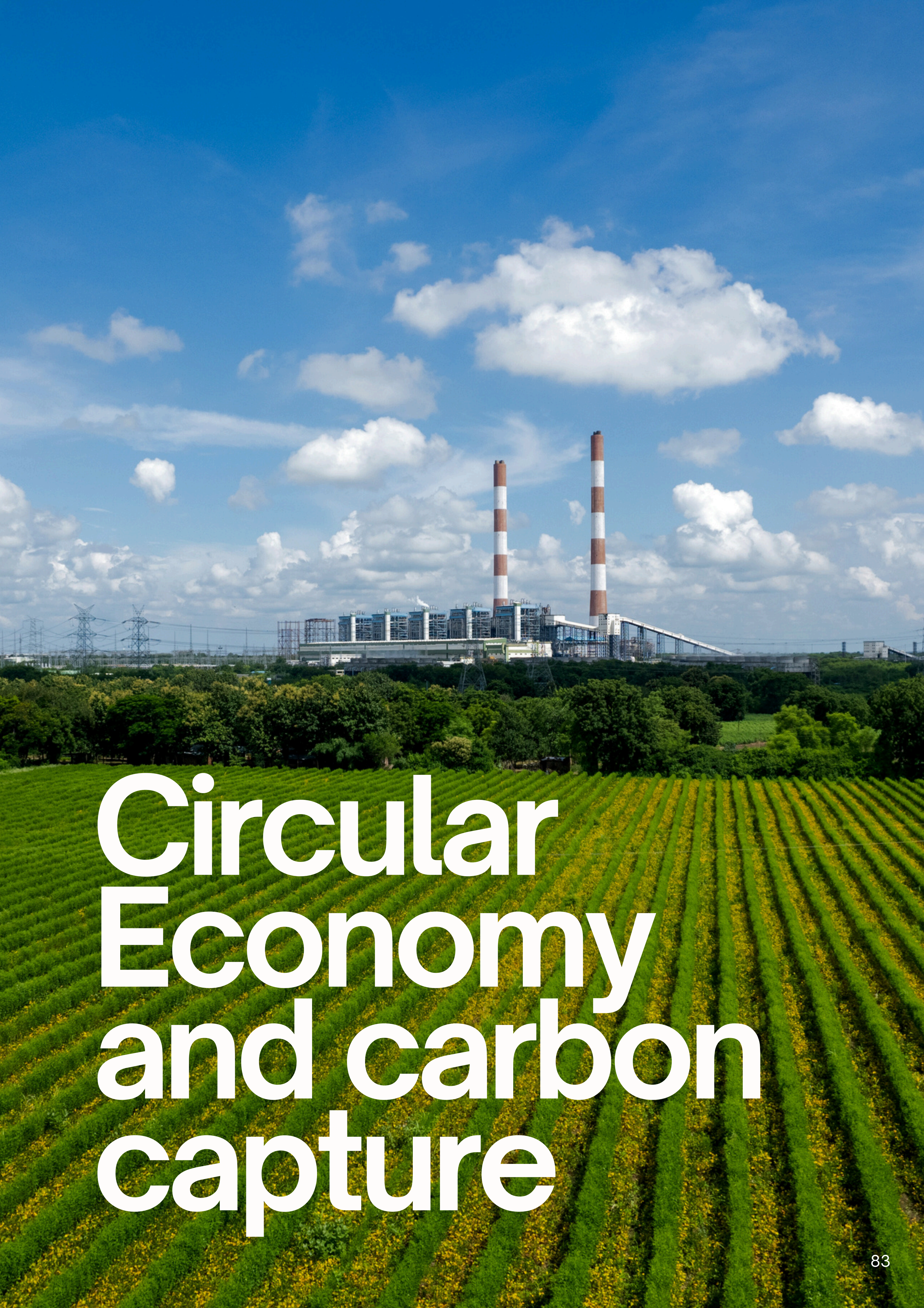
- **Circular economy opportunities:**
  - Recover waste heat from industrial facilities, data centers, and supermarkets to reduce emissions.
  - Minimize energy waste through efficient reuse of thermal resources.

Digital Integration

- **Integration of renewable energy sources:**
  advanced technologies enable the seamless incorporation of solar, geothermal, and waste heat into district heating networks.

- **IoT-driven optimization tools:**
  - Enhance operational efficiency through real-time monitoring and control.
  - Dynamically balance energy supply and demand, ensuring grid stability.

- **Smart systems and digitalization:**
  - Facilitate predictive maintenance, reducing downtime and operational costs.
  - Support flexible operation by optimizing energy flows across multiple systems.



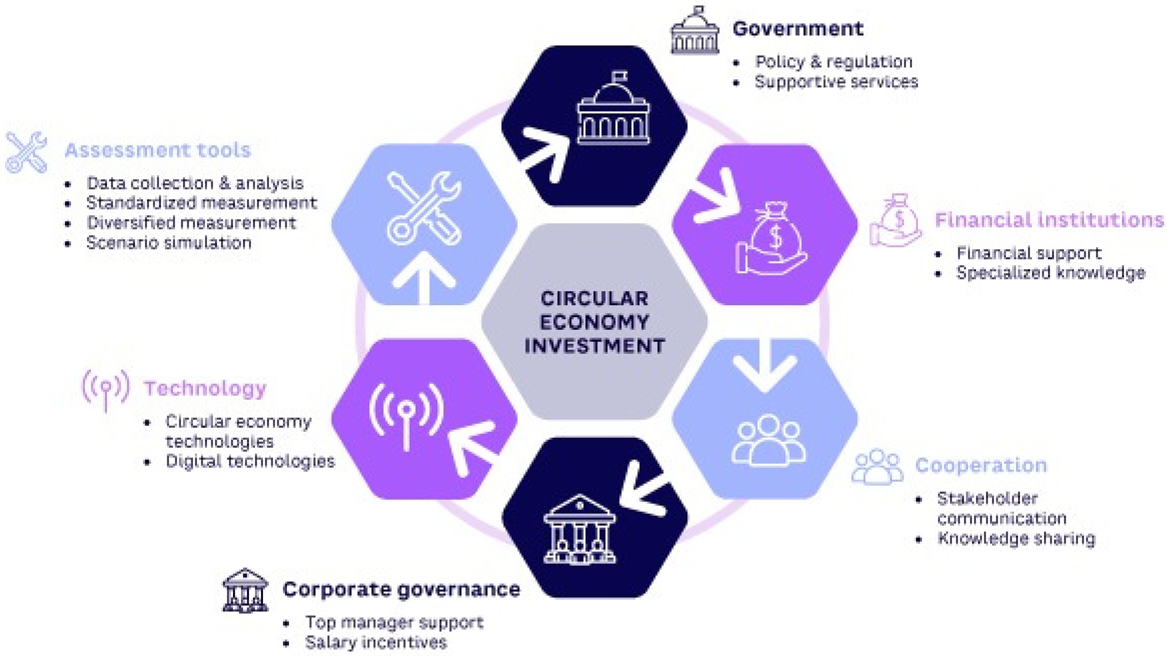
Circular Economy and carbon capture

Circular Economy and carbon capture

From Waste to Value

Circular economy projects focus on transforming waste into valuable products, including biofuels and recycled materials. These initiatives align with the EU Circular Economy Action Plan, which emphasizes the efficient use of resources, waste reduction, and recycling to foster economic and environmental resilience.

Source: Paul Dewick and Joseph Sarkis (2023)



Market Drivers

Companies are increasingly adopting circular economy initiatives as part of ESG strategies to improve sustainability performance. These initiatives are also boosted by the rising costs of raw materials and waste disposal that drive investment in circular economy technologies.
Finally also increasing consumer awareness and demand for sustainable products push businesses to adopt circular practices.

Regulatory Framework

European Union:

- **Circular Economy Action Plan (CEAP):**
  A key component of the EU Green Deal, promoting initiatives to reduce waste, enhance product lifespan, and improve resource efficiency
- **Waste Framework Directive:**
  Set targets for recycling and reuse while discouraging landfill use.
- **Renewable Energy Directive (RED II):**
  Supports the use of biomethane and other renewable gases in decarbonization efforts.
- **Extended Producer Responsibility (EPR):**
  This mandates that producers take responsibility for the lifecycle of their products, including post-consumer waste management.

Italy

- **National Circular Economy Strategy (SNCE):**
  Encourages investments in recycling facilities, biomethane plants, and WtE projects.
- **Legislative Decree 116/2020:**
  Implements EU waste directives, prioritizing waste prevention, reuse, and recycling.
- **Incentive Schemes for Biomethane:**
  Promotes the adoption of biomethane through feed-in tariffs and other subsidies.

Key technologies

Biomethane Production:

- **Anaerobic Digestion (AD):**
  Converts organic waste into biogas, which is upgraded to biomethane for use in transportation and heating.

Waste-to-Energy (WtE):

- Combustion technologies to recover energy from non-recyclable waste, producing electricity and heat.

Advanced Recycling:

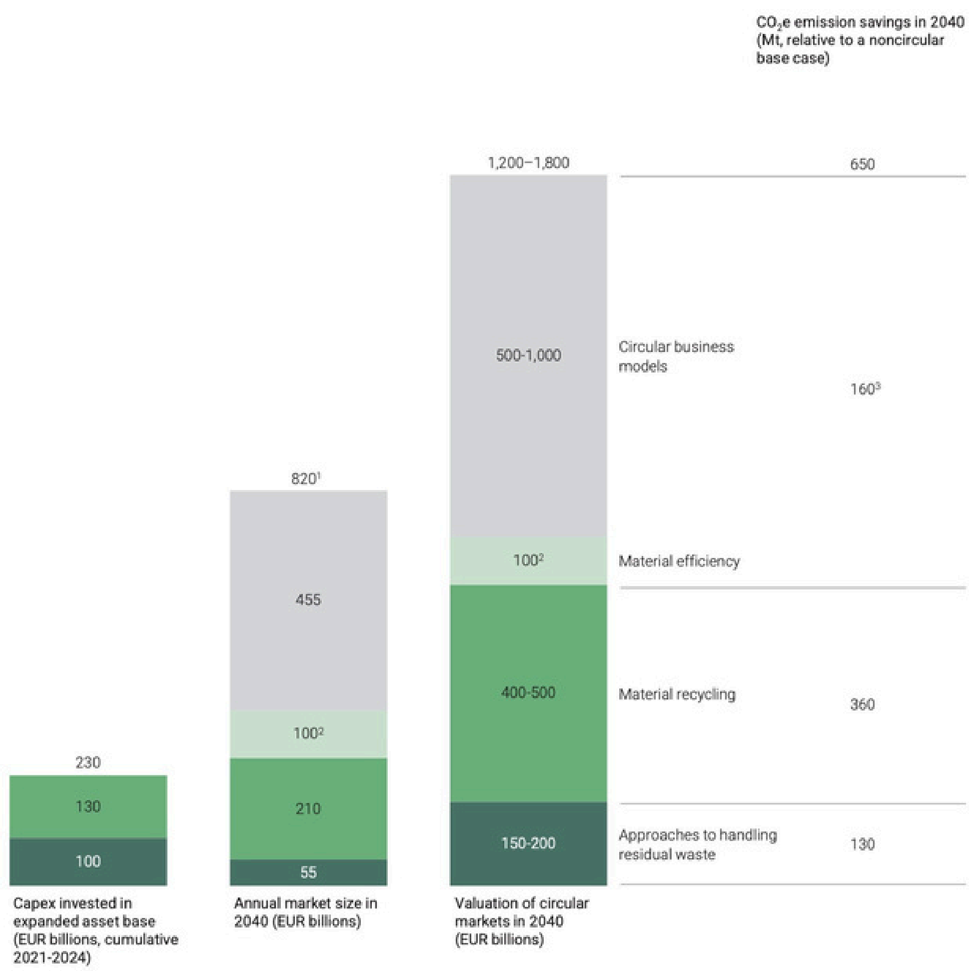
- **Chemical Recycling:**
  Breaks down plastics into their raw chemical components for reuse.
- **Mechanical Recycling:**
  Processes materials into new products or feedstock.
- **Carbon Capture and Utilization (CCU):**
  Captures CO2 emissions and converts them into valuable products, such as fuels, building materials, and chemicals.
- **Digital Solutions:**
  IoT and AI-based technologies optimize waste collection, sorting, and recycling processes.

Market development and Investment Opportunities

Projections show that shifting from a linear approach of “take, make, and dispose” to a circular system is estimated to have as much as USD 4.5 trillion potential for economic growth by 2030. The circular economy could be worth as much as USD 700 billion in global consumer goods and material savings. With a circularity rate of 11.5% in 2022, Europe consumes a higher proportion of recycled materials than other world regions. However, progress in the EU has been slow and we are still far from the ambition to double the Union’s circularity rate by 2030. By 2030, the EU’s circular economy market is projected to grow to EUR 700 billion, driven by a strong regulatory push and increasing demand for sustainable materials.[85] The cumulative investment needed in physical assets to be EUR 230bn by 2040. Such investments can also generate attractive returns, the analysis finds, with the valuation of circular markets potentially exceeding EUR 1.5 tn by 2040.

[85] OECD (2020), The Circular Economy in Cities and Regions: Synthesis Report, OECD Urban Studies, OECD Publishing, Paris, https://doi.org/10.1787/10ac6ae4-en.

The EUR 820 billion circular market could cut 650 Mt CO_2e emissions by 2040



Source: Summa Equity (2023) [86]

Public funding mechanisms to facilitate the circular economy transition in Hungary, including direct and indirect EU funding as well as other international and national financing opportunities.
The EU is providing several funding programmes covering a wide range of areas including the circular economy. The three principal funding instruments for the transition to a circular economy include shared management funds, the Horizon Europe program, and the LIFE program.[87]

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86 Summa Equity (2023), Investing in a circular and waste-free Europe by Summa Equity April 2023

87 OECD (2023), “Financing the circular economy transition”, in Towards a National Circular Economy Strategy for Hungary, OECD Publishing, Paris

Investment opportunities are:

- **Recycling and Materials Recovery:**
  Targeted investments in recycling facilities for metals, plastics, and textiles will be central, as the sector grows to supply the rising demand for secondary raw materials in compliance with EU regulations. Projected to generate additional savings and growth, the recycling industry is expected to quadruple in size by 2040, contributing to a combined circular economy revenue stream of EUR 820 billion.
- **Biofuel Production:**
  Investment in biofuel plants offers significant financial and environmental benefits by converting organic waste into renewable energy, essential for meeting the EU's renewable energy targets. Biofuel production is expected to grow at a CAGR of 10% through 2030, bolstered by governmental incentives and the EU's Renewable Energy Directive.
- **Waste-to-Materials and Sustainable Consumer Goods:**
  Developing facilities that convert waste streams into consumer products and construction materials represents a high-growth area, aligning with increasing EU targets for material reuse. The waste-to-materials sector is set to experience significant expansion, driven by the construction and retail industries' shift to sustainable materials.

Twin Transition Potential

Circular economy projects offer significant environmental and economic benefits, with strong alignment to sustainability goals and digital innovation. However, they require robust policy support and collaboration across public and private sectors for successful implementation. Circular economy projects align closely with both the green and digital transitions:

Environmental Benefits: Reduction of greenhouse gas emissions through resource optimization, biomethane production, and landfill diversion. Creating a circular economy reduces dependency on raw material imports and enhances local resource utilization, fostering economic stability.

Digital Integration: IoT and AI technologies streamline waste management and enhance efficiency, supporting the digital transformation of the waste sector.

Biomethane

Biomethane, a refined form of biogas produced through the anaerobic digestion of organic materials, is positioned as a leading renewable fuel in Europe's energy transformation. This process transforms urban and agricultural waste (e.g., manure, food scraps, crop residues) into a versatile fuel, directly contributing to waste reduction and energy independence.

Market Drivers

Europe's energy policies emphasize renewable gases, and the EU Renewable Energy Directive (RED II) targets a 32% share of renewable energy by 2030. Recently, the European Parliament has recently included, within the package of gas market reforms, the binding production target of 35 billion cubic meters of biomethane by 2030, in line with the objectives of the REPowerEu: a measure that encourages the growth of renewable gases generating positive repercussions for the primary sector. As a high-efficiency, grid-compatible fuel, Biomethane is essential in meeting this target. Biomethane is one of the solutions to differentiate the energy mix, limit dependence on foreign gas, and contribute to achieving the Italian energy transition.

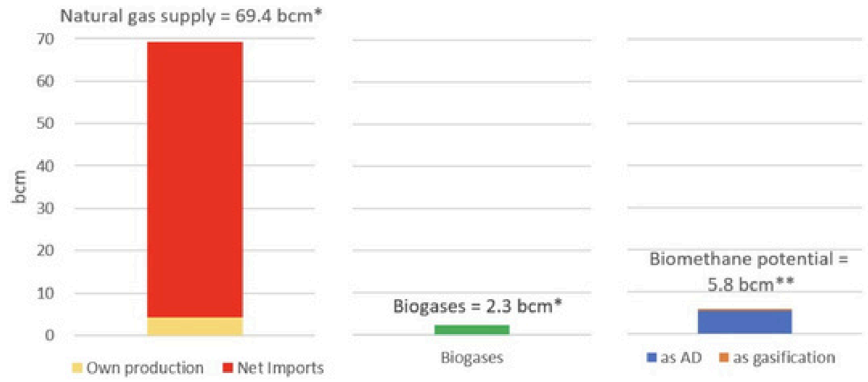


Fig. 26 Comparaison of current natural gas supply, biomethane production and potential in Italy Source: European Commission (2021)[88]

In 2020, 11 new plants went into operation in Italy, and in 2021, the production plants, between biogas and biomethane, totaled about 2000. In Italy, there are currently 85 biomethane plants. At the European level, however, the record year so far was 2021, with biomethane production reaching 3 billion cubic meters.[89]

Regulatory Framework

European Union:

- **Renewable Energy Directive II (RED II):**
  Sets a target of 14% renewable energy in transportation by 2030, with biomethane eligible for incentives under advanced biofuels.
- **Fit for 55 Package:**
  Promotes biomethane deployment to meet the EU's 2050 carbon neutrality goal.
- **REPowerEU Plan:**
  Targets 35 bcm (billion cubic meters) of biomethane production by 2030 to reduce dependence on Russian gas.

88 https://energy.ec.europa.eu/system/files/2023-09/Biomethane_fiche_IT_web.pdf

89 https://www.gruppoab.com/blog/biomethane-in-italy/

Italy

- **National Recovery and Resilience Plan (PNRR):**
  Includes significant investment in biomethane projects, with €1.92 billion earmarked for agricultural biomethane production by 2026.
- **Incentive Schemes:**
  Subsidies for biomethane production, especially for facilities that convert agricultural waste and residues into renewable gas.
- **National Energy Strategy:**
  Recognizes biomethane as a priority for achieving Italy's renewable energy targets.

Key Technologies

Anaerobic Digestion (AD):

Converts organic waste into biogas through microbial processes.
Biogas is then upgraded to biomethane by removing impurities like CO2 and H2S.

Gasification:

Converts dry biomass into synthetic gas, which is further processed to produce biomethane.

Power-to-Gas (P2G):

Integrates renewable electricity with biomethane production by combining hydrogen (produced via electrolysis) with CO2 to create methane.

Carbon Capture and Utilization (CCU):

Enhances biomethane production efficiency by capturing CO2 during the biogas upgrading process for reuse in industrial applications.

Market development and Investment Opportunities

The European Biomethane market is expected to reach 370 TWh by 2030, driven by strong policy incentives. In Italy, incentives include feed-in tariffs and production subsidies, supporting an anticipated growth rate of 15% annually. Following the announcement of the REPowerEU target in 2023, the EBA estimated that reaching 35 bcm of sustainable biomethane production will require an investment effort of €83 billion by 2030 depending on plant size, location, and type of sustainable feedstock.[90]

The first edition of the EBA Investment Outlook on Biomethane shows these efforts are taking shape: €4.1 billion will be invested in the coming 2 years, €12.4 billion by 2030, and €1 extra billion has been allocated with no specific timeframe.

Table 1: Level of investment for the timeframes 2023-2025 and 2026-2030

	2023-2025	2026-2030	Timeframe not specified
Investment	€4.1 billion	€12.4 billion	€1 billion

Investments are mostly located in France (€1.4 billion) and Italy (€1.1 billion) thanks to favourable conditions in those Member States. They are followed by the Netherlands (€951 million), Spain (€948 million), Germany (€658 million), Sweden (€635 million) and Poland (€429 million). Additionally, €5.5 billion of capital injection will stay in the EU with the final destination still open and €3.3 billion will target non-EU territories, including the UK and Ukraine.

Table 2: Destination of investments and amount per country

Destination of investment	Amount
France	€1.4 billion
Italy	€1.1 billion
The Netherlands	€951 million
Spain	€948 million
Germany	€658 million
Sweden	€635 million
Poland	€429 million
Finland	€330 million[1]
Ireland	€290 million
Greece	€150 million
Denmark	€140 million
Belgium	€38 million
Czech Republic	€25 million
Slovenia	€3 million
Europe, unspecified	€5.5 billion
Non-EU (including UK and	€3.3 billion
Not specified	€1.6 billion

Biomethane's production from organic waste prevents methane emissions from conventional waste treatment and mitigates up to 90% of CO_2 emissions when used in place of fossil fuels. The use of biogenic CO_2 to replace products based on CO_2 of fossil origin is included in the majority of business plans analysed. The importance of biogenic CO_2 in offsetting CO_2 of fossil origin is often underestimated, however; efforts should be made to assess its value fairly. One of the highlighted uses of biogenic CO_2 is the production of green synthetic methane (using green hydrogen), which could add substantial volumes of sustainable green gas into the energy system.

90 https://www.europeanbiogas.eu/wp-content/uploads/2023/06/PRESS-RELEASE-EBA-Biomethane-Investment-Outlook.pdf

Tuning in the EU Taxonomy with the REPowerEU objectives for biomethane will steer capital flows into the sector, as investors indicate compliance with the specific EU regulation on sustainable finance is key to leveraging green investments. A harmonized EU-wide cross-border trading system is of great importance as well, especially for unsubsidized projects. Incentives, such as Italy's biomethane production support schemes. Indeed, Italy has launched a significant biomethane subsidy scheme as part of its National Recovery and Resilience Plan, allocating over EUR 1 billion in support for new biomethane facilities. Investments in biomethane production facilities can leverage existing natural gas infrastructure, reducing capital expenditure while enhancing distribution efficiency. The European Biogas Association estimates that up to 100 TWh of biomethane could be grid-integrated by 2030, necessitating strategic investment in biogas upgrading and purification technology. Biomethane is essential for industries like transport and heating, which are harder to electrify and it is essential for energy transition.

Twin Transition Potential

Biomethane's twin transition potential relates to its integration with renewable energy systems, its role in enabling decarbonization, and its capacity to leverage digital technologies for operational optimization.

- **Energy Transition Potential:**
  Biomethane replaces natural gas in power generation, heating, and industrial applications, directly reducing greenhouse gas (GHG) emissions. It contributes to achieving EU targets under the REPowerEU Plan, particularly in reducing dependence on fossil gas imports. Biomethane serves as a dispatchable energy source, providing stability to grids dominated by solar and wind power. Integration of surplus renewable electricity into biomethane production (e.g., via electrolysis and methanation) enhances the circularity of energy systems. Biomethane serves as a renewable fuel for sectors like heavy transport, maritime, and industrial heat where electrification is challenging, aligning with long-term decarbonization strategies.
- **Digital Transition Potential:**
  Deployment of digital tools, such as IoT sensors and AI, enables real-time monitoring and optimization of biomethane production facilities, enhancing operational efficiency and reducing downtime. Blockchain can be used to track the origin, production processes, and environmental impact of biomethane, ensuring transparency and enabling participation in carbon credit markets. Biomethane infrastructure can be linked to digital energy management systems to optimize injection into gas grids, ensuring efficient balancing of supply and demand.

Waste-to-Energy: Efficient Waste Conversion

Waste-to-energy (WtE) facilities convert residual waste into electricity, heat, or renewable gas. As a core component of Europe's decarbonization plan, these facilities reduce landfill use while producing energy from otherwise discarded waste. WtE facilities not only reduce landfill use and greenhouse gas emissions but also provide a valuable source of renewable energy.

Market Drivers

Waste-to-energy facilities lower greenhouse gas emissions by diverting waste from landfills and displacing fossil-fuel-based energy sources.As CO_2 taxation policies grow across Europe, Waste-to-Energy (WtE) facilities face both increased costs and emerging opportunities for growth in carbon capture and utilization/storage (CCU/CCS). The European Union's intention to bring WtE under the Emission Trading System (ETS) will add costs for incineration, especially where waste has a high fossil-based CO_2 footprint. However, this shift also creates unique investment prospects, notably in CCU/CCS integration, by supporting WtE facilities with carbon mitigation capabilities.

Regulatory Framework

European Union:

- **Waste Framework Directive:**
  Establishes the waste hierarchy, prioritizing recycling and recovery over landfilling, with WtE recognized as a key component of energy recovery.
- **Landfill Directive:**
  Requires Member States to limit landfill waste to 10% by 2035, fostering WtE development to bridge the waste treatment gap.
- **Renewable Energy Directive:**
  Recognizes energy from biodegradable waste fractions as renewable, enabling WtE plants to qualify for incentives such as green certificates.

Italy:

- **National Waste Management Plan (PNGR):**
  Includes WtE as a critical technology for achieving landfill reduction and sustainable waste treatment targets.
- **Regional Policies:**
  Southern Italy has specific funding programs to address the infrastructure gap, including support for modern WtE plants.
- **Emission Standards:**
  Italy enforces stringent EU-aligned emission limits for WtE plants, driving investments in advanced emissions control systems.

Key Technologies

Incineration with Energy Recovery:

This is the most prevalent WtE technology, converting municipal solid waste (MSW) into electricity and heat. Modern facilities deploy advanced filtration and treatment to reduce emissions.

Anaerobic Digestion:

Biodegradable waste (e.g., food scraps, agricultural residue) is decomposed by bacteria in the absence of oxygen, producing biogas and digestate. The biogas can be used for heat, electricity, or purified as biomethane.

Gasification and Pyrolysis:

These processes break down organic material at high temperatures, producing a mix of gases and char that can be used as fuel or converted into chemicals.

Market development and Investment Opportunities

Europe's waste-to-energy market is anticipated to grow by 5% CAGR through 2030, with a particular focus on high-efficiency, low-emission technologies. WtE plants in Europe produce enough electricity to supply almost 19 million people per year. Additionally, around 10% of Europe's energy covered by District Heating comes from WtE. In cities with good district heating infrastructure in place, like Brescia, Malmö or Klaipėda, WtE covers more than 50% of the heating needs. The amount of primary energy produced by WtE in 2019 in Europe was equivalent to 13.8 billion cubic metres of natural gas. This corresponds to 9-10% of the natural gas imports to the EU from Russia (155 billion cubic metres in 2021). For instance, in Brescia, the WtE plant currently allows savings of around 98 million cubic metres of natural gas per year and, with the ongoing investment plan, savings will increase to more than 115 million in the near future.
Italy urgently needs investment in waste-to-energy (WtE) plants, particularly in the south, to reduce its high reliance on landfills (over 6 million tonnes of urban waste annually).In this context, Italy needs six or seven waste-to-energy plants (75% of them in southern Italy) in order to fill the infrastructure gap in the waste disposal management process compared to Europe's best performers (~5% landfilling). The need for new waste-to-energy plants in southern Italy is small compared to the 37 plants located in the north of Italy.[91]

91 https://www.ispionline.it/en/publication/waste-energy-new-perspective-sustainable-transition-35883

A paper published by The European House – Ambrosetti and A2A in 2021 estimates at nearly 4-4.5 billion euros the investment required to fill the waste-to-energy and organic waste plant gap.

WtE investments have become pivotal in reducing landfills and generating alternative energy sources. Investing in WtE typically requires substantial upfront costs, but facilities can achieve returns on investment (ROI) of 10-15% over 10-15 years, with an operation a lifespan of 20-30 years. Revenue streams include tipping fees, energy sales, and material recovery, with profitability strengthened by regulatory incentives, such as feed-in tariffs for renewable electricity generation.

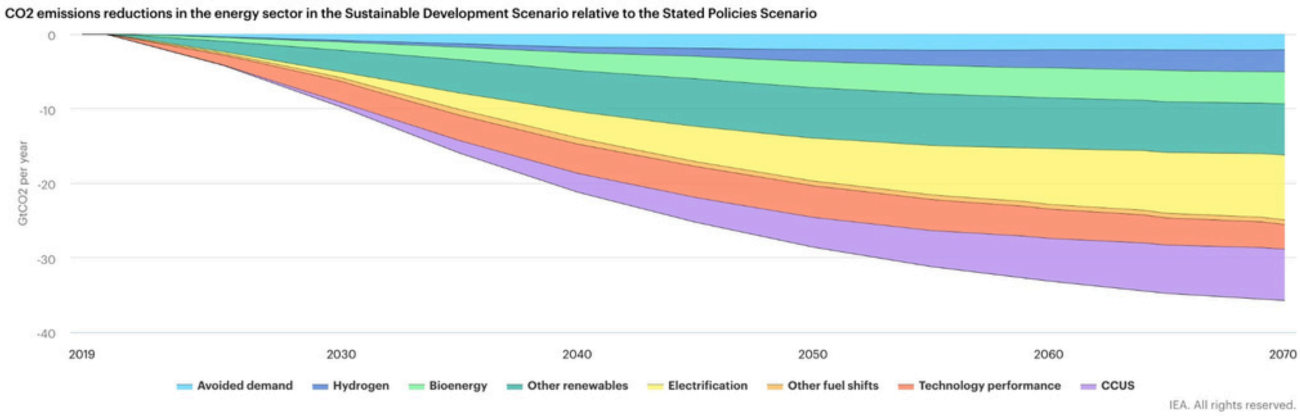
- **Developing Advanced WtE Facilities:**
  Investing in technologies like anaerobic digestion and pyrolysis, which have high energy yields and low environmental impact.
- **Leveraging Feedstock Availability:**
  Partnering with local waste management entities to secure waste feedstock contracts for a steady energy production stream.
- **Diversified Energy Output:**
  Investing in facilities that not only produce electricity but also heat and renewable gas for diversified income.
- **Emerging Technology Investments:**
  Investing in R&D or partnerships with startups focused on gasification and pyrolysis technologies can position DEA at the forefront of next-gen WtE methods. These technologies show promise in managing hard-to-treat wastes (e.g., plastics, hazardous materials) and generate a range of valuable products, including bio-oil and syngas.Innovations like green hydrogen production and carbon capture (CCUS) can boost the environmental impact and profitability of WtE facilities.
- **Invest in Carbon Capture Technologies for WtE Facilities:**
  Allocating funds towards carbon capture technology providers and WtE facilities willing to implement CCUS can yield substantial long-term returns.

Twin Transition Potential

- **Environmental Transition:**
  WtE reduces methane emissions from landfills, generates renewable energy from biodegradable waste, and supports sustainable waste management, contributing to climate goals.
- **Digital and Energy Transition:**
  The incorporation of digital technologies in WtE operations enables real-time performance monitoring, predictive maintenance, and integration with smart grids, maximizing efficiency and reliability.Synergies with other energy sectors, such as hydrogen production and grid balancing, enhance the role of WtE in decarbonized energy systems.

Carbon Capture Utilization and Storage (CCUS)

CCUS technologies capture CO_2 emissions from industrial processes, transportation, and power plants, offering a viable pathway to substantial carbon reduction in high-emission sectors. CCUS facilities align with global decarbonization efforts, with the IEA stating that CCUS could contribute nearly 15% of the total emissions reductions needed by 2050.[92] According to McKinsey analysis, CCUS uptake needs to grow 120 times by 2050 for countries to achieve their net-zero commitments3, reaching at least 4.2 gigatons4 per annum (GTPA) of CO_2 captured, with some estimates ranging from 6.0 to 10.0 GTPA. This could lead to CCUS decarbonizing 45 percent of the remaining emissions in the industry sector. Even in conservative scenarios, CCUS demand would reach approximately two GTPA by 2050—a 60-fold increase over today's pipeline of projects.[93]



Market Drivers

The Intergovernmental Panel on Climate Change (IPCC) identifies CCUS as critical to limiting global warming to 1.5°C. The technology is essential in sectors with high emissions, including cement, steel, and petrochemicals, which contribute approximately 30% of global CO_2 emissions. Europe's Green Deal and the United States' Inflation Reduction Act have introduced favorable policies, including tax credits and subsidies, to encourage CCUS deployment. In Europe, participation in the European Emissions Trading System (ETS) also incentivizes carbon-intensive industries to adopt CCUS solutions. Europe's Innovation Fund has allocated EUR 10 billion to support low-carbon technologies, including CCUS.[94] By 2030, the EU, with the Net Zero Industry Act (NZIA), expects CCUS technologies to capture and store approximately 50 million tons of CO_2 annually.[95]

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92 IEA (2020), CCUS in Clean Energy Transitions, IEA, Paris https://www.iea.org/reports/ccus-in-clean-energy-transitions

93 https://www.mckinsey.com/industries/oil-and-gas/our-insights/scaling-the-ccus-industry-to-achieve-net-zero-emissions

94 https://ec.europa.eu/commission/presscorner/detail/en/ip_19_1381

95 https://climate.ec.europa.eu/eu-action/industrial-carbon-management/legislative-framework_en

Regulatory Framework

European Union:

- **Net-Zero Industry Act (2024):**
  Establishes a 50 Mtpa CO_2 storage target by 2030, incentivizing cross-border transport infrastructure.
- **EU Industrial Carbon Management Strategy (2024):**
  Includes plans for a CO_2 transport regulatory package, streamlining infrastructure development.
- **ETS Innovation Fund:**
  Provides funding for large-scale CCUS projects, such as Northern Lights and Porthos.

Italy:

- **Integrated National Energy and Climate Plan (PNIEC):**
  Italy's PNIEC emphasizes CCUS as a key technology for achieving a 55% reduction in greenhouse gas emissions by 2030 and net-zero by 2050.
- **National Recovery and Resilience Plan (PNRR):**
  Funded by the EU Recovery Fund, the PNRR allocates resources for green innovation, including CCUS infrastructure development.

Key technologies

Capture Technologies:

- **Post-Combustion Capture:**
  Retrofitting existing plants using chemical solvents to extract CO_2.
- **Direct Air Capture (DAC):**
  Capturing atmospheric CO_2 using chemical processes for niche applications.
- **Oxyfuel Combustion:**
  Burning fuel in pure oxygen for concentrated CO_2 streams.

Transport Infrastructure:

- Pipelines are the most efficient and scalable method, while ships are used for flexible cross-border transport.

Storage Solutions:

- **Geological Storage:**
  Injecting CO_2 into depleted oil and gas fields or saline aquifers.
- **Utilization Pathways:**
  Converting CO_2 into value-added products like fuels, chemicals, and building materials.

Digital Integration:

- Advanced monitoring and verification technologies ensure storage integrity and operational transparency.

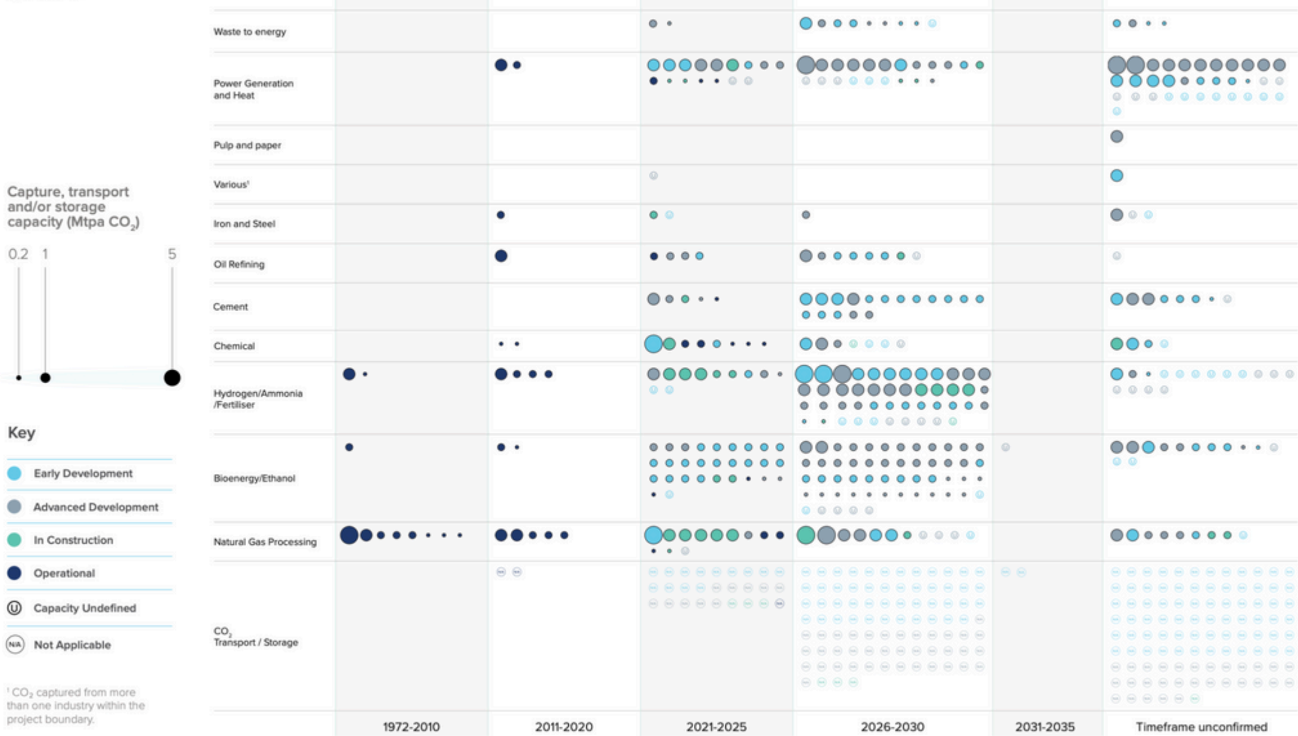
Market development and Investment Opportunities

The CCUS market is forecasted to reach USD 15 billion by 2030, with significant growth spurred by both public funding and private sector participation.Global investment in CCUS projects has grown significantly, with over 35 new projects announced in 2023 alone across Europe, North America, and the Middle East. These investments are often backed by regulatory support, reflecting a policy-driven trend to reduce greenhouse gas emissions.

Europe has witnessed an increase from six to ten commercial CCS projects in construction between July 2023 and July 2024. This growth reflects substantial progress in meeting European decarbonization targets, yet scaling challenges persist.The UK government has committed up to £21.7 billion in funding over the next 25 years to support the Teesside and Merseyside CCUS clusters, set to capture 20-30 Mtpa of CO_2. This commitment, announced in October 2024, highlights the UK's ambitious role in CCUS infrastructure (UK Department for Energy Security & Net Zero, 2023).The EU’s ambitious net-zero targets have incentivized CCUS deployment in sectors like steel, cement, and chemicals, which collectively account for 20% of Europe’s industrial emissions.

CCUS projects are expected to reduce costs over the next decade, with McKinsey estimating cost reductions of up to 35% by 2030 as technology scales.The Global CCS Institute identifies over 5,000 gigatons of potential CO_2 storage capacity worldwide, with significant reserves in Europe’s North Sea, estimated to accommodate up to 100 gigatons of CO_2.

Figure 3.1-3
CCS project pipeline by industry and year operational



[1] CO_2 captured from more than one industry within the project boundary.

Investment opportunities are related to:

- **Industrial CCUS Facilities:**
  With hard-to-abate sectors facing increased carbon taxes, demand for CCUS facilities is on the rise. Cement, steel, and chemical production facilities require high levels of decarbonization but lack scalable alternatives to CUSS. Investment opportunities in CCUS relate to retrofits for existing facilities, especially within high-emission zones in Europe and North America. Partnerships with industries and government support can enhance returns.
  Established government-backed projects and emission pricing strategies reduce risks associated with market fluctuations in the CCUS space.

- **CO_2 Utilization Technologies:**
  Utilization technologies transform captured CO_2 into valuable products, such as synthetic fuels, building materials, and chemicals. This approach complements the circular economy by creating new market products from emissions. Investment into CO_2 utilization technologies as they become more commercially viable, creating sustainable revenue streams and reinforcing brand commitment to sustainability.

- **CO_2 Storage Infrastructure:**
  The development of geological storage sites (e.g., depleted oil fields, saline aquifers) is essential for large-scale carbon storage. The North Sea, with its extensive underground storage capacity, offers significant opportunities for CCUS infrastructure. Collaborations with governments to develop storage sites reduce capital risk and may offer co-funding options, strengthening CCUS infrastructure across Europe.

- **Green Hydrogen Synergy:**
  CCUS has the potential to enhance green hydrogen production by capturing emissions from hydrogen derived from natural gas. This technology has gained traction across Europe, especially in countries with high green hydrogen demand like Germany and the Netherlands.

Twin Transition Potential

- **Energy Transition:**
  - CCUS ensures a measurable reduction in greenhouse gas emissions, contributing directly to climate goals.
  - Provides a circular economy opportunity through CO_2 utilization technologies.
- **Digital Transformation:**
  - Deployment of advanced sensors, AI-driven analytics, and blockchain for real-time monitoring and compliance reporting.
  - Enables predictive maintenance and operational optimization, enhancing efficiency and reducing costs.

Decarbonizing Hard-to-Abate Industries

The decarbonization of hard-to-abate industries (e.g., steel, cement, chemicals) represents a significant challenge due to high emissions and energy intensity. In Europe, these industries contribute approximately 15% of total CO_2 emissions, underscoring the need for low-carbon solutions. The decarbonization of Europe's hard-to-abate industries—specifically steel, cement, and chemicals—presents a growing investment opportunity in the context of the EU's ambitious climate targets. With these industries generating a considerable share of Europe's greenhouse gas (GHG) emissions, the region is focusing on strategic investments to align these sectors with its 2030 and 2050 carbon reduction commitments.

Market Drivers - Regulatory framework

European Union:

The decarbonization of hard-to-abate industries, such as steel, cement, and chemicals, is heavily influenced by EU-wide regulations that set ambitious emission reduction targets. Key frameworks include:

- **EU Green Deal (2019):**
  Aims to achieve net-zero greenhouse gas emissions by 2050, requiring substantial reductions in industrial emissions.
- **Fit for 55 Package (2021):**
  Mandates a 55% reduction in emissions by 2030. This includes provisions targeting industrial decarbonization, such as stricter emissions limits under the EU Emissions Trading System (ETS).
- **Net-Zero Industry Act (2024):**
  Focuses on scaling up clean technologies, including industrial decarbonization processes, with incentives for innovation and deployment.
- **Carbon Border Adjustment Mechanism (CBAM):**
  Ensures that imported products face equivalent carbon pricing as EU-made goods, encouraging global compliance and safeguarding EU industries.

Italy:

Italy complements EU regulations with national strategies to decarbonize hard-to-abate industries:

- **Integrated National Energy and Climate Plan (PNIEC):**
  Prioritizes the reduction of industrial emissions and the adoption of breakthrough technologies like Carbon Capture, Utilization, and Storage (CCUS), hydrogen, and electrification.
- **National Recovery and Resilience Plan (PNRR):**
  Allocates funding for green industrial innovation, including retrofitting existing industrial facilities to meet stricter emissions targets.
- **Incentive Schemes and Carbon Contracts for Difference (CCfDs):**
  Italy is exploring financial mechanisms to support the adoption of low-carbon technologies in heavy industries.

Sectoral focuses

Steel Industry

- **Overview:** Steel production emits approximately 1.85 tonnes of CO_2 per tonne of steel. EU regulations require a 55% reduction in emissions by 2030, pushing steel manufacturers towards low-carbon technologies like hydrogen-based reduction and CCUS.
- **Investment opportunities:** Green steel initiatives, such as those in Sweden and Germany, target production using hydrogen-based direct reduction, which reduces emissions by up to 90%. Investing in green steel by supporting infrastructure for hydrogen supply and CCUS-enabled facilities. Investment in these supply chains can foster long-term partnerships with steel producers committed to net-zero pathways.

Cement Industry

- **Overview:** Cement contributes 8% to global CO_2 emissions, primarily through clinker production. The EU supports the transition to alternative fuels and CCUS to minimize emissions in cement manufacturing.
- **Investment opportunities:** Oxyfuel Combustion and Alternative Clinkers: Advanced combustion technologies like oxyfuel, along with alternative materials, offer pathways for emissions reduction in cement production.
  As a capital-intensive sector, the cement industry is particularly reliant on external funding for decarbonization. Private investments plays a pivotal role in financing CCUS installations and alternative clinker production.

Chemical Industry

- **Overview:** The chemical sector faces decarbonization challenges due to high energy demands and complex processes. However, initiatives like the Sustainable Chemistry Initiative in Germany and France's energy-transition policies provide support for electrification and alternative chemical processes.
- **Investment opportunities:** Low-Carbon Feedstocks and Recycling: Innovations in low-carbon feedstocks and chemical recycling (particularly plastics) present opportunities to reduce the emissions footprint of chemical manufacturing. CCUS and Electrification Projects: As the sector moves toward CCUS and electrification, investment opportunities lie in pilot projects and scaling initiatives that develop and refine these technologies, particularly in regions like Benelux and Northern Italy, where chemical production is concentrated.

Market Potential and Investement opportunities

The steel, cement, and chemical sectors collectively contribute to approximately 15-20% of total CO_2 emissions in Europe due to their high reliance on fossil fuels and the inherent carbon-intensive processes of production.
These sectors face increasing regulatory pressure to adopt clean technologies to meet EU emissions reduction targets, including net-zero emissions by 2050. Achieving these goals will require substantial transformation, presenting robust investment prospects across decarbonization technologies and infrastructure.Under the European Green Deal, the EU has established the Fit for 55 package, mandating a 55% reduction in emissions by 2030. This has directed additional funding and regulatory support towards projects that aim to decarbonize hard-to-abate industries. The EU estimates a need for over EUR 300 billion by 2050 to decarbonize these sectors.

Investments opportunities are related to:

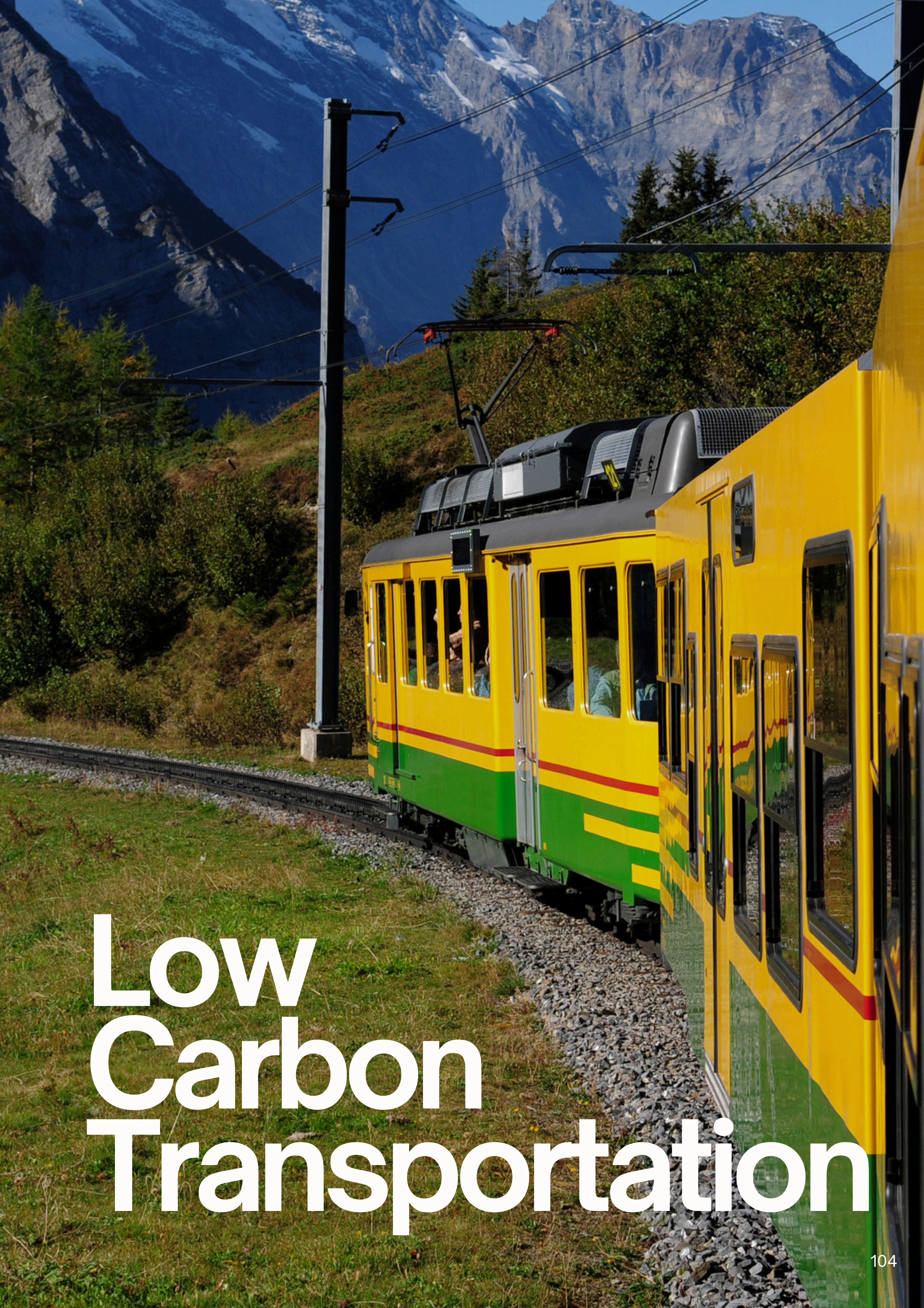
- **Carbon Capture, Utilization, and Storage (CCUS):**
  CCUS technology is especially critical in sectors like cement and steel, where alternative production methods currently cannot eliminate carbon emissions entirely. Direct investments in CCUS infrastructure, particularly in regions with planned industrial clusters, as well as in companies innovating in CO_2 utilization, such as mineral carbonation (turning CO_2 into building materials) or chemical recycling.
- **Hydrogen as a Low-Carbon Fuel:**
  In the steel sector, hydrogen is emerging as a critical alternative fuel, with green hydrogen (produced from renewable energy) poised to replace coal in steel production. There are opportunities in hydrogen production, transport, and storage infrastructure. Partnerships with hydrogen suppliers or investment in integrated hydrogen-powered facilities within these industries can drive substantial returns.
- **Electrification and Renewable Energy Integration:**
  For chemical and cement industries, electrification of production processes using renewable sources can reduce dependency on fossil fuels. Advanced heat pumps, direct electrification of kilns, and electric arc furnaces are some technologies under deployment. The decreasing costs of renewable energy and improved storage solutions are making full or partial electrification feasible.
- **Circular Economy and Materials Recycling:**
  Enhanced recycling within these industries, especially chemical and steel recycling, reduces emissions and conserves raw materials. Technologies such as closed-loop recycling and advanced sorting and refining methods are becoming integral.

Twin Transition Potential

Decarbonizing hard-to-abate industries represents a high-impact area for the twin transition of green energy transformation and digital innovation.

- **Green Transition Potential:**
  Hard-to-abate industries account for approximately 15-20% of global CO_2 emissions. Decarbonizing these sectors is essential to achieving climate targets. CCUS technologies can capture emissions at the source, while green hydrogen offers an alternative to fossil fuels in high-temperature industrial processes.

- **Digital Transition Potential:**
  Advanced technologies such as IoT, AI, and digital twins enable more efficient process control, predictive maintenance, and optimization of energy use in industrial plants. Blockchain and smart sensors facilitate accurate carbon tracking, ensuring compliance with stringent regulatory frameworks like the EU ETS. Automating labor-intensive processes in industries like steel and cement can reduce energy consumption and operational costs.



Low Carbon Transportation

Low Carbon Transportation

Mobility is fundamental to economic and social development; however, in its current form, the transport sector proves unsustainable in the majority of nations. Transport-generated pollution represents one of the most pressing challenges: it is estimated to cause approximately 7.8 million years of life lost annually, with a global economic impact of roughly 1,000 billion dollars in health-related damages.[98] Furthermore, the transport sector accounts for approximately one quarter of global greenhouse gas emissions, primarily stemming from fossil fuel combustion. With increasing motorisation in low and middle-income countries and a continuously expanding vehicle fleet in industrialised nations, the imperative to decarbonise transport is evident.[99]
In 2019, petroleum accounted for over 90% of energy consumption in the transport sector, generating nearly 8.5 gigatonnes of CO_2, a figure that temporarily declined to 7.0 gigatonnes during the COVID-19 pandemic. Nevertheless, sector emissions have risen sharply over recent decades, with road transport constituting 70% of these emissions.[100]

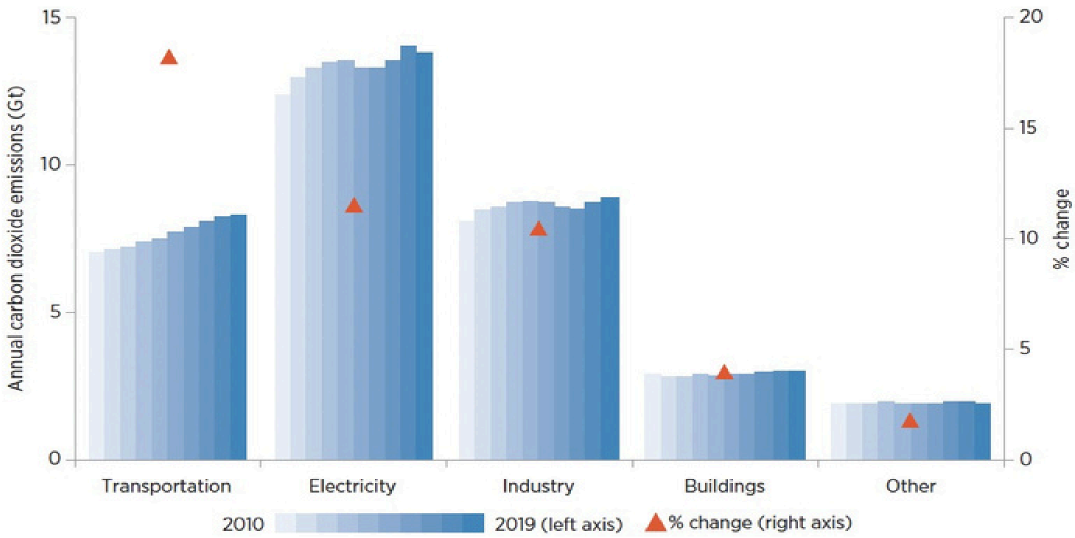


Fig.27 - Annual carbon dioxide emissions, by sector, 2010-19 Source: IEA, 2021

Despite the challenges inherent in electrifying the entire vehicle fleet, significant transformation opportunities remain, particularly in urban areas where emissions, congestion, and safety concerns are especially acute. In response to these challenges, the mobility industry is introducing innovations such as mobility-as-a-service (MaaS) systems, advanced traffic and parking management, freight-sharing solutions, and novel two and three-wheeled transport concepts.[101]

[98] Annenberg, Susan, Joshua Miller, Daven Henze, and Ray Minjares. 2019. A Global Snapshot of the Air Pollution–Related Health Impacts of Transportation Sector Emissions in 2010 and 2015. Washington, DC: International Council on Clean Transport.

[99] IEA (International Energy Agency). 2020. Tracking Transport 2020. Paris: IEA.

[100] IEA (International Energy Agency). 2021. Net Zero by 2050: A Roadmap for the Global Energy Sector. Vienna: IEA; Jaramillo, P., S. Kahn Ribeiro, P. Newman, S. Dhar, O. E. Diemuodeke, T. Kajino, D. S. Lee, S. B. Nugroho, X. Ou, A. Hammer Strømman, J. Whitehead. 2022. “Transport.” In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change: Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, 1049–160. Cambridge, UK: Cambridge University Press.

[101] European Environment Agency. (2022). Transport and environment report 2022: Digitalisation in the mobility system: challenges and opportunities

In recent years, low-carbon mobility has become a primary objective for global environmental policies, with the European Union at the forefront through the European Green Deal. This programme, launched in December 2019, aims to establish Europe as the first zero-emissions continent by 2050 and to reduce net emissions by at least 55% by 2030 compared to 1990 levels. The "Fit for 55" package, introduced in 2021, encompasses measures to streamline the transition towards electric vehicles and other low-emission solutions, reducing administrative complexity and facilitating large-scale infrastructure deployment.[102]

Concurrently, Italy has adopted the National Integrated Energy and Climate Plan (PNIEC), which envisions a substantial reduction in transport sector emissions, promoting targeted incentives such as subsidies for electric vehicle purchases and charging infrastructure development. Owing to these initiatives, the Italian market is experiencing an expansion in electric mobility support infrastructure and a renewal of public transport fleets.[103] Nevertheless, challenges persist regarding territorial heterogeneity and the necessity to accelerate the integration of digital technologies, such as smart grids, for efficient energy management.

Electric Mobility

Current data demonstrate electric mobility's critical role in low-carbon transport system transition. Quantitative analysis of the European market indicates significant growth metrics in 2023, with electric passenger vehicle registrations reaching approximately 3 million units, representing a 16% year-on-year increase.[104]

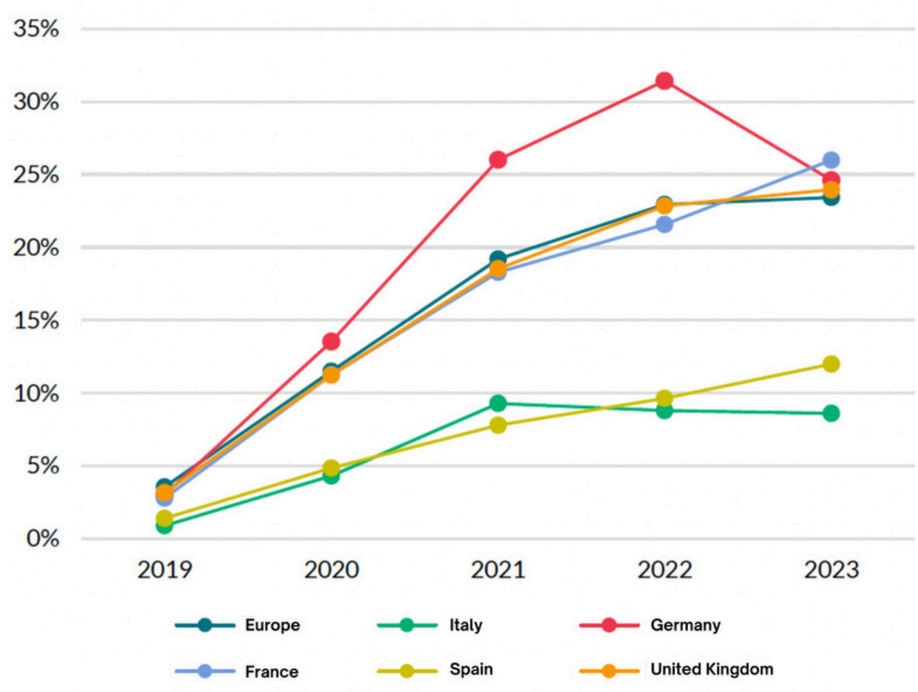


Fig. 28 - Share of Electric Vehicles in Total Registrations

Source: Energy&Strategy Group, 2024

[102]European Commission. The European Green Deal: https://ec.europa.eu/stories/european green-deal/

[103]Ministero dello Sviluppo Economico, Ministero dell'Ambiente e della Tutela del Territorio e del Mare, & Ministero delle Infrastrutture e dei Trasporti. (2020). Piano Nazionale Integrato per l'Energia e il Clima (PNIEC).

[104]Energy & Strategy Group. (2024). Smart Mobility Report 2024: Da "follower" a "leader"? Come abilitare per l'Italia un cambio di passo sulla decarbonizzazione dei trasporti.

Statistical evidence shows Battery Electric Vehicles (BEVs) dominating the sector, comprising 67% of new registrations. Electric vehicle market penetration achieved 23.4% of total passenger vehicle registrations across European markets, demonstrating a marginal increase (+0.5%) from the preceding period.

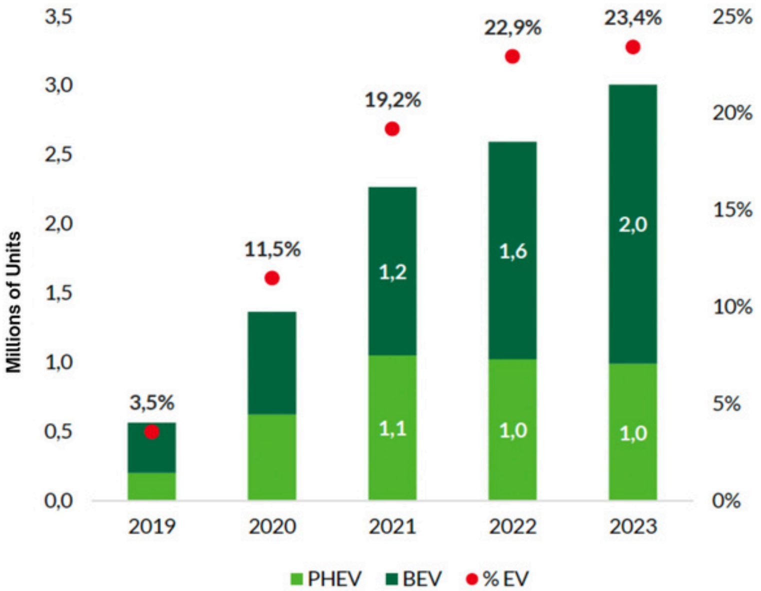


Fig. 29 - Registrations of Electric Passenger Cars in Europe
Source: Energy&Strategy Group, 2024

The Italian market exhibits statistically significant divergence from broader European trends. Quantitative assessment reveals an 8.6% market share, substantially below continental averages, with data indicating a 0.2% decline from 2022 - marking two consecutive years of negative growth. Comparative analysis with German market metrics is particularly noteworthy; despite experiencing a 6.2% contraction, Germany maintains triple the electric vehicle penetration rate in new registrations relative to Italian figures.

Market Drivers - Regulatory framework

European Union:

Green Deal:

- A cornerstone initiative aiming to make Europe the first climate-neutral continent by 2050.
- Sets a target of reducing greenhouse gas emissions by 55% by 2030 compared to 1990 levels.

Fit for 55 Package:

- Mandates the phase-out of internal combustion engine (ICE) vehicle sales by 2035.
- Introduces financial incentives and regulatory frameworks for developing EV charging infrastructure.

- **Alternative Fuels Infrastructure Regulation (AFIR):**
  - Establishes mandatory targets for the geographic coverage and density of alternative fuel stations.
  - Requires charging stations every 60 km along major European transport corridors (TEN-T) by 2025.
- **Battery Regulation 2023/154:**
  - Implements a battery passport to track lifecycle data for transparency and sustainability.
  - Sets collection and recycling targets:
    - 63% collection rate for portable batteries by 2027.
    - 90% recycling efficiency for cobalt and nickel by 2031.

Italy:

- **National Integrated Energy and Climate Plan (PNIEC):**
  - Defines clear objectives for transport sector decarbonization.
  - Offers incentives for electric vehicle (EV) purchases and the development of charging infrastructure.
- **National Recovery and Resilience Plan (NRRP):**
  - Allocates €741 million for public and private EV charging stations.
  - Focuses on bridging territorial gaps in sustainable mobility infrastructure.
- **Ecobonus Scheme:**
  - Provides tiered financial incentives (€6,000–€14,000) for the purchase of EVs and plug-in hybrids, based on vehicle specifications and purchaser income.
  - Includes temporary tax exemptions:
    - 5 years for fully electric vehicles (BEVs).
    - 3 years for plug-in hybrid vehicles (PHEVs).
- **National Strategic Plan for Sustainable Mobility (PSNMS):**
  - Allocates funds for the renewal of urban public transport fleets, prioritizing electric and hydrogen vehicles.
  - Targets 90% of urban bus fleets to achieve zero-emission status by 2030.

Expert Insight:
The Rise of Electric Mobility: Regional Challenge

Developed with insights from Alberto Dalla Riva, Senior Lead Business Developer at Ørsted

Electric mobility is now one of the fastest growing technologies, along with solar and batteries. The sector has recorded impressive figures, with China leading the transition: almost 35% of newly registered vehicles are already electric, and it is predicted that 50-60% of new global sales will be electric by 2030.
While Asia is accelerating, the European automotive industry is facing a difficult period of transition, with a structural crisis that could worsen in the coming years.
The technology and production gap with Asian competitors is becoming an increasingly obvious problem.
The situation in Italy remains more uncertain: electricity is still largely produced from gas, and energy costs are higher than in other European countries. This factor is slowing down the uptake of electric vehicles, but in the long term the reduction in battery costs and the improvement in charging infrastructure could help to accelerate the market. A notable example of successful EV adoption comes from Scandinavia, where massive investments in charging infrastructure have facilitated rapid transition. Norway has already reached 100% EV sales, and charging technology is improving rapidly.

Despite progress, a critical factor for the future of electric mobility will be the expansion and modernization of electricity distribution networks.
Efficient grid development is essential to:

- Manage rising energy demand from EVs
- Ensure optimal integration with renewable energy sources

Key technologies

Efficiency and Performance

Current electric vehicle (EV) efficiency ranges from 5 to 7 km/kWh, offering significantly lower operational costs per kilometer compared to internal combustion engine (ICE) vehicles. Many EVs now achieve ranges exceeding 350 km per charge, addressing key consumer concerns about range anxiety. High-power charging infrastructure developments have reduced charging times dramatically, enabling 80% charge in under 10 minutes for compatible vehicles.[105]

Battery Technology

Global battery demand reached over 750 GWh in 2023, reflecting a 40% year-on-year growth.[106] Battery production is concentrated in three major regions:

- **China:** 415 GWh capacity
- **Europe:** 185 GWh capacity
- **United States:** 100 GWh capacity

Between 2022 and 2023, battery costs decreased by 14%, with LFP (Lithium Iron Phosphate) technology achieving:

- **$130/kWh** for complete battery systems
- **$95/kWh** for battery cells

Circular Economy

Second-life battery applications are emerging as a significant opportunity, with projected capacities of 77 GWh by 2050. Recycling efficiency is expected to rise from the current 15–25% to 90% by 2030, supporting a circular economy and reducing dependency on raw material extraction.[107]

[105] Strategy& and Motus-E. (2024). Il futuro della mobilità elettrica in Italia @2035: Final Report.

[106] International Energy Agency (IEA). (2024). Global EV Outlook 2024: Moving towards increased affordability.

[107] Motus-E. (2024). Evoluzione dell'elettrificazione del TPL.

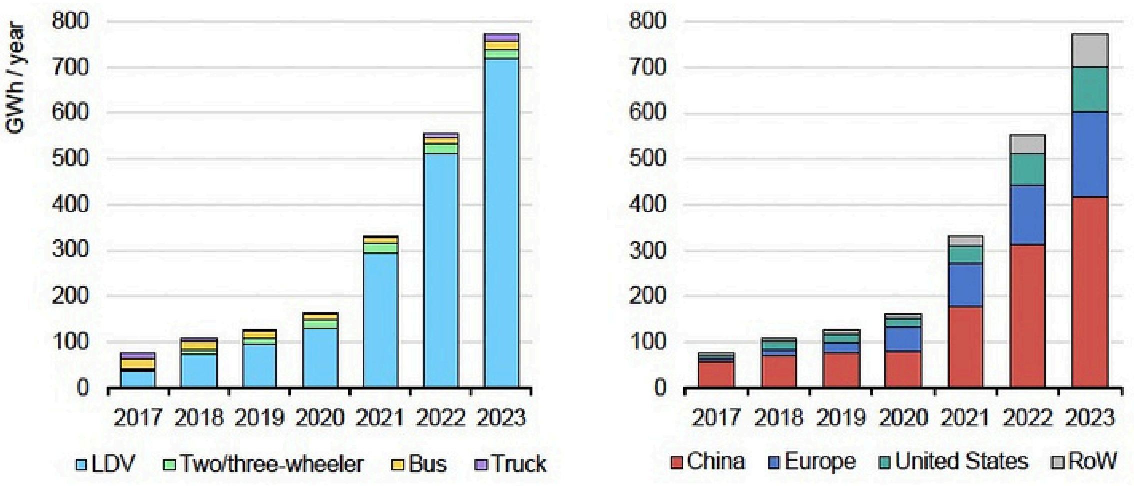
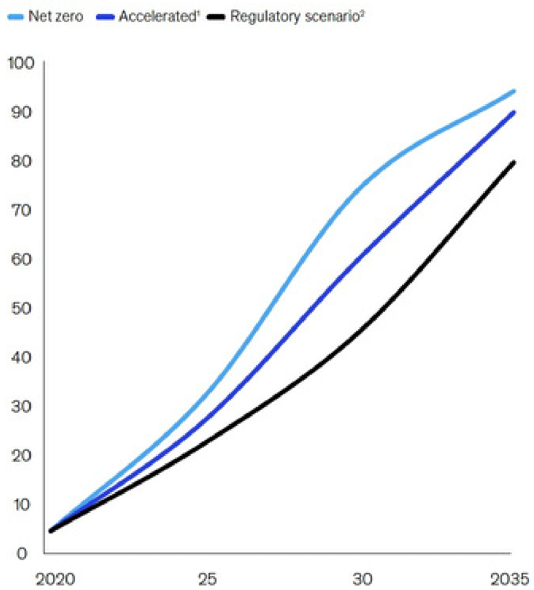


Fig.30 - Electric vehicle battery demand by mode and region, 2017-2023
Source: IEA, 2024

Market development and Investment Opportunities

A McKinsey study highlights two distinct paths for the evolution of Italy's electric mobility market, both showing strong growth but differing in speed and scale. The accelerated scenario, more ambitious, projects a 56% penetration of pure electric vehicles (BEVs) in new registrations by 2030, with a circulating fleet of 4.6 million electric vehicles. This scenario extends to project 11.4 million electric vehicles in circulation by 2035, the year in which, due to European regulations, 100% of new registrations must consist of zero-emission vehicles. The conservative scenario, whilst maintaining the final target of 100% electric new registrations in 2035, envisions a more gradual adoption path. In this case, the BEV market share would reach 39% by 2030, with a circulating fleet between 3.5 and 4.3 million electric vehicles. The 2035 projection in this scenario sees 9.8 million electric vehicles on Italian roads.[108]

Fig.31 - Market Scenarios Source: McKinsey, 2021



European battery production capacity requirements indicate necessary expansion to 965 GWh by 2030 to meet projected demand of 874 GWh. Global competitive analysis demonstrates Chinese market advantage through reduced production costs. 2023 data indicates lithium battery price reductions correlating with raw material price stabilisation, achieving 95 $/kWh for LFP cells.[109] However, European competitiveness requires significant investments in local production capabilities and supply chain integration to ensure competitive prices and long-term strategic independence. Second-life battery applications represent an emerging market segment with significant growth potential. Capacity projections indicate 77 GWh by 2050.

108McKinsey & Company. (2021). Why the automotive future is electric: Mainstream EVs will transform the automotive industry and help decarbonize the planet. McKinsey Center for Future Mobility.
109Motus-E. (2024). Ibidem

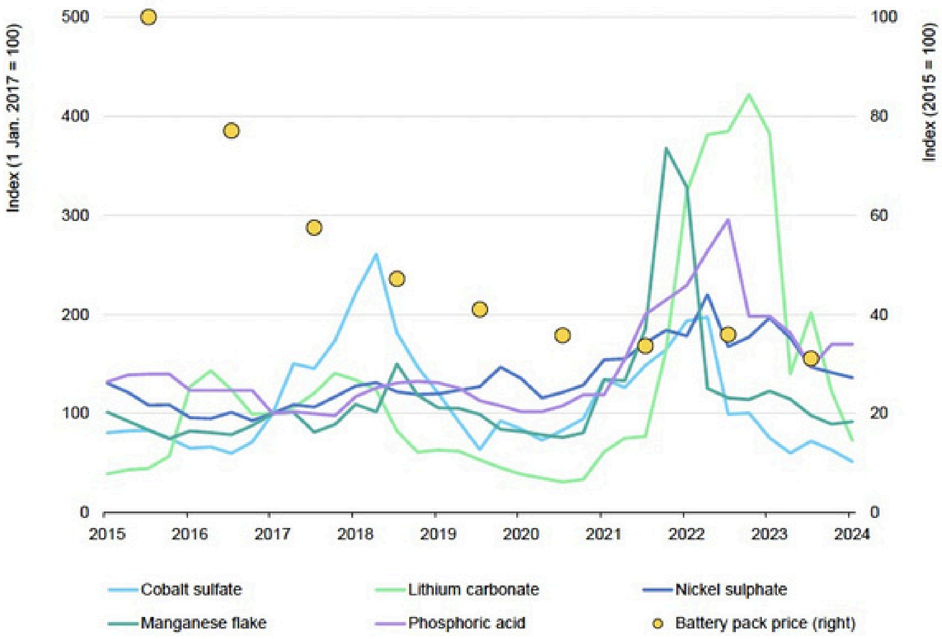
Technical analysis demonstrates significant residual capacity post-primary lifecycle (8 years/100,000 miles), enabling deployment in reduced-demand applications.[110]

Application diversity analysis indicates multiple implementation vectors:

- Residential energy storage systems
- Grid support infrastructure
- Renewable energy integration optimisation

Fig. 32 - Price of selected battery metals (left) and lithium-ion battery packs (right), 2015-2024

Source: IEA analysis based on data from Bloomberg and Bloomberg New Energy Finance Lithium-Ion Price Survey, 2023.



Economic analysis indicates restoration costs of approximately 20$/kWh for PHEV batteries, demonstrating a favorable cost-benefit ratio compared to new storage system acquisition.[111]

[111]Briceno-Garmendia, C., Qiao, W., & Foster, V. (2023). The Economics of Electric Vehicles for Passenger Transportation. Sustainable Infrastructure Series. Washington, DC: World Bank.

Twin Transition Potential

Electric mobility sits at the intersection of the green and digital transitions, offering a transformative pathway for sustainable and innovative mobility systems. The twin transition framework highlights the synergistic potential of environmental imperatives and digital advancements to redefine the sector:

Environmental Benefits: by displacing fossil fuel-based vehicles, electric vehicles (EVs) contribute directly to decarbonization goals, reducing greenhouse gas emissions and improving urban air quality. Integration with renewable energy sources, such as solar and wind, within charging infrastructure amplifies these benefits, creating a more sustainable energy ecosystem. Innovations in vehicle design—such as energy-efficient powertrains and the adoption of lightweight, recyclable materials—further reduce the sector's environmental footprint while promoting resource efficiency .

Digital Integration: The deployment of smart technologies, including vehicle-to-grid (VGI) systems and AI-driven charging algorithms, enables dynamic interaction between EVs and the power grid, stabilizing energy demand and facilitating renewable energy integration. IoT-based telematics and predictive analytics improve vehicle performance and optimize fleet management, reducing operational costs and enhancing user experience. Moreover, advancements in data-driven systems support the seamless integration of electric mobility into intelligent transportation networks.

Electric mobility, as a nexus of environmental and digital innovation, exemplifies the potential of the twin transition to accelerate sustainable urban development, enhance energy resilience, and unlock new economic opportunities .

Charging Infrastructure

Quantitative analysis of the European charging infrastructure market reveals significant heterogeneity in its structural composition. By end-2023, public access charging points reached approximately 725,000 units, with slow charging stations demonstrating clear predominance at 83% of total infrastructure. Market evolution indicates substantial growth trajectories, with slow charging points experiencing a 37% increase and rapid charging installations showing 57% growth compared to the previous year.[112]

Geographic distribution analysis demonstrates significant member state disparities. The Netherlands maintains market leadership with approximately 8 charging points per 1,000 inhabitants, followed by Norway, Denmark, Belgium, and Sweden in decreasing order of density. High-power charging point distribution (⩾50 kW) presents particular significance, with Norway, Portugal, Spain, Austria, and Germany exceeding the European mean of 13%.

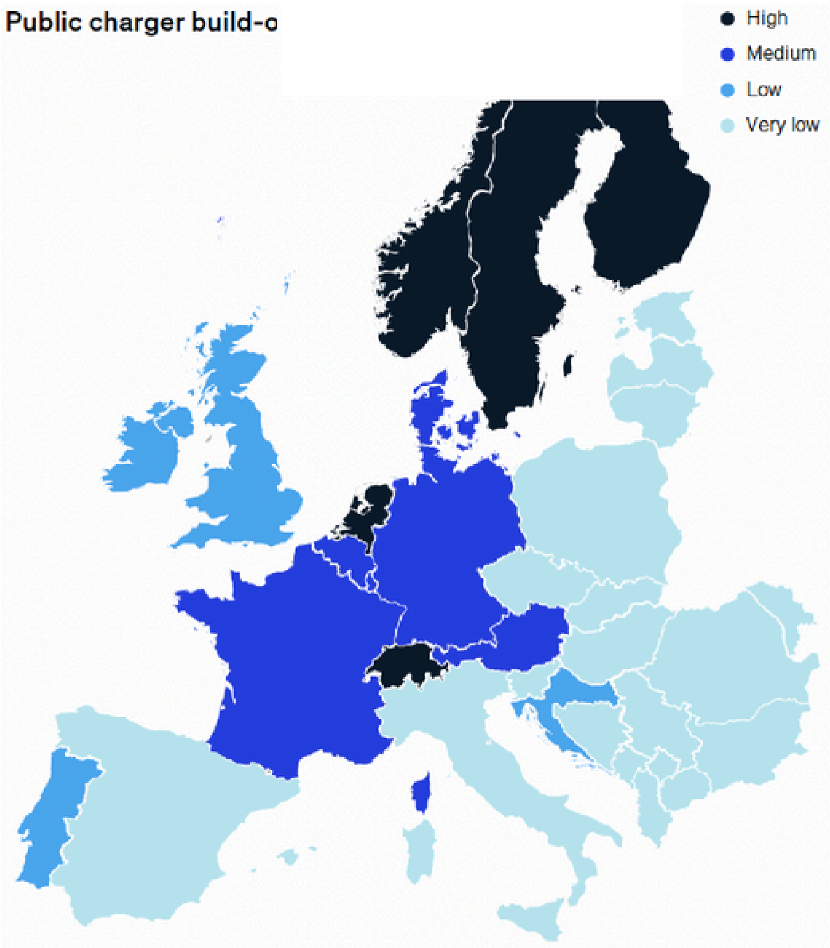
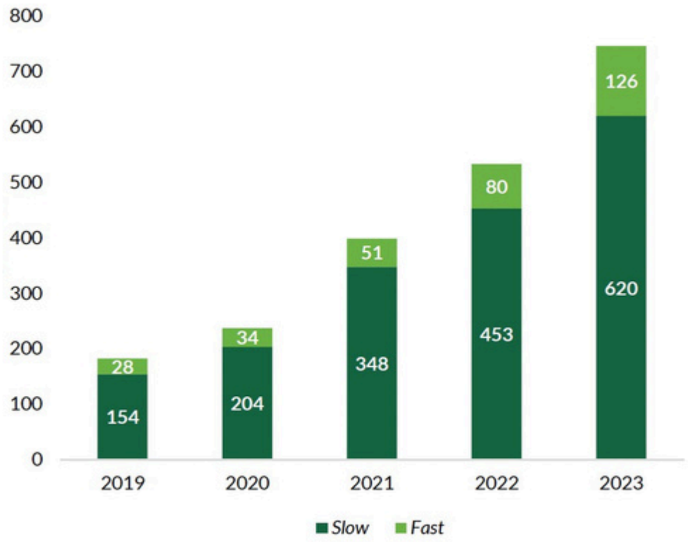


Fig. 34 - Public charger build-out Source: McKinsey & Company,2021

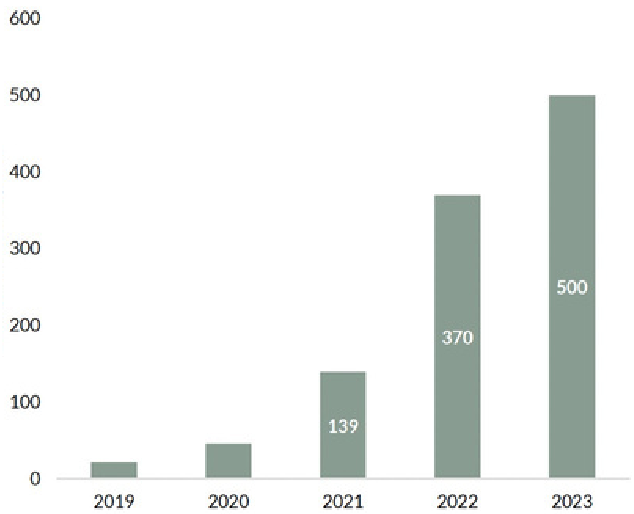
[112]Strategy& and Motus-E. (2024). Smart Mobility Report 2024: Da "follower" a "leader"? Come abilitare per l'Italia un cambio di passo sulla decarbonizzazione dei trasporti.

Fig.35 - Public access charging points in Europe (in thousands)
Source: Strategy& and Motus-E., 2024



Italian infrastructure metrics indicate over 49,000 public charging points by end-2023, representing 28% year-on-year growth. Despite relatively low density metrics (0.8 points per 1,000 inhabitants versus the European mean of 1.4), Italy demonstrates notable high-power charging point penetration at 16%, exceeding European averages. Private sector deployment exhibits robust growth characteristics, with approximately 500,000 installed charging points representing 35% growth from 2022. This development, partially facilitated by Superbonus incentive mechanisms, has established a 10:1 private-to-public infrastructure ratio. Notably, this expansion demonstrates independence from electric vehicle registration trends, which exhibited slight decline during the corresponding period.

Fig.35 - Public access charging points in Europe (in thousands)
Source: Strategy& and Motus-E., 2024



Market Drivers - Regulatory framework

European Union:

- **Green Deal and Fit for 55 Package:**
  - Establishes a target of installing at least one million charging stations by 2030.
  - Focuses on optimizing geographic coverage and accessibility to ensure uniform adoption across regions.

Italy:

- **National Recovery and Resilience Plan (NRRP):**
  - Allocates €741 million for the development of public charging infrastructure.
  - Reports a 25% completion rate for implementation as of Q1 2024.
- **Ministerial Decree 109/2024:**
  - Revises requirements for rural charging infrastructure tenders due to insufficient qualifying bids in 2023.

Key technologies

Plug & Charge Technology

- Streamlines the EV charging process by automating user authentication and payment.
- Requires significant infrastructural updates and collaboration between manufacturers, infrastructure providers, and regulators to overcome technical barriers.

Vehicle-to-Grid Integration (VGI)

- **V1G (Unidirectional):**
  Scheduled for rollout between 2026 and 2027 to enable basic energy return to the grid.
- **V2G (Bidirectional):**
  Expected operational deployment between 2028 and 2035, allowing EVs to act as mobile energy reserves in corporate and public contexts.

Smart Charging Systems

- Utilize AI and IoT to regulate charging schedules, balance grid loads, and enhance energy efficiency.

- Incorporate storage systems to mitigate grid strain and ensure stability during peak demand periods.[112]

Market Potential and Investement opportunities

The rapid expansion of charging infrastructure presents significant investment opportunities, with a requirement to install over 15,000 new charging points weekly until 2030 to support the growing EV market. Business models are evolving towards pay-per-use, subscription-based, and public-private partnership approaches, increasing access to private capital. Utilities and energy companies are thereby able to develop integrated solutions, including partnerships for managing fast and ultra-fast charging stations in strategic areas.[114]

Additionally, future projections indicate that V2G technology will initially be implemented in corporate settings (2028-2030) and subsequently in public contexts (2030-2035), with estimated economic benefits of up to 800 million euros for the system. The growth of smart charging and energy integration presents significant opportunities for new business models within the energy sector, from intelligent load management and consumption optimization to integration with renewable energy sources. These developments require a systemic approach encompassing the entire electric mobility value chain, from vehicle production to energy infrastructure management.[115]

Finally, an analysis of system-wide economic benefits and supplier revenues from Motus reveals an overall advantage of between 700 and 800 million euros for the system, with supplier revenues ranging between 170 and 195 million euros. This gap underscores the need for pricing models that maximize revenue without compromising system-wide benefits.
Sensitivity analysis on pricing offers considers three main scenarios:

- **Reference Scenario:**
  Prices of 115 €/MWh during peak demand and 55 €/MWh during off-peak.
- **Competitive Scenario:**
  Prices of 155 €/MWh during peak demand and 30 €/MWh during off-peak.
- **Non-Competitive Scenario:**
  Prices of 270 €/MWh during peak demand and 15 €/MWh during off-peak.

This pricing structure illustrates that, in an optimal scenario, supplier revenues can be balanced with system-wide benefits. However, careful management of pricing and incentives is essential to ensure the economic sustainability of the charging infrastructure sector, thus ensuring that the environmental and economic benefits of electric mobility are realized effectively.[116]

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113 MOTUS-E, CESI, Politecnico di Milano, & RSE. (2023). Vehicle-Grid Integration (VGI): Studio sul potenziale tecnico-economico della completa integrazione tra veicoli e reti elettriche; Motus-E & Strategy& - Il futuro della mobilità elettrica in Italia @2035: Strategy& & MOTUS-E. (2024). Il futuro della mobilità elettrica in Italia @2035.

114 Why the Automotive Future is Electric: McKinsey & Company. (2021). Ibidem.

115 Briceno-Garmendia, C., Qiao, W., & Foster, V. (2023). Ibidem.;MOTUS-E, CESI, Politecnico di Milano, & RSE. (2023). Vehicle-Grid Integration (VGI): Studio sul potenziale tecnico-economico della completa integrazione tra veicoli e reti elettriche; European Environment Agency (EEA). (2022). Transport and environment report 2022: Digitalisation in the mobility system: challenges and opportunities.

116 MOTUS-E, CESI, Politecnico di Milano, & RSE. (2023). Vehicle-Grid Integration (VGI): Studio sul potenziale tecnico-economico della completa integrazione tra veicoli e reti elettriche.

Twin Transition Potential

The development of charging infrastructure serves as a foundational pillar for decarbonized and intelligent mobility systems:

Environmental Integration:

- **Renewable Energy Synergies:**
  advanced charging networks are increasingly integrated with renewable energy sources such as solar and wind, enabling grid decarbonization. High-power charging stations (>50 kW) equipped with energy storage systems not only mitigate peak-load grid strain but also optimize the temporal alignment of energy supply and demand, ensuring maximum utilization of green energy sources.

- **Decarbonization Objectives:**
  Green Deal and the Alternative Fuels Infrastructure Regulation (AFIR) mandate a network density that supports at least one million charging stations by 2030, emphasizing accessibility and equitable deployment across urban and rural areas.

Digital Integration:

- **Vehicle-to-Grid (V2G) Technology:**
  bidirectional energy flow capabilities transform EVs into distributed energy resources, supporting grid stability by returning energy during peak demand. V2G systems are projected for widespread deployment in corporate and public contexts from 2028 onwards, with unidirectional V1G already contributing to grid load optimization .

- **Smart Charging Infrastructure:**
  AI-driven algorithms and IoT-enabled networks facilitate real-time monitoring, dynamic load balancing, and predictive energy management, enhancing operational efficiency and reducing costs. These technologies underpin the transition from static to adaptive energy distribution systems.

- **Plug & Charge Systems:**
  this standardization streamlines user interaction by automating identification, authentication, and payment processes, effectively eliminating manual interventions and aligning the charging experience with internal combustion engine (ICE) refueling simplicity .

Operational and Economic Impact:

- The adoption of integrated digital platforms enables predictive maintenance, reducing infrastructure downtime and prolonging asset life cycles. Moreover, dynamic pricing models driven by data analytics optimize energy tariffs, incentivizing off-peak charging and improving grid utilization.

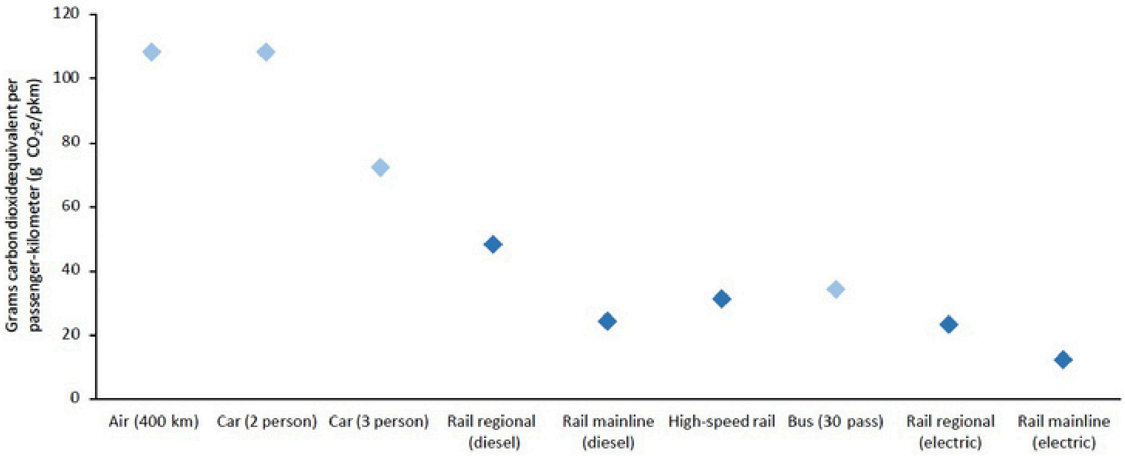
- Public-private partnerships (PPPs) and blended financing models are critical to accelerating deployment, leveraging public funding such as the €741 million allocated under Italy’s National Recovery and Resilience Plan (NRRP) to attract private sector investment.

Charging infrastructure, at the nexus of the twin transition, catalyzes a systemic shift toward resilient, sustainable, and technologically advanced mobility ecosystems, bridging gaps between decarbonization goals and digital energy innovation.

Electrified Public Transport Systems

The transport sector represents one of the most significant challenges in European economy decarbonisation, contributing 25% of total European Union greenhouse gas emissions in 2022.[117] Within this context, electrified public transport emerges as a strategic solution, considering that railway transport accounts for merely 0.4% of total transport sector emissions. This datum assumes particular relevance when compared with private transport dominance, which currently represents 75% of passenger transport in Europe.[118]

Fig. 37 - Typical Traction-Related Emissions for Intercity Passenger Trips by Mode



Source: Lawrence, M., & Bullock, R., 2022

European market analysis demonstrates a clear transition towards electrification, with 73% of new public transport vehicle registrations utilizing alternative propulsion systems and 40% adopting zero-emission solutions. The emerging hydrogen vehicle market presents particular interest, which, although limited to 1.3% of total registrations, shows significant development potentia.[119] Concurrently, increasing interest in long-distance rail connections, including night services, is observed, although the network remains insufficiently developed to offer a substantial alternative to road transport.
In the Italian context, the transition towards electrified public transport presents distinctive characteristics. With 27.5% zero-emission registrations, the Italian market demonstrates a lag compared to European averages, characterized by marked geographical disparity: 80% of electric vehicles are concentrated in northern regions, primarily in the metropolitan areas of Milan, Turin, and Genoa. This heterogeneous distribution is further accentuated by fleet average age, which exceeds other principal European markets by 33%.[120]

[117] McKinsey & Company. (2021). Ibidem.

[118] Lawrence, M., & Bullock, R. (2022). The role of rail in decarbonizing transport in developing countries. Mobility and Transport Connectivity Series. Washington, DC: International Bank for Reconstruction and Development / The World Bank.

[119] Motus-E. (2024). Ibidem.

[120] Ivi.

Market Drivers - Regulatory framework

European Union:

- **European Climate Law:**
  - Sets binding climate neutrality goals by 2050.
  - Intermediate 2030 objectives include:
    - 55% reduction in health impacts from air pollution.
    - 30% reduction in population exposed to transport noise compared to 2005 levels.

- **Connecting Europe Facility (CEF):**
  - Allocates €7 billion for 134 projects, with:
    - 83% of funds supporting climate initiatives.
    - 80% designated for the railway sector.
- **European Rail Traffic Management System (ERTMS):**
  - €24 billion allocated for TEN-T infrastructure.
  - €5 billion dedicated to rolling stock modernization.
- **Recovery and Resilience Facility (RRF):**
  - Directs 40% of resources (€38.4 billion) to railway sector development.

Italy:

- **National Strategic Plan for Sustainable Mobility (PSNMS):**
  - Allocates €7.5 billion, with:
    - €3.7 billion for sustainable mobility initiatives.
    - €1.915 billion specifically for urban fleet renewal.
  - Targets:
    - 90% zero-emission urban buses by 2030.
    - Progressive CO_2 reduction for intercity transport:
      - 45% by 2030, 65% by 2035, and 90% by 2040.

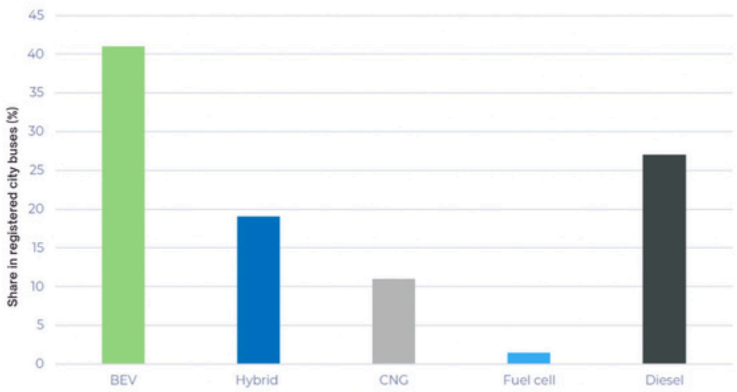
Key technologies

Technological evolution in electrified public transport develops along two primary directions: pure electric propulsion and hydrogen technologies.

Pure Electric Propulsion

- **Electric Bus Advancements:**
  - Battery technology (LFP - Lithium-Iron-Phosphate):
    - 34% capacity increase for 12-meter buses since 2020.
    - Cost reductions to $130/kWh for battery packs and $95/kWh for cells.[121]
  - 71% of buses use central motor configurations, improving efficiency and reducing maintenance costs.

Fig.38 - European bus market Source: Motus-E, 2024



Hydrogen Technologies[122]

- **Railway Applications:**
  - Hydrogen trains offer operational autonomy of 600–800 km, ideal for non-electrified regional lines and freight transport.
- Applications include fuel cell systems combined with batteries or ICEs, and alternative energy vectors like ammonia.

[121] Motus-E. (2024). Ibidem.
[122] Lawrence, M., & Bullock, R. (2022). Ibidem.

- **Electric Charging Networks:**
  - Planned capacity expansion:
    - From 72 MW currently to 1 GW by 2024 and 4 GW by 2026.
  - Dominant standard: CCS2, with an average capacity of 68 kW per bus.
- **Hydrogen Infrastructure:**
  - Includes storage solutions (pressurized, liquid) to support regional and freight mobility.

Market Potential and Investement opportunities

The electrified public transport market attracts significant investment from European financial institutions. The European Investment Bank has recently approved innovative operations, including 2 billion euros leasing for Munich trains and 3.4 billion financing for the Palermo-Catania line. Particular attention focuses on research and development, exemplified by 20 million euros funding for MerMec projects in railway digitalization.[124] CEF 2014-2020 programme results demonstrate sector investment scale, with 92 signed agreements resulting in 5,604 kilometers of track modernization and 2,848 vehicle acquisitions.[125] Market projections through 2050 anticipate radical fleet composition transformation, with 88% electric buses and 9% hydrogen vehicles, requiring approximately 2,000 annual registrations.[126] Railway sector objectives include freight transport doubling and high-speed services tripling.

The electrified public transport investment landscape rapidly evolves toward innovative business models, characterized by intensifying public-private collaboration. This transition responds to growing economic, infrastructural, and technical resource requirements for large-scale sustainable mobility project implementation. Within this context, consortium-based models and public-private partnerships emerge, exemplified by consortia between ATM Milan, ANM Naples, and ATAC Rome, representing synergy between competencies and financial capabilities for local public transport tender management and development. These consortia perform strategic roles in scale economy creation, operational cost reduction, and overall electrified mobility initiative efficiency enhancement. Through collaboration, companies share technical expertise and financial resources, improving capacity to address local and international sustainability requirements. The consortium approach facilitates coordinated charging infrastructure management and long-term fleet planning, rendering electrified local public transport increasingly viable and attractive for cities.

[123] Motus-E. (2024). Ibidem

[124] European Investment Bank (EIB). (2023). InvestEU: €3.4 billion to modernise the Palermo-Catania railway line.

[125] European Commission. (n.d.). EU funding for ERTMS

[126] Motus-E. (2024). Ibidem

From an investment perspective, public-private partnerships provide a solid foundation for external capital attraction, including European funds dedicated to transport decarbonization. Through these alliances, cities ensure optimal resource allocation and timely infrastructure implementation.[127]

Twin Transition Potential

Public transport systems are a pivotal element in advancing the twin transition, where environmental sustainability and digital innovation converge to create efficient, resilient, and low-carbon mobility networks.

Environmental Integration:

- **Decarbonization and Efficiency:**
  public transport modes, particularly electrified railways and buses, play a crucial role in reducing greenhouse gas (GHG) emissions. Rail transport, for instance, accounts for less than 0.4% of transport-related GHG emissions while supporting 8% of passenger transport in the EU, underscoring its superior energy efficiency and minimal environmental footprint .
- **Electrification and Hydrogen Technologies:**
  with 56% of the EU's railway network already electrified, efforts are underway to extend electrification and deploy hydrogen-powered trains for non-electrified regional lines. These technologies provide a sustainable alternative for both passenger and freight transport, directly aligning with climate neutrality objectives.
- **Modal Shift and Urban Sustainability:**
  encouraging a shift from private vehicles to public transport reduces urban congestion, lowers air pollution, and promotes sustainable city planning .

Digital Transformation:

- **Smart Operations:**
  IoT-enabled systems enhance real-time traffic management, optimize scheduling, and minimize service disruptions. Advanced digital tools integrate data across mobility networks, creating seamless multimodal travel options.
- **Predictive Maintenance and Optimization:**
  data-driven analytics enable operators to implement predictive maintenance, reducing downtime and extending the lifespan of transport assets. Integration with GIS further supports targeted infrastructure investment and planning .
- **Enhanced User Experience:**
  digitalization fosters seamless multimodal travel through integrated ticketing and journey planning systems, allowing passengers to transition effortlessly between modes of transport, including rail, buses, and micro mobility options .

By integrating green and digital advancements, public transport becomes a cornerstone of the twin transition, offering scalable solutions to urbanization challenges while advancing Europe's environmental and technological objectives.

[127] Werland, S., & Rudolph, F. (2019). Funding and financing of sustainable urban mobility measures. Wuppertal Institute. Developed within the SUITS and SUMPs-Up projects, funded under the European Union's Horizon 2020 Research and Innovation programme; Casady, C. B., Cepparulo, A., & Giuriato, L. (2024). Public-private partnerships for low-carbon, climate-resilient infrastructure: Insights from the literature. Journal of Cleaner Production, 470, 143338.

Mobility as a Service (MaaS) and Sharing Models

Mobility as a Service represents a fundamental paradigm shift in the transport sector, marking the transition from traditional vehicle ownership models toward mobility service access. This novel approach manifests through integrated systems enabling users to plan, book, and pay for diverse mobility services through a single digital platform.[128]

The shared mobility market presents a complex, articulated structure characterized by segments differentiated through operational modalities and value propositions. E-hailing represents one of the most significant segments, characterized by digital booking and payment systems for chauffeur-driven transport services. This service has evolved to include various operational modalities, from traditional ride-hailing where single users book exclusive journeys, to innovative ride-pooling enabling journey sharing with other passengers, optimizing costs and environmental impact.[129]

Car-sharing constitutes another fundamental shared mobility pillar, distinguished by flexible access provision to vehicles distributed across urban territories. This segment articulates through various operational modalities, each responding to specific mobility requirements.
The free-floating model, characterized by vehicle collection and return at any point within operational areas, contrasts with structured station-based systems requiring vehicle return at predefined stations. Peer-to-peer car-sharing represents particular innovation in this domain, introducing collaborative economy elements enabling private vehicle sharing between users.[130]

Shared micro mobility emerges as the market's most dynamic, rapidly evolving segment. This sector encompasses various light vehicles, from electric scooters to bicycles, both traditional and electric, through to electric mopeds. These services' distinctive characteristic resides in effective response capability to urban mobility requirements over short distances, offering agile solutions for "last mile" transport and contributing to urban center congestion reduction.[131]

Market Drivers - Regulatory framework

European Union:

European Green Deal:

- Establishes a vision for decarbonizing the transport sector with shared mobility as a central element.
- Extends beyond emission reductions to define an integrated sustainability pathway for urban mobility.

[128] Enoch, M., & Potter, S. (2023). MaaS (Mobility as a Service) market futures explored. Transport Policy, 134, 31–40.

[129] Heineke, K., Kloss, B., Möller, T., & Wiemuth, C. (2021). Shared mobility: Where it stands and where it's headed. McKinsey & Company.

[130] McKinsey & Company. (2023). Spotlight on 2023: The trends transforming mobility. McKinsey Center for Future Mobility.

[131] McKinsey & Company. (2023). Start me up: Where mobility investments are going. McKinsey Center for Future Mobility.

- **Fit for 55 Package:**
  - Introduces transport-specific targets to encourage innovative solutions.
  - Includes the Clean Vehicle Directive, which mandates:
    - Rigorous low-emission standards for vehicles.
    - Specific requirements for public fleet transitions to sustainable mobility options.
- **Localized Urban Regulations:**
  - Directives are implemented at the local level, balancing:
    - Public space management.
    - Integration with existing transit systems.
    - User safety alongside environmental sustainability.
  - Emphasizes flexibility to address unique urban needs while maintaining regulatory coherence.

Key technologies

- **Internet of Things (IoT):**
  - Forms the backbone of MaaS infrastructure by connecting devices for real-time vehicle monitoring and fleet management.
  - Enables functionalities such as predictive maintenance, dynamic resource allocation, and optimized fleet utilization.[132]
- **Artificial Intelligence (AI):**
  - Analyzes data generated by IoT devices to deliver actionable insights.
  - Supports:
    - Accurate demand forecasting.
    - Route optimization
    - Dynamic pricing strategies to balance user needs and operational efficiency.
  - Machine learning algorithms enhance service personalization and continuous improvement of system performance.[133]
- **Systemic Integration:**
  - Combines digital tools into a resilient MaaS ecosystem, fostering seamless multimodal travel.
  - Enhances user satisfaction by offering adaptable and predictive services tailored to diverse urban demands.

[132] Enoch, M., & Potter, S. (2023). Ibidem.

[133] Servou, E., Behrendt, F., & Horst, M. (2023). Data, AI and governance in MaaS – Leading to sustainable mobility? Transportation Research Interdisciplinary Perspectives, 19, 100806.

Market Potential and Investement opportunities

The shared mobility market achieved significant global dimension, reaching 130-140 billion dollars in 2019. Within this market, e-hailing emerges as the dominant segment, representing over 90% of total value. This predominance reflects not only greater technological and operational maturity but also enhanced user acceptance and business model scalability. Market evolution between 2016 and 2019 demonstrates particularly significant micro mobility sector growth, registering an exponential increase from less than one million journeys in 2017 to over 160 million in 2019. This trajectory evidences fundamental consumer preference transformation and urban movement modality evolution.[134] Since 2010, the shared mobility sector attracted total investments exceeding 100 billion dollars, with particularly significant e-hailing segment distribution (95 billion dollars). Investment origin reveals illuminating market perception: 72% capital derives from venture capital and private equity, 21% from technology companies, whereas only 4% from traditional automotive companies.[135]

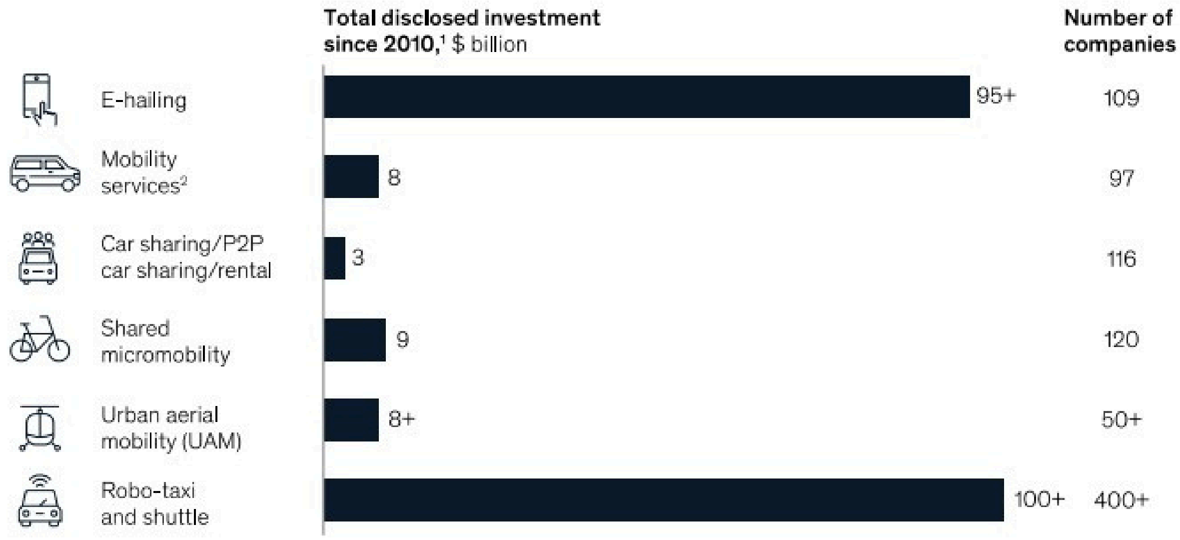


Fig. 39 - Investments in shared-mobility companies, 2010-2021 Source: McKinsey, 2021

In the micromobility segment, investments reached 9 billion dollars, significantly exceeding traditional car-sharing (3 billion dollars). Urban aerial mobility attracted over 8 billion dollars through June 2021, demonstrating strong emerging technology sector interest.[136]
The Italian market provides concrete growth examples: by 2022 end, the sharing vehicle fleet reached 113,000 units, representing a 27% increase from 2021 and more than doubling compared to 2019. Micro Mobility represents 95% of the total fleet, with scooters (44%) and bicycles (43%) as protagonists. In car-sharing, 44.4% fleet comprises full-electric vehicles, followed by petrol (31.6%) and hybrid (21.6%) vehicles.[137]

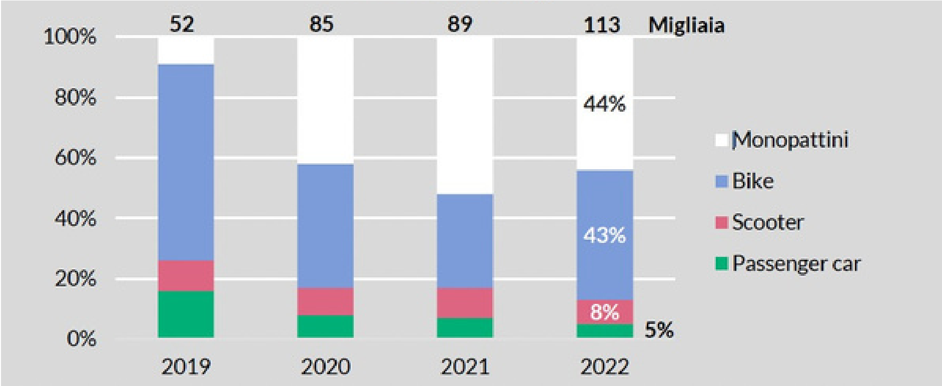
[134] Holland-Letz, D., Kloss, B., Kässer, M., & Müller, T. (2019). Start me up: Where mobility investments are going. McKinsey & Company.

[135] Heineke, K., Kloss, B., Möller, T., & Wiemuth, C. (2021). Shared mobility: Where it stands and where it's going. McKinsey Center for Future Mobility

[136] Heineke, K., Kloss, B., Möller, T., & Wiemuth, C. (2021). Ibidem.

[137] Osservatorio Smart Mobility. (2024). Smart Mobility Report 2024: Da “follower” a “leader”? Come abilitare per l'Italia un cambio di passo sulla decarbonizzazione dei trasporti. Energy & Strategy.

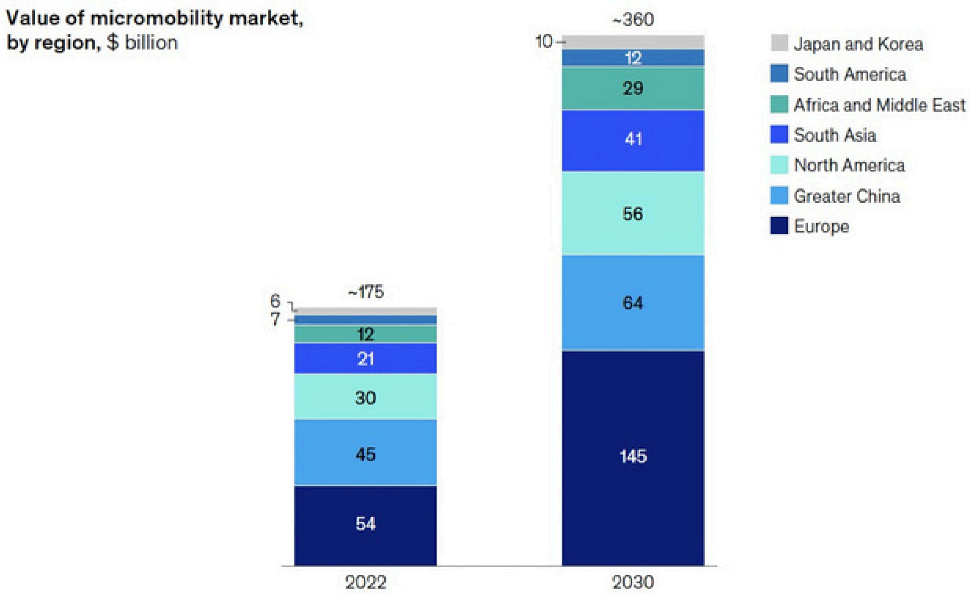
Fig.40 - Shared vehicle fleets Source: Osservatorio Smart Mobility, 2024.



Market projections indicate substantial growth forthcoming years. Global micro mobility sector should reach 300-500 billion dollars by 2030, tripling current e-hailing market dimensions. According to the McKinsey ACES Consumer Survey, nearly one-third of respondents anticipate increased micromobility utilization, while approximately half consider private vehicle replacement with alternative transport modes.[138]

Global micro mobility market, valued approximately 175 billion dollars in 2022, should reach 360 billion dollars by 2030, with Europe representing the largest value share. This growth shall primarily derive from e-bike sales and sharing service expansion.[139]

Fig. 41 - Value of micro mobility market, by region, $ billion



Source: McKinsey Center for Future Mobility, 2024

[138] Holland-Letz, D., Kloss, B., Kässer, M., & Müller, T. (2019). Ibidem.

[139] Heineke, K., Kampshoff, P., & Möller, T. (2024). Spotlight on 2023: The trends transforming mobility. McKinsey Center for Future Mobility.

In the autonomous vehicle segment, forecasts indicate large-scale L4 capability adoption around 2026, initiating with autonomous parking and highway driving applications. More complex applications, including urban environment driving, require extended timelines for large-scale implementation.[140] Electric mobility and sharing service convergence creates new market opportunities. In 2022, 44.4% Italian car-sharing fleets comprised electric vehicles, a percentage destined for significant increase in forthcoming years through government incentives and urban sustainability policies.[141] MaaS platforms evolve incorporating increasing service numbers: from traditional public transport to new micro mobility services, through urban aerial mobility services. This trend receives support through increasingly favorable European regulatory framework, demonstrated through Green Deal initiatives and Fit for 55 package. Market prospects receive further reinforcement through emerging hybrid business models combining sharing economy elements with structured services. Success of platforms integrating peer-to-peer car-sharing with professional fleet management services demonstrates innovative approach potential, attracting investor interest through resource utilization optimization capability and accelerated scalability versus traditional models. In conclusion, market analysis and investment opportunity examination reveals sectors undergoing profound transformation, characterized by solid investment foundation and significant growth projections.

Twin Transition Potential

Mobility as a Service (MaaS) represents a paradigm shift in urban transportation, integrating digital and green innovations to deliver seamless, sustainable, and user-centric mobility solutions.

Environmental Integration:

- **Reduction of Emissions:**
  MaaS encourages modal shifts from private car usage to shared, public, or active transport modes, leading to reduced greenhouse gas (GHG) emissions. The adoption of shared micro mobility solutions (e.g., electric bikes and scooters) further supports emission reductions in urban areas.
- **Energy Efficiency:**
  integrated MaaS platforms optimize energy consumption by ensuring seamless connections between transport modes, minimizing the reliance on high-emission options.
- **Sustainable Urban Planning:**
  MaaS aligns with urban strategies such as Sustainable Urban Mobility Plans (SUMPs), facilitating the efficient design of transport corridors and reducing the environmental footprint of urban commuting .

Digital Integration:

- **IoT-Enabled Systems:**
  MaaS heavily relies on Internet of Things (IoT) technology for real-time vehicle tracking, predictive maintenance, and adaptive route planning. This enhances service reliability and operational efficiency.
- **Data-Driven Optimization:**
  advanced analytics and artificial intelligence (AI) provide insights into travel patterns, enabling demand-responsive services and reducing idle capacity.
- **Seamless User Experience:**
  through single-platform applications, MaaS offers intermodal journey planning, integrated ticketing, and dynamic pricing, which streamline the consumer experience while optimizing system-wide resource use.

[140] Heineke, K., Kampshoff, P., & Möller, T. (2024). Ivi.

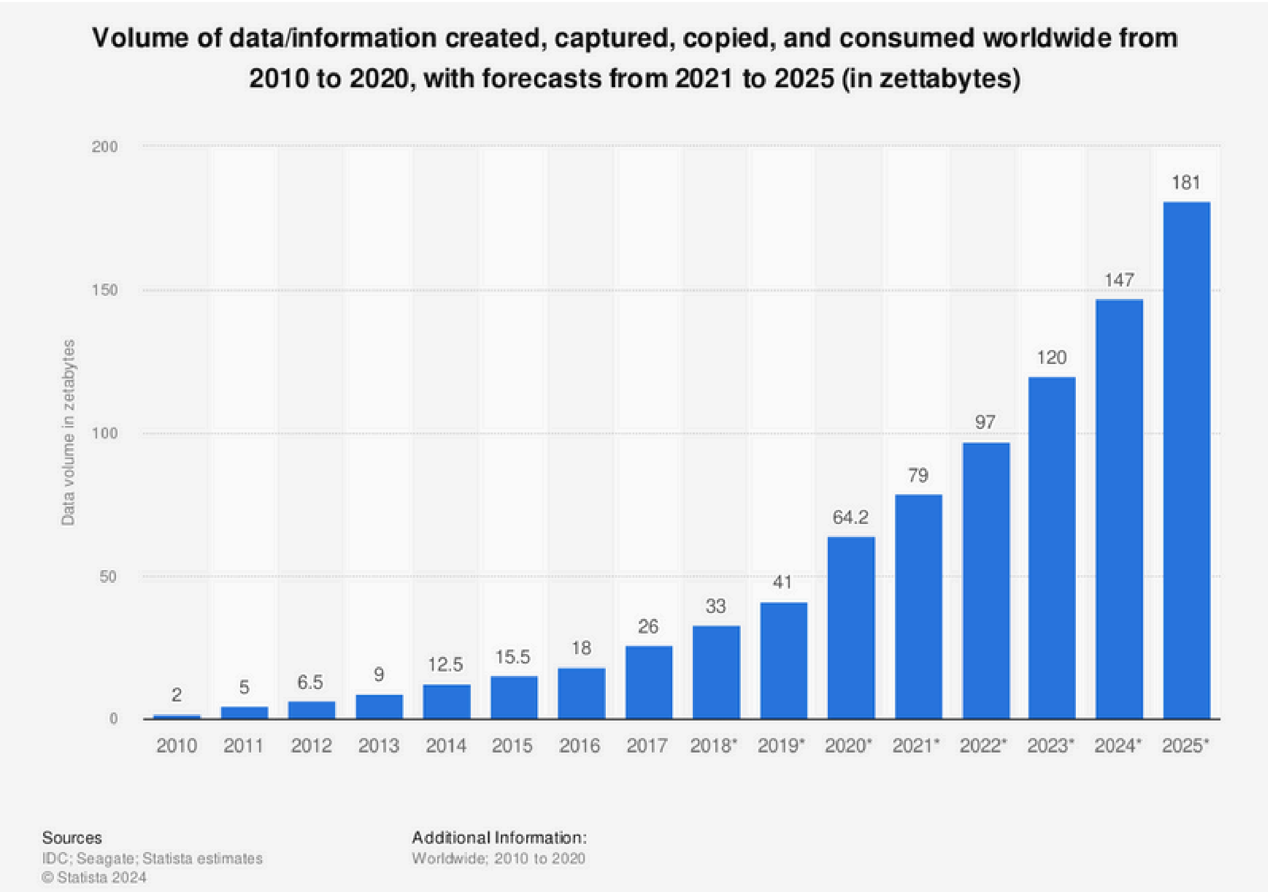
[141] Osservatorio Smart Mobility. (2024). Ibidem.

Digital Transition

Digital Transition

Higher computing power

Higher computing power represents a cornerstone of the digital economy, with demand driven by the increasing digitization of industries, the Internet of Things (IoT), artificial intelligence (AI), and big data analytics. Investment in edge and cloud data centers offers robust opportunities, enabling low-latency applications, scalable solutions, and support for energy-efficient infrastructure. Global data generation is expected to reach 181 zettabytes by 2025, emphasizing the need for advanced data processing and storage solutions.[142]

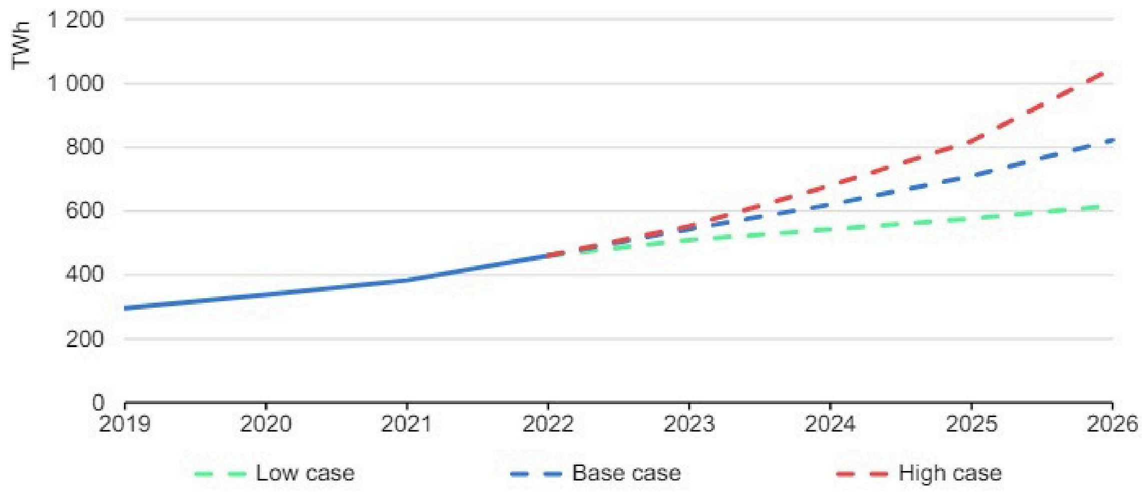


Edge and cloud data centers address this by providing localized, efficient, and secure computing power. Infrastructure investments in Edge Data Centers and Cloud Data Centers present significant opportunities to support the growing demand for decentralized computing while ensuring efficiency and scalability. However, Electricity demand from data centres, cryptocurrencies and AI could reach as much as 1,000 Terawatt Hours (TWh) in 2026, compared to 460TWh today, the IEA projects.

Communication networks that facilitate the transfer of data from the point of generation to the point of processing are also contributing to the DC energy load. The IEA's latest statistics show that DCs and communication networks account for 2-3% of global electricity consumption and 1% of GHG emissions. But this is set to rise markedly, even if expansion stays at the lowest estimate.

[142] https://www.weforum.org/stories/2024/05/data-growth-drives-ict-energy-innovation/

Global electricity demand from data centres, AI, and cryptocurrencies, 2019-2026



Notes: Includes traditional data centres, dedicated AI data centres, and cryptocurrency consumption; excludes demand from data transmission networks. The base case scenario has been used in the overall forecast in this report. Low and high case scenarios reflect the uncertainties in the pace of deployment and efficiency gains amid future technological developments.

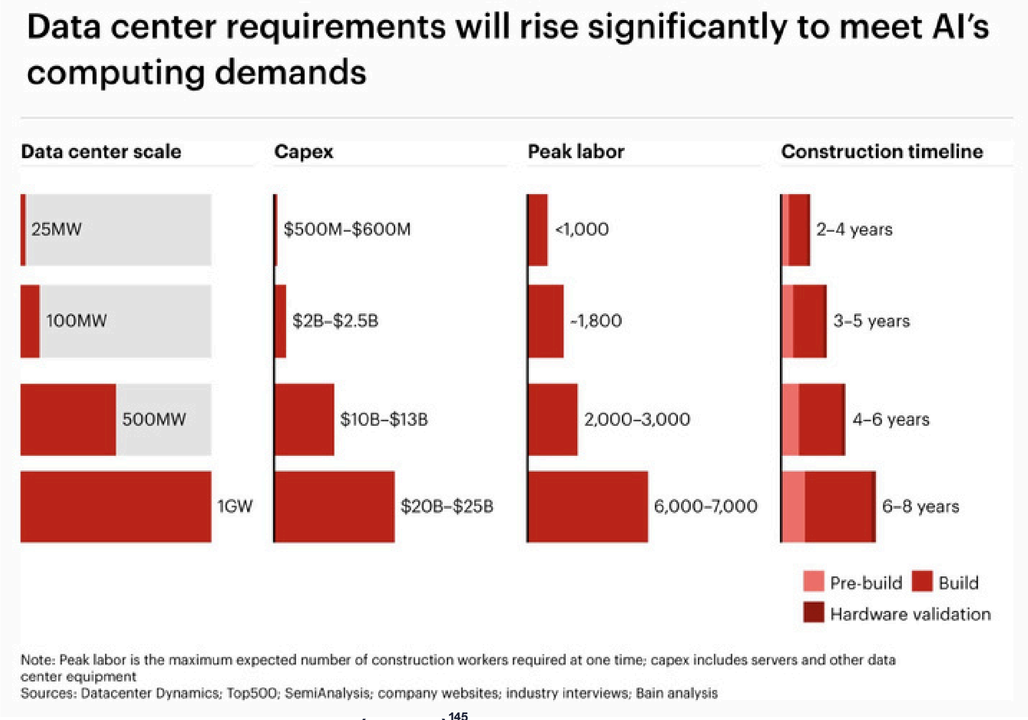
Sources: Joule (2023), de Vries, The growing energy footprint of AI; CCRI Indices (carbon-ratings.com); The Guardian, Use of AI to reduce data centre energy use; Motors in data centres; The Royal Society, The future of computing beyond Moore's Law; Ireland Central Statistics Office, Data Centres electricity consumption 2022; and Danish Energy Agency, Denmark's energy and climate outlook 2018.

Market Drivers

The market for computing power is driven by the proliferation of IoT devices, AI applications, and the growth of latency-sensitive services. IoT adoption is expected to exceed 25 billion connected devices by 2030, generating enormous data that requires efficient processing and management.[143] Technologies such as autonomous vehicles, augmented reality, and industrial IoT are spurring demand for edge computing to minimize delays and optimize performance. AI applications, forecasted to grow at a 36% CAGR by 2030 (McKinsey, 2024), demand high-performance computing power, increasingly provided by cloud and edge solutions.[144] With global data traffic doubling every three years, enterprises require scalable storage and processing capabilities.
By 2030, 70% of data center demand will cater to advanced-AI workloads, with an annual growth rate of 33% between 2023 and 2030 (McKinsey, 2024).
Currently, hyperscale cloud service providers operate large-scale data centers with capacities ranging from 50 megawatts to over 200 megawatts. As AI continues to drive demand for higher computational power, these companies are expected to consider facilities exceeding 1 gigawatt. This shift will have significant repercussions for the ecosystems that support these operations, including infrastructure design, power generation, and cooling technologies, while also impacting market valuations. The need to accommodate the computing, electrical, and cooling demands of gigawatt-scale data centers will likely shape the architectural trends of smaller facilities as well.

143 https://www.statista.com/statistics/1194688/iot-connected-devices-communications-technology/

144 https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/ai-power -expanding-data-center-capacity-to-meet-growing-demand



Source: Bain & Company(2024)[145]

Moreover, as businesses increasingly shift workloads to cloud environments, the need for expansive, high-capacity cloud data centers continues to rise. Sustainability is another key driver, with enterprises prioritizing data centers integrating renewable energy and energy-efficient cooling systems.The deployment of 5G technology is set to transform the global connectivity landscape, with projections indicating that by 2030, 5G networks will cover 60% of the world's population (Ericsson Mobility Report, 2024).[146] This advancement is driving an unprecedented demand for decentralized, low-latency computing, a requirement effectively addressed by edge data centers. These facilities, positioned closer to end-users, are uniquely equipped to handle the real-time processing needs of 5G-enabled applications, such as autonomous vehicles and augmented reality systems, by reducing latency and enhancing computational efficiency. Simultaneously, smart city initiatives are emerging as a major driver of infrastructure investment. By 2030, spending on smart infrastructure is anticipated to surpass $1.5 trillion. (BNEF, 2024),[147] fueling the need for computing power to manage applications like smartgrids, real-time traffic monitoring, and urban planning systems. Edge data centers play a pivotal role in supporting these projects, providing the local computational resources required for efficient data processing and actionable insights. Sustainability imperatives are further shaping the evolution of computing infrastructure. The ICT sector faces mounting pressure to decarbonize, with energy-efficient data centers becoming critical to meeting global environmental targets. Innovations such as advanced cooling systems and the integration of renewable energy sources are redefining the operational footprint of data centers, making them key enablers of sustainability in the digital age. Moreover, distributed edge computing reduces energy losses associated with data transmission over long distances, aligning seamlessly with global carbon neutrality goals. Governments and industries alike are also focusing on data sovereignty and regulatory compliance, further bolstering the demand for localized data center solutions.

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[145] https://www.bain.com/insights/ai-changes-big-and-small-computing-tech-report-2024/

[146] https://www.ericsson.com/en/reports-and-papers/mobility-report/articles/challenging-telecom-market-5g_gad_source=1&gclid=CjwKCAiAjeW6BhBAEiwAdKltMi2li0FGK52PpuXSgDeYHmbXMlvRDTKUY530S2pB4Qxs7E7cqzeQ5hoC-BcQAvD_BwE&gclsrc=aw.ds

[147] https://www.forbes.com/sites/sarwantsingh/2014/06/19/smart-cities-a-1-5-trillion-market-opportunity/

Expert Insight:
Generative AI and Skilling: The Next Frontier of DigitalTransformation

**Developed with insights from Gerardo Volpone,
Tech Strategist and Sustainability Community Italy lead at Microsoft**

Generative AI is revolutioning key sectors, with unprecedented investment in digital infrastructure. Microsoft, for example, has announced USD 80 billion globally and USD 4 billion in Italy alone to strengthen its AI infrastructure. However, an often neglected issue is that of skills: the need to train professionals with advanced skills to manage the digital transition. Generative AI requires not only engineers and data scientists, but also experts in ethics, governance and implementation strategies. Without adequate investment in skills, the large-scale adoption of AI could be slowed, leaving key areas of digital transformation untapped. One area that could benefit greatly from generative AI is robotics.

The expectation is that there will also be a ‘ChatGPT moment’; in this area, making robotics more accessible, intuitive and widespread. If generative AI has simplified human-machine interaction, it is plausible that advanced robotics and AI will converge in the coming years, bringing automated solutions to more and more areas.

Regulatory Framework

European Framework:

- **Digital Decade Policy Program (2021-2030):**
  Aims to ensure 75% of EU enterprises adopt advanced digital technologies, including cloud computing and IoT solutions, by 2030. Sets also ambitious targets for edge computing infrastructure to ensure 100% gigabit connectivity for households and widespread 5G coverage by 2030.
- **European Data Strategy (2020):**
  Encourages the development of data centers with enhanced energy efficiency and data sovereignty.
- **Green Deal:**
  Imposes energy efficiency and carbon-neutrality targets on data centers, pushing innovation in edge and cloud computing.

Italy:

- **National Recovery and Resilience Plan (PNRR):**
  Allocates €6.7 billion to digital transformation, boosting investments in fiber, 5G, and data centers.
- **Smart Grid and Connectivity Policies:**
  Support infrastructure expansion, with edge data centers critical for localized energy management and smart grid integration.
- **National Broadband Strategy:**
  Supports investments in fiber networks and 5G, providing a foundation for edge data center deployment.
- **Tax Incentives for Digital Transformation:**
  Encourages businesses to adopt cloud computing and AI technologies, indirectly boosting demand for data center infrastructure.
- **Energy Efficiency Standards:**
  Italian regulations align with EU guidelines, requiring data centers to implement energy-efficient designs and renewable energy integration.

Key technologies

Edge Data Centers:

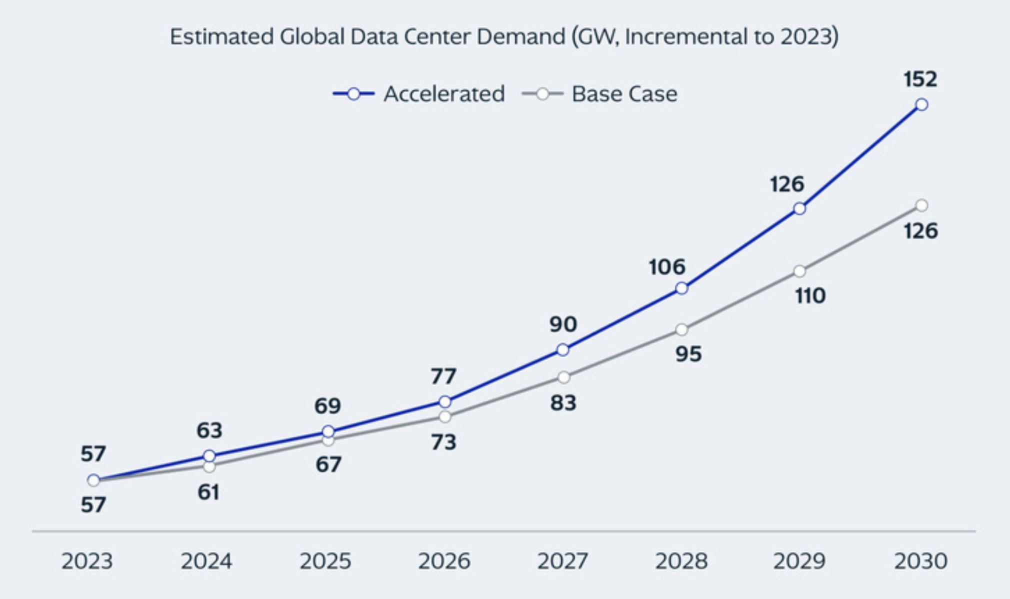
- Smaller, distributed facilities that bring data storage and processing closer to end-users, essential for low-latency applications.
  - **Edge Compute:** Medium-sized centers (1–20MW) for high-performance processing at the network edge.
  - **Connected Edge Data Centers:** Small facilities (200kW–1MW) for modular and flexible deployment.

Cloud Data Centers:

- Large-scale facilities (20MW+) providing centralized computing resources for diverse workloads, essential for enterprise-level cloud services.

Market Potential and Investement opportunities

The edge computing market is forecasted to grow substantially, driven by urbanization, IoT expansion, and the deployment of 5G networks. By 2030, the market size for edge solutions is expected to exceed $60 billion, while cloud data center investments are projected to reach $220 billion by 2025.[148] Europe is witnessing significant adoption, fueled by sustainability initiatives and urban smart city projects, while Asia-Pacific leads in edge deployments due to rapid digitalization and urban growth. Strategic investment opportunities include the development of sustainable cloud data centers, leveraging advanced cooling technologies, and renewable energy. The deployment of edge data centers aligned with 5G infrastructure presents a unique opportunity to cater to the growing needs of latency-sensitive industries. These investments not only address immediate market demands but also position stakeholders to capitalize on long-term growth trends in the digital economy.



Source: KKR (2024)[149]

[148] https://www.gminsights.com/pressrelease/edge-computing-market

[149] https://www.kkr.com/insights/hubs-digital-infrastructure

Supported by these trends, global data center demand is expected to grow at a compound annual rate of 12%-15% between now and 2030, while construction spending is expected to sum up to more than $303 billion between now and 2030, according to Synergy Research Group. While there are several different types of data centers, hyperscale centers have been the largest growth area to date and are expected to dominate growth for the coming years. These are very large facilities that can achieve economies of scale and superior performance because of their size. Hyperscale providers have more than quadrupled capital expenditures between 2015 and 2022 to $122 billion3 and are increasingly turning to trusted third-party infrastructure providers to meet their growth needs.

Edge Data Centers

- **Urban Expansion:**
  Deploying edge data centers in densely populated areas addresses low-latency requirements for smart city applications.
- **Sector-Specific Growth:**
  Healthcare, automotive, and retail sectors are driving demand for localized computing. For example, autonomous vehicle data traffic is projected to reach 40 terabytes per hour per vehicle by 2030 (Intel, 2023).
- **Cross-Industry Collaboration:**
  Partnerships between telecom operators, cloud providers, and infrastructure funds enhance deployment capabilities.

Cloud Data Centers

- **Enterprise Migration:**
  Cloud services adoption is expected to grow by 18% annually (Gartner, 2024), presenting opportunities for data center expansions.
- **Energy Efficiency Retrofits:**
  Upgrading legacy data centers to meet sustainability and performance standards offers a significant investment avenue.
- **AI Workloads:**
  Data centers optimized for AI and machine learning are crucial as AI adoption scales across industries.

The global race to build AI-ready data centers is creating unprecedented opportunities for investors:

- **Addressing Supply Deficits:**
  To meet the projected demand of 219 GW by 2030, the industry must double its capacity within the next decade. This gap highlights significant opportunities for investment in both edge and cloud infrastructure.
- **Strategic Partnerships:**
  Hyperscale cloud providers are increasingly partnering with colocation providers to address capacity constraints. Companies offering build-to-suit services are particularly well-positioned to attract investment.
- **Geographic Hotspots:**
  Remote areas with abundant energy, such as Indiana and Wyoming in the United States, are becoming hubs for AI model training data centers, while urban centers require edge facilities to support latency-sensitive applications.

- **Sustainability as a Value Driver:**
  Facilities powered by renewables or equipped with advanced cooling technologies are gaining investor preference, aligning with global decarbonization goals.

Twin Transition Potential

Higher computing power infrastructure, particularly edge and cloud data centers, provide critical support for the twin transitions of sustainability and digital transformation, addressing the surging demand for scalable, low-latency, and energy-efficient data solutions. As industries embrace IoT, AI, and 5G technologies, this sector offers compelling opportunities for long-term value creation.

Green Transition Potential

- **Decarbonization Impact:**
  Energy-efficient data centers directly reduce the ICT sector's carbon footprint. The EU's carbon-neutral target by 2050 relies on innovations in data center sustainability.
- **Distributed Energy Savings:**
  Edge data centers reduce energy losses associated with data transmission to centralized locations.

Digital Transition Potential

- **IoT and Smart Cities:**
  Edge and cloud data centers underpin the digital backbone of urban transformation, supporting applications from traffic management to energy optimization.
- **IAI and Advanced Analytics:**
  Investments in higher computing power accelerate AI and data-driven decision-making across sectors.

Expert Insight:

Data Centres: The Energy Dilemma of Digital Expansion

Developed with insights from Alberto Dalla Riva, Senior Lead Business Developer at Ørsted, and Gerardo Volpone, Tech Strategist and Sustainability Community Italy lead at Microsoft

In recent years, data centres have become a strategic infrastructure for global digitisation, but their expansion is creating critical energy and environmental challenges. Data centres in the US have reached total saturation, with energy demand outstripping available capacity. In Europe, some countries are even restricting the construction of new data centres to prevent their energy consumption from absorbing too much renewable energy, undermining decarbonisation targets. A case in point is Ireland, where data centres already consume between 20% and 30% of the country's energy, a percentage that is set to increase with the advent of artificial intelligence. In response to the growing demand for energy, technology companies are investing billions in developing new, stable sources of green energy, including:

- Reviving old nuclear plants to power data centres
- Safer and more scalable modular nuclear reactors (SMRs)
- Advanced geothermal (novel geothermal) to provide consistent renewable energy.

Efforts are also underway to develop more sustainable data centres, with a focus on innovative solutions that can reduce their environmental impact. The acquisition and development of nuclear power technologies indicate how the sector is exploring reliable energy alternatives to support digital infrastructure expansion while maintaining sustainability goals.

Mobility as a Service (MaaS) and Sharing Models

The wireless transmission market is expanding rapidly, driven by the proliferation of mobile devices and the increasing demand for high-speed Internet connectivity. Wireless infrastructure serves as a critical enabler for network services such as broadband, emergency communications, broadcasting and the Internet of Things (IoT). This development not only responds to consumer demands, but also creates a favourable environment for strategic investments in key areas such as telecommunications infrastructure, high-density urban networks and smart devices.

Market Drivers

The transition to 5G and network densification is essential to meet the growing demand for data transmission capacity and speed. The deployment of fifth-generation networks is reshaping the mobile ecosystem by fostering the convergence of network and cloud infrastructures, supporting a wide range of applications from smart cities to industrial automation. However, the deployment of 5G networks requires significant infrastructure upgrades, with targeted investments in telecom tower infrastructure and small cell networks to improve coverage and performance, particularly in urban environments.[150]

In parallel, the introduction of IoT technologies and smart meters is revolutionising various sectors, including energy, transport and manufacturing. Smart meters facilitate energy management and real-time consumption monitoring, while enabling demand-side flexibility programmes and greater integration of renewable energy sources.[151]

Across Europe, initiatives such as the Clean Energy Package and national smart meter roll-out programmes are accelerating the digitalisation of energy infrastructures, bringing direct benefits to both consumers and network operators.[152]

Another key area of interest is Wireless Power Transmission (WPT), which uses electromagnetic fields to transmit energy without wires. This rapidly developing technology has applications in sectors such as automotive, smart homes, healthcare and aerospace. WPT offers innovative solutions such as dynamic charging for electric vehicles, power transfer to remote areas and charging of medical biosensors.[153]

Europe is a leader in the adoption of these technologies, supported by an advanced regulatory framework and policies that promote digital and green transitions. However, challenges remain in terms of scalability, data security and high implementation costs, which require innovative solutions and cooperation between public and private stakeholders.[154]

[150] Small Cell Forum. (2024). SCF Market Forecast Report, July 2024.

[151] Ernst & Young LLP. (2024). The economic contribution of the European wireless infrastructure sector: A report for the European Wireless Infrastructure Association.

[152] Vitiello, S., Andreadou, N., Ardelean, M., & Fulli, G. (2022). Smart Metering Roll-Out in Europe: Where Do We Stand? Cost Benefit Analyses in the Clean Energy Package and Research Trends in the Green Deal. Energies, 15(2340).

[153] Strategic Management Partners. (2024). Wireless Power Transmission: Ambiti di applicazione, tecnologie emergenti e previsioni di mercato per la trasmissione wireless di energia.

[154] World Economic Forum. EU high-speed internet and the digital divide. Retrieved September 2022, from https://www.weforum.org/stories/2022/09/eu-high-speed-internet-digital-divide/.

Regulatory framework

European regulations

- **Decision No 676/2002/EC**
  Adopted in 2002, this decision ensures optimal management of radio frequencies for wireless transmissions.
- **Directive 2009/72/EC and Directive 2009/73/EC (Third Energy Package)**
  Introduced in 2009, these directives introduced the concept of smart metering for electricity and gas and set requirements for infrastructure deployment.
- **Directive 2012/27/EU on Energy Efficiency**
  Adopted in 2012, this directive sets minimum standards for smart metering systems, including data protection and interoperability.
- **Commission Recommendation 2012/148/EU**
  Published in 2012, this provides guidelines for the design of smart metering and IoT infrastructures, with an emphasis on security and data protection.
- **Directive 2014/32/EU (Measuring Instruments Directive)**
  Introduced in 2014, it regulates standards for measuring instruments, including smart meters, to ensure conformity and interoperability.
- **Commission Recommendation 2014/724/EU**
  Published in 2014, this Recommendation introduced the Data Protection Impact Assessment (DPIA) for smart metering systems to protect consumer privacy.
- **Regulation (EU) 2016/679 (General Data Protection Regulation, GDPR)**
  Adopted in 2016, this regulation establishes strict data protection rules that are essential for IoT applications and smart city projects.
- **European Electronic Communications Code (EECC, Directive (EU) 2018/1972)**
  Introduced in 2018, it regulates access to telecommunications infrastructure and promotes the development of new networks, including 5G.
- **Clean Energy for All Europeans Package (2019)**
  Published in 2019, it promotes digitalisation and energy efficiency in line with Europe's green transition goals.
- **Commission Recommendation 2020/1307**
  Published in 2020, this recommendation simplifies the authorisation procedures for the installation of small cells in 5G networks.
- **Rolling Plan for ICT Standardisation (2021-2023)**
  This document outlines standardisation priorities for Smart Grids, Smart Metering and IoT to support interoperability and security across the EU.

Italian regulations

- **Legislative Decree 102/2014**

  This decree transposes Directive 2012/27/EU into Italian law, focusing on smart metering for electricity, gas, and water utilities.

- **National Integrated Energy and Climate Plan (PNIEC)**

  Published in 2019, it promotes the adoption of smart technologies to improve energy efficiency and reduce consumption.

- **Decree 76/2020**

  Introduced in 2020, it includes measures to streamline the installation of telecommunications infrastructure, such as small cells and 5G networks.

- **National Recovery and Resilience Plan (PNRR) (2021)**

  This plan includes significant investment in digitalisation, telecommunications infrastructure, 5G network development and smart city solutions.

- **PON Metropolitan Cities**

  Active since 2020, this project funds sustainable and digital urban development, including IoT and smart city initiatives.

Key technologies

Wireless Power Transfer (WPT)

- WPT systems are based on a transmitter, connected to a power source, which generates an electromagnetic field through a coil. This field transfers energy to a nearby receiver via magnetic coupling.[155] Key technologies include:

  - **Magnetic induction:** uses coils to create a variable magnetic field for energy transfer, effective over short distances (a few centimetres).
  - **Magnetic resonance:** uses resonant coils to achieve efficient energy transfer over longer distances (up to several metres).
  - **Capacitive energy transfer:** uses alternating electric fields to transfer energy between closely spaced plates, providing an alternative to magnetic-based systems.

  For long-range applications:

  - **Microwave transmission:** uses high-frequency electromagnetic waves to transmit energy over distances of metres to kilometres, suitable for industrial and urban infrastructure.
  - **Infrared transmission:** transmits energy as light radiation through infrared diodes. This method is effective over short distances and requires a direct line of sight.

  These technologies are used in a variety of sectors, including healthcare (for continuous power supply to medical devices), automotive (wireless charging of electric vehicles) and smart urban infrastructure.[156]

[155] Strategic Management Partners. (2024). Wireless Power Transmission: Ambiti di applicazione, tecnologie emergenti e previsioni di mercato per la trasmissione wireless di energia.

[156] European Commission. (2024). Study on wireless charging technologies: Final report. Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs. Luxembourg: Publications Office of the European Union.

Wireless Network Infrastructure

- Wireless infrastructure, including telecom towers and small cells, supports the growing demand for mobile and fixed wireless access.[157] Notable advancements include:

  - **Small Area Wireless Access Points (SAWAPs):** predominantly support 4G networks, with increasing 5G deployments, particularly in indoor environments.
  - **5G expansion:** enabling ultra-fast connectivity and laying the groundwork for future 6G deployments.

6G and Cloud-Native Networks

- The next generation of wireless networks, 6G, is expected to be cloud-native and AI-integrated. Unlike its predecessors, 6G will focus on software-defined architectures to introduce new capabilities without extensive infrastructure upgrades. Its defining features include:

  - **Small cell architectures:** likely to lead early 6G deployments, offering high-performance connectivity with lower deployment risks compared to macro networks.
  - **Semiconductor innovations:** cutting-edge hardware developments will drive the capabilities of future networks and devices.

  Although still in the early stages of development, 6G is expected to enable revolutionary use cases in urban automation, large-scale industrial applications and the sensor-based Internet of Things (IoT).[158]

Smart metering and IoT integration

- Smart meters and IoT-enabled devices are central to the digitalisation of energy networks.[159] Their key features include:

  - **Real-Time monitoring:** tracks energy consumption and grid performance, enabling rapid outage management.
  - **Integration with Energy Management Systems:** links to home energy management systems (HEMS) and building energy management systems (BEMS) to visualise energy use and optimise efficiency.
  - **Consumer empowerment:** facilitates active participation in demand response programmes, allowing consumers to adjust consumption in response to market signals.

  Despite challenges such as installation costs and data security concerns, smart metering plays a critical role in achieving energy efficiency and grid modernisation.[160]

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[157] Ernst & Young LLP. (2024). The economic contribution of the European wireless infrastructure sector: A report for the European Wireless Infrastructure Association.

[158] Small Cell Forum. (2024). SCF Market Forecast Report.

[159] Tounquet, F., & Alaton, C. (2020). Benchmarking smart metering deployment in the EU-28: Final report. Directorate-General for Energy, European Commission. Luxembourg: Publications Office of the European Union.

[160] De Paola, A., Andreadou, N., & Kotsakis, E. (2023). Clean Energy Technology Observatory: Smart Grids in the European Union - 2023 Status Report on Technology Development, Trends, Value Chains, and Markets. Publications Office of the European Union.

Expert Insight:
Edge Computing and urban challenges

Developed with insights from Alessandra Poggiani, General Director of Cineca and Gerardo Volpone, Tech Strategist and Sustainability Community Italy lead at Microsoft

Edge computing is gaining traction as an important complement to public cloud systems, particularly for applications requiring low latency, improved privacy, and efficient workload management.

Advances such as small language models capable of running on lightweight machines and new processors managing up to 200 billion parameters locally are driving innovation in this space. These developments position edge computing as a strategic solution for real-time processing in sectors like industrial automation, IoT, and smart cities.

However, experts caution against expecting widespread adoption in the short term, especially in historical urban centers with infrastructure limitations. These environments face significant challenges in deploying edge systems due to the complexity of retrofitting legacy networks. Instead, the focus remains on High-Performance Computing (HPC) as an enabler for critical AI applications, which require immediate scalability and computational power.

Looking ahead, edge computing's role will likely expand alongside cloud systems, providing localized solutions that align with specific use cases. Urban infrastructure upgrades and advancements in compact, high-performance hardware will be essential to unlocking the full potential of edge computing in diverse environments.

Market Development and Investment Opportunities

The wireless transmission and smart metering markets are growing at different rates in different regions. Europe has made significant progress in the adoption of smart meters, with leading countries such as Italy, Spain and Sweden achieving close to 100% penetration. In contrast, markets such as Germany and Belgium face slower adoption due to regulatory and economic constraints. Asia-Pacific is emerging as the fastest-growing region for wireless charging adoption, driven by the proliferation of smart home devices and rapid urbanisation. Meanwhile, North America continues to dominate IoT adoption, driven by strong investment from major mobile operators, who will collectively invest $54 billion annually from 2020.[161]

Wireless Power Transfer (WPT)

The global Wireless Power Transfer (WPT) market, currently valued at $9.4 billion, is forecast to exceed $32 billion by 2029, reflecting a compound annual growth rate driven by advances in inductive and resonant charging technologies.[162] Figure 41 highlights the potential revenue distribution across different application areas by 2029. The 'smart home' segment will generate the highest revenue at $18 billion, reflecting the rapid adoption of wireless charging solutions for consumer electronics, IoT devices and home automation systems. The proliferation of Qi standards and the integration of wireless charging into smart furniture and appliances are key drivers for this sector. Industrial applications are expected to generate revenues of $5 billion. This reflects the increasing use of wireless power systems in manufacturing environments to improve operational efficiency, particularly through wirelessly powered sensors, robotics and automation technologies. The automotive sector is expected to contribute $4 billion, primarily through the adoption of wireless in-car charging for consumer electronics and the development of dynamic wireless charging solutions for electric vehicles. The medical sector, with an expected revenue of $3 billion, highlights opportunities in wirelessly powered medical devices and wearables. These technologies provide uninterrupted power for critical applications such as implants and diagnostic tools, ensuring reliability and safety.

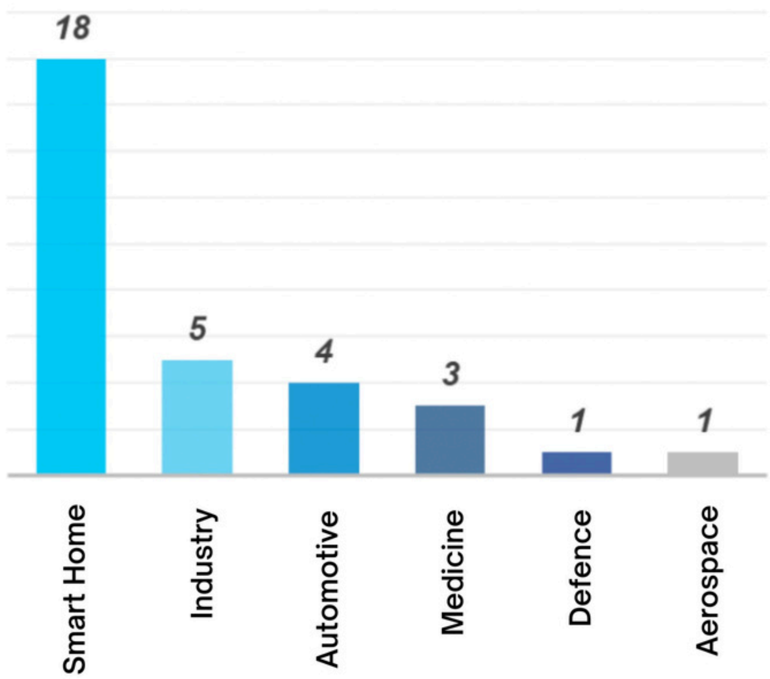

Fig. 42. Revenues by area of application 2029 (bn $)

Source: Strategic Management Partners, 2024

[161] Joint Research Centre (JRC). (2023). Clean Energy Technology Observatory: Smart Grids in the European Union - 2023 Status Report on Technology Development, Trends, Value Chains, and Markets. Publications Office of the European Union.

[162] Strategic Management Partners. (2024). Wireless Power Transmission: Technologies, Applications, and Market Trends.

Inductive WPT alone is expected to generate $24 billion by 2029, far outpacing the less mature laser-based technologies. The pandemic has increased interest in contactless charging solutions, particularly for consumer electronics, which dominate current adoption.

Applications Across Key Sectors

- Consumer electronics and smart homes: wireless charging is transforming homes into hubs of convenience, enabling simultaneous charging of multiple devices, from smartphones to IoT sensors. Innovations such as wireless-enabled furniture and kitchen appliances are further driving adoption.

- Automotive: the integration of WPT systems into electric vehicles (EVs) enables both static and dynamic charging. Road-integrated charging infrastructure designed for in-motion power transfer addresses range anxiety and supports the broader EV ecosystem.

- Healthcare: wireless charging is critical for medical wearables and implantable devices, providing uninterrupted power without invasive procedures. Biosensors and diagnostic tools also benefit from this technology, ensuring reliability in critical care environments.

- Industrial Automation: in manufacturing environments, wirelessly powered sensors and robots reduce downtime and increase efficiency. WPT systems are increasingly being used to streamline operations in smart factories.

Smart Metering and IoT Integration

Smart meters are at the forefront of energy grid modernisation, supporting real-time consumption monitoring, demand response programmes and the integration of renewable energy sources. The global Advanced Metering Infrastructure (AMI) market was valued at $19.4 billion in 2020 and is forecast to reach $36.3 billion by 2028, reflecting the growing adoption of smart metering systems to improve grid reliability and optimise energy efficiency. Key drivers of smart metering growth include advances in communication network infrastructure, integration with home energy management systems (HEMS), and the rise of renewable energy sources such as rooftop solar. These systems enable real-time visualisation of energy consumption, enabling consumers to effectively manage their consumption while contributing to climate neutrality goals.[163]
Smart meters play a key role in this:

- Grid management: support real-time state estimation, outage detection and voltage quality monitoring to ensure grid reliability.

- IoT-driven efficiency: IoT-enabled meters integrated with home energy management systems (HEMS) to provide consumers with detailed consumption insights.

- Renewable Integration: enabling seamless connectivity with distributed energy resources (DERs), such as rooftop solar panels and wind turbines.[164]

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[163] De Paola, A., Andreadou, N., & Kotsakis, E. (2023). Clean Energy Technology Observatory: Smart Grids in the European Union - 2023 Status Report on Technology Development, Trends, Value Chains, and Markets.

[164] Vitiello, S., Andreadou, N., Ardelean, M., & Fulli, G. (2022). Smart Metering Roll-Out in Europe: Where Do We Stand? Cost Benefit Analyses in the Clean Energy Package and Research Trends in the Green Deal.

Investment priorities include scaling up IoT-connected meters in developing regions and fostering public-private partnerships for large-scale deployments.

Small Cells and 5G Expansion

Small cells are a cornerstone of 5G network densification, enabling improved connectivity for enterprises, the implementation of smart city infrastructure and immersive technology applications. The small cell market is forecast to grow at a compound annual growth rate (CAGR) of 8.6% between 2022 and 2030, with deployments peaking at 9.5 million radio units (RUs) in 2028. After 2029, deployments are expected to gradually decline, mainly due to market saturation and the transition to 6G technologies.[165]

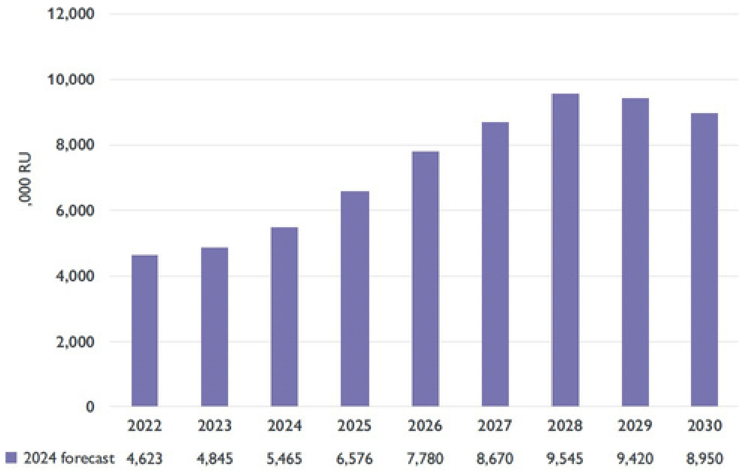


Fig. 43. Small cell total deployments 2022-2030

Source: Small Cell Forum, 2024

The deployment trajectory reflects a steady increase from 2022 to 2028, in line with the growing demand for advanced connectivity solutions. However, growth is expected to moderate between 2024 and 2026, constrained by economic challenges, geopolitical tensions and reduced capital expenditure (capex) by mobile operators. The slowdown after 2028 underlines the industry's preparation for the next wave of innovation, with new 6G technologies expected to emerge around the early 2030s. These trends are reflected in the accompanying chart, which visualises the lifecycle of small cell deployments over the decade.

Several key opportunities highlight the transformative potential of small cell networks:

- Private campus networks: accounting for 46% of enterprise small cell deployments by 2030, these networks are critical for providing secure, high-capacity connectivity, particularly in industrial and academic environments.
- Smart cities: small cells are essential in urban environments, supporting IoT devices, traffic management systems and public safety measures. This segment is forecast to grow at a CAGR of 22%, driven by the increasing adoption of connected infrastructure.
- Immersive technologies: the proliferation of augmented and virtual reality (AR/VR) applications is accelerating the demand for low-latency connectivity, contributing to a CAGR of 30.5% in this segment.

[165] Small Cell Forum. (2024). SCF Market Forecast Report.

6G and Beyond

While still in the research phase, 6G technologies are poised to redefine connectivity with cloud-native and AI-native architectures. Early adoption is expected in enterprise small cell networks, which provide a less risky proving ground for new capabilities. Investment in semiconductor R&D and cross-industry collaboration will be key to shaping the 6G ecosystem.[166]

Despite promising growth, the sector faces several challenges:

- Economic constraints: global economic stagnation and mobile operator CAPEX cuts.
- Regulatory barriers: delays in standardisation and spectrum allocation for emerging technologies such as 6G.
- Supply chain disruptions: ongoing chipset shortages impacting production timelines and cost structures.

To mitigate these risks, stakeholders should prioritise cross-industry partnerships, advocate for supportive regulatory frameworks and invest in localised manufacturing to reduce reliance on volatile supply chains.

Twin Transition Potential

The integration of advanced wireless transmission technologies, IoT-enabled smart devices, and next-generation network infrastructures presents a transformative opportunity to align private investment with sustainability and digitalisation goals. These advances are paving the way for more efficient, scalable and interconnected systems across industries.

Green Transition Potential

- **Decarbonization through efficiency:**
  innovations such as wireless power transmission (WPT) and IoT-enabled smart grids significantly reduce energy losses and facilitate the integration of renewable energy sources. By 2029, these technologies are expected to play a key role in achieving net-zero emission targets.
- **Dynamic energy management:**
  smart grids and small cell networks improve energy efficiency through real-time monitoring and optimisation, reducing the environmental impact of urban and industrial systems.

Digital Transition potential

- **Smart Cities and IoT Applications:**
  With a projected CAGR of 22%, smart city initiatives are leveraging wireless networks and IoT solutions to optimise urban operations, from transportation systems to energy distribution. These technologies are the backbone of the digital transformation of cities.
- **Immersive and data-driven solutions:**
  the growing demand for augmented reality (AR), virtual reality (VR) and data-driven applications is driving investment in low-latency, high-capacity connectivity, with enterprise small cells expected to grow at a CAGR of 8.6%.

[166] Cole, Z., Lajous, T., Queder, F., & Wrulich, M. (2024). Shaping the future of 6G: Next-generation technology could spark innovation, attract investment, grow adoption, and revitalize telecommunications. McKinsey & Company.

Increasing fiber connectivity

The expansion of fiber optic networks represents a cornerstone of the modern digital economy, offering unparalleled bandwidth, reliability, and speed compared to traditional copper-based systems. As global data consumption continues to surge, driven by advancements in cloud computing, IoT, and streaming technologies, fiber connectivity is becoming indispensable. Europe has emerged as a critical market for fiber optic infrastructure investments, with numerous national initiatives prioritizing the deployment of Fiber-to-the-Home (FTTH) and Fiber-to-the-Building (FTTB) solutions. These investments are instrumental in bridging the digital divide, supporting economic growth, and advancing the twin transitions of digitalization and decarbonization. Fiber optic connectivity is at the heart of Europe's digital future, presenting a compelling investment opportunity. By aligning with the twin transitions of digitalization and decarbonization, investments in fiber networks can deliver robust financial returns while supporting societal and environmental goals. With supportive regulatory frameworks, advancing technologies, and strong market drivers, the sector is poised for transformative growth in the coming decade.

Market Drivers

The demand for fiber connectivity is being driven by an array of critical factors that underscore its pivotal role in shaping the modern digital landscape. The growth of the digital economy, with increasing reliance on services such as telemedicine, e-learning, and remote work, has amplified the need for high-speed, reliable broadband. Fiber optics has emerged as the backbone of this transformation, enabling seamless connectivity and robust data transmission. With global internet traffic projected to grow at a compound annual rate of 20%through 2030, the expansion of fiber networks is indispensable for sustaining this digital evolution (Cisco Annual Internet Report, 2024).[167]
The rollout of 5G networks and the proliferation of Internet of Things (IoT) devices have further heightened the necessity for robust infrastructure. As 5G becomes the standard for connectivity, its reliance on fiber networks for high-speed backhaul is critical. This dependency ensures seamless, low-latency communication required for real-time applications, from autonomous vehicles to smart manufacturing, making fiber connectivity integral to the success of these technologies.
In parallel, consumer expectations for ultra-fast internet continue to rise. The demand for data-heavy applications such as 4K streaming and online gaming underscores the need for scalable and reliable infrastructure. Fiber optics delivers the unparalleled speed and capacity required to meet these expectations, making it the preferred choice for modern connectivity solutions. Beyond consumer and technological drivers, fiber networks are also seen as strategic assets for national economic competitiveness. Governments recognize that robust broadband infrastructure is essential for fostering innovation, attracting investments, and maintaining global competitiveness. In line with these priorities, the European Commission has set ambitious targets for universal gigabit connectivity by 2030. This vision is supported by extensive fiber deployments, reflecting a strong commitment to leveraging digital infrastructure as a catalyst for economic growth and societal advancement. Through these dynamics, fiber connectivity continues to solidify its role as a cornerstone of the digital economy, offering immense opportunities for investment and development in both established and emerging markets.

[167] https://www.cisco.com/c/en/us/solutions/executive-perspectives/annual-internet-report/index.html

Regulatory framework

European Union

The regulatory landscape in Europe is highly supportive of fiber optic infrastructure expansion, driven by national and EU-level initiatives:

- **EU Digital Strategy:**

  The European Commission's Digital Compass sets a target for all European households to have gigabit connectivity and 5G coverage by 2030. Policies such as the Connecting Europe Facility (CEF) and the European Investment Bank's (EIB) funding programs offer financial and technical support for broadband projects.

- **National Broadband Plans:**

  Many EU member states have implemented tailored broadband strategies, offering subsidies, tax incentives, and public-private partnership models to accelerate fiber deployments. For example, Germany's "Gigabit Strategy" and France's "Plan Très Haut Débit" aim to achieve near-universal fiber coverage by the end of the decade.

- **Regulatory Streamlining:**

  To reduce deployment costs and timelines, governments are introducing measures to streamline permitting processes, encourage infrastructure sharing, and reduce administrative barriers for network operators.

Italy

- **National Recovery and Resilience Plan (PNRR):**

  Under the PNRR, Italy has allocated over €6 billion to digital transformation, with a significant portion dedicated to broadband expansion. This includes subsidies for operators deploying fiber networks in regions lacking adequate connectivity.

- **The Italian Ultra-Broadband Plan:**

  Is the cornerstone of the country's regulatory strategy, aimed at ensuring nationwide high-speed broadband coverage. Key aspects of Italy's framework include:

  - **Fiber Deployment Initiatives:** Italy has introduced initiatives to expand FTTH and Fiber-to-the-Building (FTTB) networks. Projects funded through public-private partnerships and EU grants are focused on reducing the digital divide, particularly in rural and underserved areas.
  - **Strategic Investments in Rural Areas:** Italy's regulatory framework prioritizes rural connectivity through measures such as direct government investments and incentives for operators to deploy high-speed networks in less commercially attractive areas.

Key technologies

Passive Optical Networks (PON):

- Modern PON technologies, such as GPON and XGS-PON, enable high-speed broadband delivery to multiple users over a single fiber, reducing infrastructure costs while ensuring scalability.

Dense Wavelength Division Multiplexing (DWDM):

- This technology enhances the capacity of fiber networks by allowing multiple data streams to travel simultaneously on different wavelengths, significantly increasing bandwidth.

Fiber to the Premises (FTTP):

- FTTP solutions, including FTTH and FTTB, ensure direct fiber connections to homes and buildings, delivering superior speed and reliability compared to hybrid fiber-copper systems.

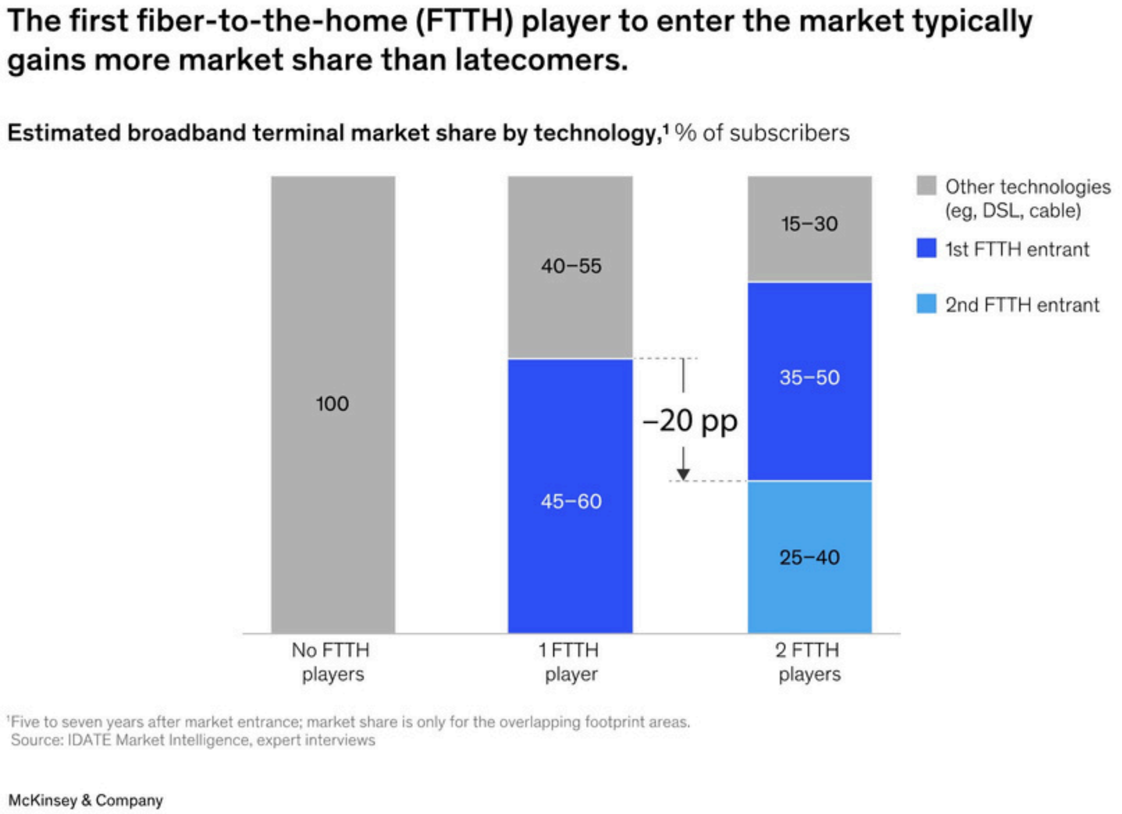
Software-Defined Networking (SDN):

- SDN technology enables dynamic management of network resources, optimizing performance and reducing operational costs.

Market Development and Investment Opportunities

The fiber optic sector represents a compelling opportunity for investors, driven by increasing demand for high-speed broadband and technological advancements. Europe alone is projected to require an estimated €300 billion in investments to achieve its gigabit connectivity targets by 2030 (FTTH Council Europe, 2024)[168]. This immense demand paves the way for infrastructure funds to play a critical role in expanding and upgrading networks, aligning with both economic growth and societal digitalization goals. Fiber network deployment is accelerating globally, with operators in Europe and the U.S. adding 15.2 million households to fiber access in 2022 alone, compared to 9.9 million in 2018. Despite progress, 40% of the world's population still lacks high-speed fiber access, presenting a significant growth opportunity. However, capturing this potential requires improving return on investment by reducing costs and maximizing market share through rapid deployment. Operators must identify markets that balance penetration potential, average revenue per user (ARPU), and construction costs.

[168] https://www.ftthcouncil.eu/resources/all-publications-and-assets/2043/european-ftth-b-market-panorama-2024



Advanced AI planning models can analyze a wide range of variables, such as network routes, deployment methods, and socio-demographics, to optimize network deployment and avoid costly mistakes. For example, an operator using AI models reduced deployment costs by 5–7% and improved market penetration by 10%. Collaborative relationships with suppliers ensure stable supply chains, cost savings, and reduced delays. By sharing demand forecasts and committing to bulk purchases, operators can secure better terms and enhance supply predictability. Long-term partnerships have been shown to reduce construction costs by 5–8%.[169]

The European market is uniquely characterized by a fragmented landscape of numerous small and regional operators. This fragmentation presents a strategic opportunity for consolidation, enabling investors to scale operations, reduce costs through economies of scale, and enhance service quality. As larger entities emerge through mergers and acquisitions, the potential for streamlined operations and market dominance increases, delivering attractive returns for stakeholders.

Rural and underserved areas also offer significant investment potential. Despite advancements in urban connectivity, substantial gaps persist in rural regions. Targeted investments in these areas not only promise robust financial returns but also contribute to closing the digital divide, addressing a critical societal challenge. By enhancing broadband access, investors can support regional development while capitalizing on untapped markets. The convergence of fiber and 5G networks is another pivotal growth area. Fiber infrastructure is essential for 5G backhaul, ensuring seamless integration and the delivery of next-generation mobile connectivity. As 5G deployment accelerates, investments in supporting fiber networks will become increasingly critical, creating substantial opportunities for infrastructure funds.

[169] https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/the-keys -to-deploying-fiber-networks-faster-and-cheaper

Moreover, both greenfield and brownfield projects offer diverse pathways for investment. Greenfield projects, which focus on developing networks in emerging and underserved regions, provide opportunities for high growth and market expansion. Conversely, brownfield investments in established networks offer stability and predictable cash flows, appealing to investors seeking lower-risk profiles. The fiber optic sector combines growth potential, technological necessity, and strategic opportunities for scaling and innovation, making it an ideal domain for investment. By addressing critical connectivity gaps and leveraging synergies with emerging technologies, investors can align with the twin transitions of digitalization and sustainability, ensuring long-term value creation. Fiber optics has long been the cornerstone of high-speed internet and continues to gain traction across Europe. The European Commission's 2024 white paper emphasizes transitioning from copper networks to fiber, aiming for 80% migration by 2028 and 100% by 2030. With fiber networks currently reaching 56% of EU households, there is substantial room for expansion. The FTTH Council Europe predicts 63.4% coverage by the end of 2023, highlighting the growing investment in fiber infrastructure. Ambitious projects, such as a new 1,400 km submarine fiber optic cable connecting Northern European nations, reflect the commitment to enhancing capacity and redundancy. National initiatives, like United Fiber Group's expansion in Greece, Bulgaria, Croatia, and Slovenia, demonstrate targeted efforts to extend fiber-to-the-home (FTTH) access and bridge the digital divide. Satellite networks are becoming a vital component of the EU's connectivity ecosystem, particularly in remote areas where fiber deployment is challenging. Initiatives such as the European Union Governmental Satellite Communications (GOVSATCOM) program and the IRIS² satellite constellation aim to provide secure, resilient satellite communication for government and commercial applications. Advanced satellite technologies, like Very High Throughput Satellites (VHTS) and mega-constellations, are being developed to complement terrestrial fiber networks. Innovations such as the HydRON (High Throughput Optical Network) project envision a fully optical space network by 2025, integrating satellite and terrestrial fiber systems for seamless global connectivity.[170]

A hybrid approach combining fiber optics and satellite networks offers robust, flexible solutions to meet diverse business needs. This strategy ensures:

- **Reliability:**
  Redundant connections minimize downtime and enhance operational resilience.
- **Scalability:**
  Fiber supports high-demand urban areas, while satellite addresses rural connectivity challenges.
- **Customization:**
  Tailored solutions optimize service quality, balancing low latency for real-time applications and high bandwidth for data-heavy tasks.

[170] https://www.telecomrevieweurope.com/articles/reports-and-coverage/the-future-of-business-connectivi ty-from-fiber-optics-to-satellite-networks/

Expert Insight:
Higher Computing Power and its strategic implications

Developed with insights from Alessandra Poggiani, General Director of Cineca.

The evolving landscape of higher computing power is deeply intertwined with artificial intelligence (AI) and the infrastructure required to support it. High-Performance Computing (HPC) systems have emerged as indispensable for AI development, processing vast datasets and enabling breakthroughs in machine learning, simulations, and analytics. However, the demands of these systems, particularly in terms of energy, pose challenges that influence the trajectory of investment and innovation.

HPC and Energy Integration

As HPC facilities grow in size and capability, their energy requirements soar, necessitating innovative solutions. Experts highlight the emerging trend of pairing HPC data centers with renewable energy parks, such as photovoltaic plants, to enhance sustainability and cost efficiency. This approach not only mitigates the environmental footprint but also aligns with Europe's decarbonization goals.

Quantum Computing as a future disruptor

Quantum computing presents a promising but experimental alternative to traditional HPC. While its potential to reduce computational volume and energy use is immense, the technology remains in its infancy. Early prototypes show promise, but widespread application is still years away. This leaves HPC as the cornerstone of AI-driven industries for the foreseeable future, emphasizing the need for robust investment in both HPC and renewable energy integration.

Europe is at the forefront of HPC development, with Italy playing a leading role through initiatives like the Leonardo supercomputer. Co-financed by the EU, such projects underscore Europe's commitment to strengthening its computing capabilities.

Twin Transition Potential

Investing in fiber connectivity contributes meaningfully to both the green and digital transitions:

- **Digital Transition:**
  Fiber networks are fundamental to the digital transformation of industries and societies. They enable smart technologies, remote work, e-commerce, and e-governance, fostering innovation and economic resilience.
- **Green Transition:**
  Fiber optics are significantly more energy-efficient than traditional copper networks, reducing the environmental footprint of data transmission. The integration of renewable energy sources into network operations further enhances their sustainability profile.

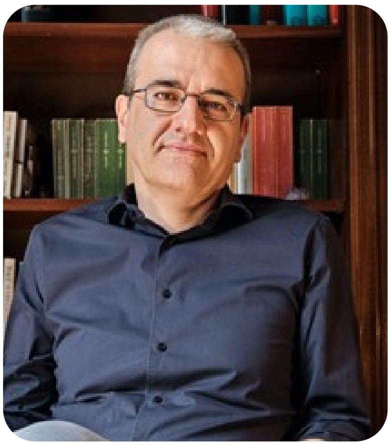
Our team of experts

Alberto Dalla Riva
Senior Lead Business Developer - **Ørsted**

Alessandra Poggiani
General Director - **Cineca**

Ernesto Ciorra
Innovation and Sustainability Expert

Gerardo Volpone
Tech Strategist and Sustainability Community Italy lead - **Microsoft**



Nicola Armaroli
Research Director - **CNR**

One transition

For years, the Energy and Digital sectors have been driving forces of the global economy. Both have shaped industries, driven innovation, and supported economic growth in transformative ways.
Traditionally, discussions have centered around the energy transition or the digital transition as separate challenges. Things, however, have changed. There is now growing recognition that these are not distinct pathways but parts of a single, unified transition.

This realization has given rise to the concept of the "Twin Transition," which underscores the deep interconnection between these two industries. The climate crisis, the development of artificial intelligence, and the rising energy demands of data centers now define pivotal global dynamics. Together, these sectors hold the key to addressing critical challenges and unlocking transformative opportunities on a global scale.

The *"For a Twin Transition Investing strategy"* report aims to shed light on these challenges, analyzing the current state of both sectors, the emerging trends, and how their convergence is shaping the future of the global economy.

EIIS European Institute of Innovation for Sustainability

The European Institute of Innovation for Sustainability (EIIS) is committed to advancing sustainable development by educating individuals, businesses, and organizations. EIIS fosters meaningful connections and generates lasting value by designing and delivering innovative educational programs on critical sustainability topics.
Collaborating with leading companies, prominent organizations, and renowned international experts, EIIS develops courses that go beyond theoretical knowledge, equipping participants with the practical expertise required to address the complex challenges of the modern world.

DEA CAPITAL REAL ESTATE SGR

TWIN TRANSITION INFRASTRUCTURE FUND

DeA Capital Real Estate is an **investment management business** focused exclusively on European real estate, with a network of seven offices of 180 local experts in Milan, Rome, Paris, Madrid, Warsaw, Munich and London.

Within this framework, the **Twin Transition Infrastructure Fund (TTIF)** was created to address the evolving landscape of infrastructure investments.

With a strategic focus on **Energy Transition and Digital Transformation**, TTIF seeks to identify and support high-performing infrastructure companies, assets, and projects with strong potential for value creation in these interconnected sectors. The fund concentrates its investments in **Italy and Western European markets**, leveraging DeA Capital's local presence and expertise to drive impactful and sustainable growth.

February 2025

"The whole battery industry is in deep ferment, and frankly, what was thought two years ago has been already surpassed. "

(Nicola Armaroli - CNR, Research Director)

"Advances like compact language models and processors handling 200 billion parameters locally are revolutionizing this field."

(Alessandra Poggiani - CINECA, Director General)

"Solar dominates new power capacity, driving a paradigm shift: near-free energy and a future where consumers might be even paid to use electricity."

(Alberto Dalla Riva - Lead Business Developer, Strategy and Innovation, Ørsted)