Shaping Tomorrow's Energy Landscape:

Balancing Sovereignty, Affordability and Climate Responsibility

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03

ENERGY FLOWS

CAN WE MAKE THE SHIFT?

PETER KING
Global Head of Energy
Capgemini Invent

MARISSA PAPAS
Director, Energy
Transition and Utilities

In this chapter we explore how fundamental changes to the way that energy is produced and used will be needed to hit Net Zero targets. With energy production and use as the primary cause of CO_2 emissions, this is the first place that the world looks for decarbonisation.

I chose to focus on the flow of energy as I feel this is fundamental to our understanding of the operation of the energy system. Using the flow concept we can better understand how the whole system is interconnected. How gas becomes electricity for lighting, how oil becomes petrol for cars to move people, and how trees in Canada become biomass in a power station in the north of England.

Across these articles we cover topics as diverse as energy can be – how the various technologies will play a role and how we can overcome the challenges of decarbonisation.

This chapter includes:

1. A huge shift in how energy flows - an overview of the challenge
2. Energy transition in oil and gas companies
3. Renewable tech at scale
4. Nuclear tech
5. Electric vehicles
6. Gigafactories supporting the energy transition
7. Future reform of electricity connections (UK)
8. LCOE comparison
9. Energy networks are the pace setters for net zero

03

1. A HUGE SHIFT IN HOW ENERGY FLOWS
2. ARE OIL AND GAS COMPANIES TRULY COMMITTED TO THE ENERGY TRANSITION?
3. RENEWABLE TECH AS SCALE
4. CLIMATE CHANGES AND ENERGY SOVEREIGNTY ISSUES ARE TRIGGERING A NUCLEAR REVIVAL
5. GIGAFACTORIES – IS THE BATTERY INDUSTRY READY TO SUPPORT THE ENERGY TRANSITION?
6. ELECTRIC VEHICLES: THE 5 TECHNOLOGICAL FORCES DRIVING THE NEXT 5 YEARS
7. ELECTRICITY CONNECTIONS: IS THE IMPACT OF ELECTRIFICATION HOLDING BACK DECARBONIZATION?
8. GLOBAL BENCHMARKS - LEVELIZED COST OF ENERGY
9. NETWORKS AT THE CENTRE OF THE ENERGY TRANSITION: Will energy networks enable or hinder the transition to net zero?

A HUGE SHIFT IN HOW ENERGY FLOWS

PETER KING, UK

A daunting task

Huge changes to the way that energy flows through our systems are needed to achieve Net Zero. We need to shift from roughly 75% of energy coming from fossil fuels to close to zero.

The task is daunting. Every year we consume 35 billion barrels of oil, 4 trillion cubic metres of natural gas, and 8 billion tonnes of coal. These are more than sources of energy; they are woven into the fabric of our ways of living and our economies. If we switch them off the consequences won't just be the lights going out or queues at petrol stations, economies will collapse, supply chains will fail, food will run out. I read that 50% of the protein in our bodies comes from one of the chemical plants where the Haber-Bosch process fixes Hydrogen and Nitrogen to make fertilizer – dependent on fossil fuels.

We have only just started on this generation long change. It's easy to hear that renewables provided 100% of the power required and think that we have made progress, without realising that electricity is just a small percentage of the energy that we use, and that despite the renewables peaks the vast majority of worldwide electricity is still generated from fossil fuels.

This will require electrification of almost every aspect of our daily lives, and for a few hard to electrify processes deeper technology solutions will be needed. We will need electricity grids that are many times larger than today's, they will need to be smarter, easier to connect to, and will have moved away from centrally driven systems to energy meshes.

Energy Technologies are key. We know which we need – the big 5 of the transition are:

Technology #1: Wind onshore wind is one of the cheapest sources of electricity, whereas offshore can help overcome residents' fears. In development wind requires a complex supply chain, in operation it needs careful planning to manage the intermittent nature of the weather.

Technology #2: Solar according to the International Energy Agency PV is the cheapest form of electricity generation with hydro. There are huge parts of the world that combine consistent daily sunshine with large areas of unused land. The supply chain for solar panels has become concentrated in China and this needs to be addressed. But solar in shining only during the daylight…

Technology #3: Nuclear hugely complex, expensive, and sometimes dangerous, but today this is the only low-carbon always available at scale option. Decarbonising a major industrial economy does not look possible without using nuclear. New reactor designs offer greater opportunities for decarbonising hard to abate industries like steel and mining.

Technology #4: Batteries whilst they are expensive, and the economic case is not always easy to make, it is hard to envision a future highly complex energy system without significant amounts of energy storage. Just as petrol tanks will be replaced by EV batteries, oil bunkers will need to be replaced by Gigawatt scale batteries.

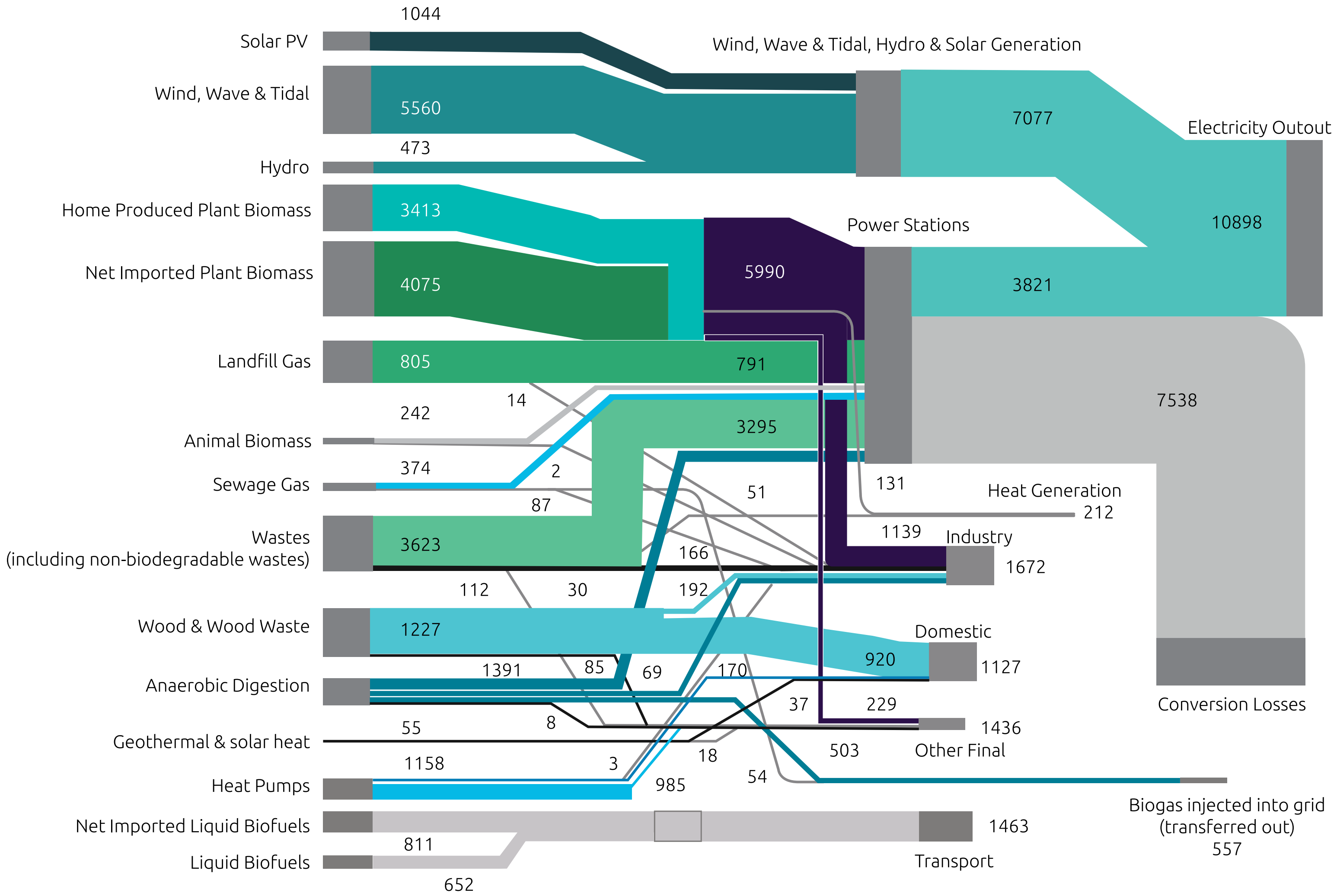
Technology #5: Hydrogen whilst the case for widespread use of Hydrogen is far from clear, there are enough potential roles to make it a major character in our decarbonisation story. Green steel, fertilizer and ammonia, shipping, long distance haulage, are some initial cases. Unfortunately, progress with Hydrogen trials for domestic heating have not gone well which leaves its future in this space in doubt.

To put scale to this challenge, a set of rough calculations shows:

- We will need 3 million wind turbines to be installed by 2030– compared to 340 thousand today, which is a 9 times increase in capacity 6 years.
- The areas of land needed for solar are vast – the solar equivalent of a EPR2 station producing 3.2GW would require approximately 17 square kilometres of panels. For comparison a large city like Paris covers 40 square kilometres. 2050 estimates of requirements approach the area of the earth currently covered by roads.
- Between 800 and 1,200 nuclear power plants – compared to 440 today. With almost all current plants needing to be decommissioned in the period to 2050 means building 25 – 40 new plants every year.
- Battery capacity requirements are hard to estimate, adding up the battery needs for grids, vehicles, industrial plants, and businesses results in a vast number. Capacity for all energy use for 2 days of world energy use would be around 900 GWH – which is many years' worth of current battery production capacity.
- The required increases in Hydrogen production are so large that comparison with current production levels is almost meaningless. A whole new industry will need to be built.

FIGURE 1

Renewable energy flow chart 2021



https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1135950/DUKES_2022.pdf

ARE OIL AND GAS COMPANIES TRULY COMMITTED TO THE ENERGY TRANSITION?

ALEJANDRO BENGUIGUI, UK

Energy Transition in oil and gas companies

As the world seeks to combat climate change and reduce GHG emissions, the choices made by O&G companies today will be critical to shape the energy landscape and society for generations to come. Disparity among O&G players means decisions are not consistent across the sector, but the energy transition is gaining momentum. Some players have started major overhauls of their businesses, betting heavily on a transition to less carbon intensive revenue streams. Renewables, lead by wind and solar, remain key alternatives to move away from fossil fuels, but new choices may yet disrupt the O&G industry in the longer term.

A report receiving a considerable amount of attention in 2017 (Carbon Majors Report, CDP), found that around 71% of worldwide GHG emissions between 1988 and 2015 could be traced back to 100 fossil fuel companies – that is considering Scope 1 & 3 – and more strikingly still, only 25 were at the root of half emissions. Although shocking, particularly to the public, instead of proving O&G companies are exclusively to blame for climate change, two key insights are truly at the heart of these figures. First, society at large has a high demand for energy which has, so far, mainly been met in an economically and technically viable way through fossil fuels. Second, the energy industry is marked by the fact that, at its core, it is dominated by giant players. These include state-owned National Oil Companies (NOCs), private and public investor-owned International Oil Companies (IOCs) and Independents, mainly focused on upstream Exploration and Production (E&P).

It is therefore key to the struggle against climate change and the reduction of global GHG emissions that these key players lead the energy transition. The size of these companies and resources at their disposal, consolidated by record profits in 2022, together with first-hand influence on how energy is supplied to society, put them in a perfect position to act and have meaningful impact on the short and long term.

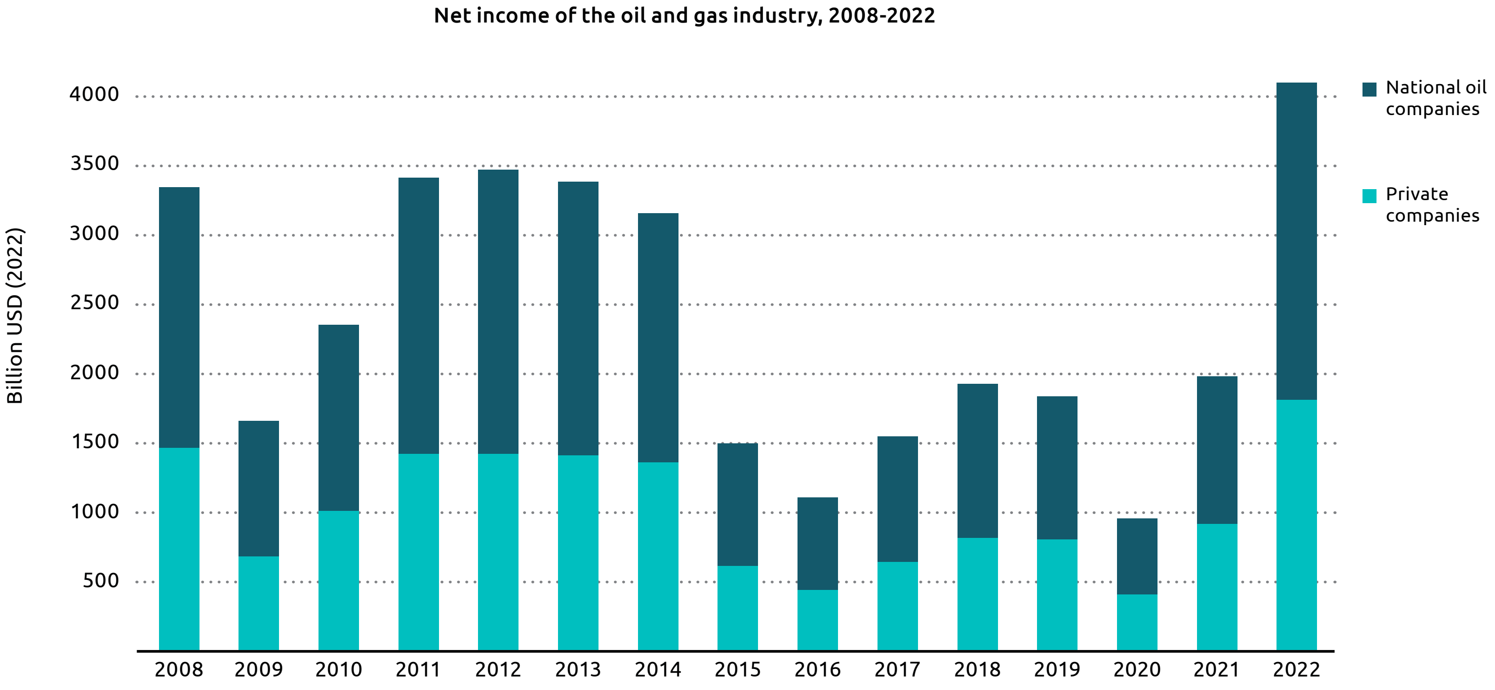
In recent decades, over 70% GHG emissions could be traced back to 100 companies

However, their interest and understanding on the best way forward to move away from hydrocarbons is different for each company, given their distinct origins, business models, shareholders' interests and government policies from the countries in which they operate. As of now, governments and policy-makers have, with mixed results, increasingly put together incentives, penalties, and investment in infrastructure to support the transition to alternative clean solutions (renewables, electrification, biofuels…). Public opinion is increasingly shifting towards sustainability and acknowledging the effort required to ensure a liveable tomorrow for future generations, particularly in Western societies. The general public widely considers fossil fuel companies to lag behind and be more of a hindrance than a catalyst for change. Albeit intentions, Net Zero targets, and actions are not uniform across the sector, such companies are all connected by the same truth: it is essential that all O&G players accelerate and deepen their commitments to reduce GHG emissions for the energy transition to occur and succeed in time.

Despite the ambition to reduce reliance on hydrocarbons, demand for oil and gas remains strong. Post pandemic economic recovery and geopolitical instability – particularly the war in Ukraine – have led to rising prices in 2021 and especially in 2022. In stark contrast to a difficult 2020, businesses have been exceptionally profitable in 2022, offering an appealing incentive to remain focused on fossil fuels. IEA data shows net income from the O&G industry soared last year, doubling 2021's results and reaching up to US$ 4,000 billion, a historic figure, with NOCs accounting for more than half of the sector's earnings. However, windfall profits also present companies with an opportunity to shift capital investment towards more sustainable and future-proof businesses. Yet from a global perspective, low-carbon capital expenditure still represents a minimal part of O&G profits reinvested. Although it has seen significant growth in 2021 and 2022, clean energy investment remains 1% of cash spending after two years of record income. Alternatively, these companies have seized the opportunity to pay down net debt and Globally, 2022 O&G's record profits have not translated into a meaningful increase in appetite for low-carbon investment noticeably increase dividends to shareholders. Still, only a fraction of these companies' capital investment can have a profound impact on the development of low-carbon technologies. In this context, investment portfolios underline their short and medium-term vision, as well as the role they expect to take in the energy transition.

FIGURE 1

Net income of the global oil and has industry reached a record high of USD 4 trillion in 2022

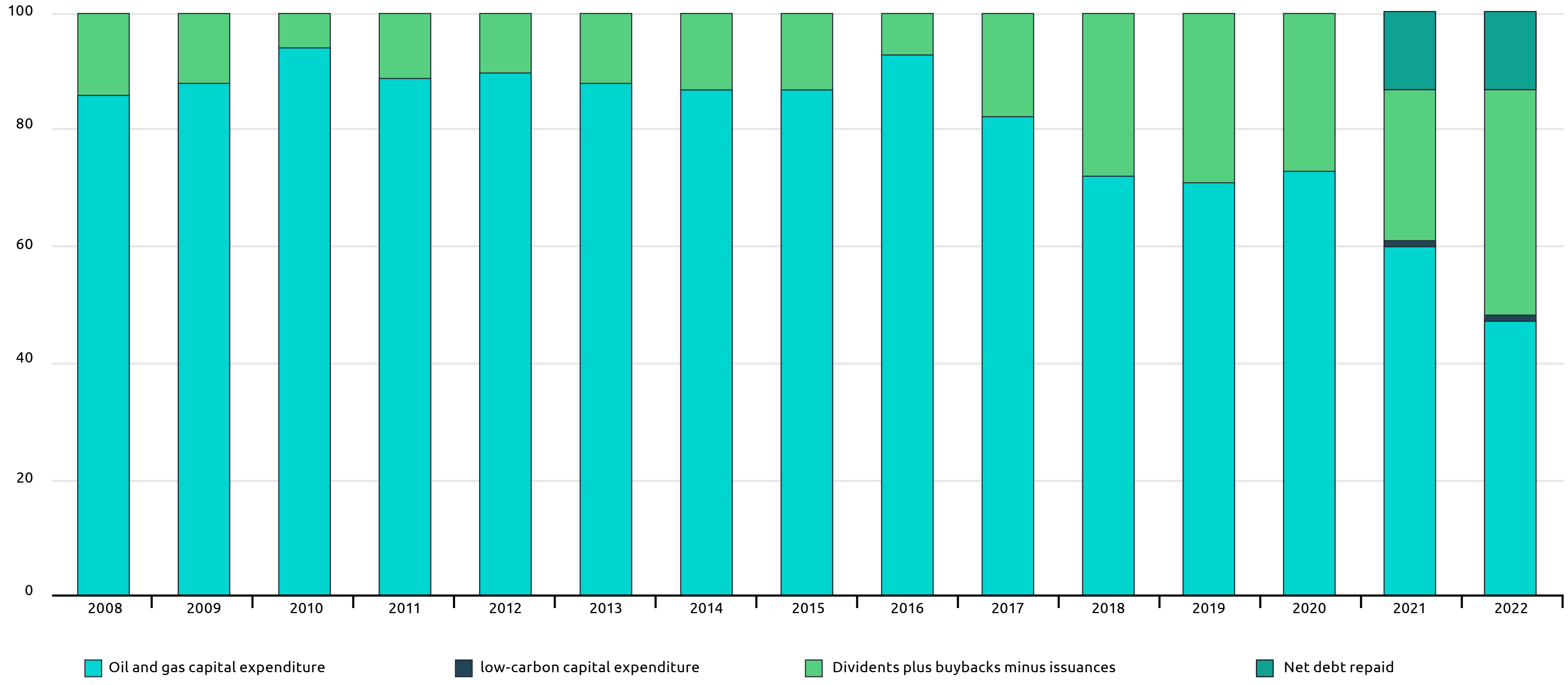


Notes: Net income is calculated from oil and gas production at prevailing oil and gas prices (including subsidies) after operating costs but before taxes: "private companies: here includes listed and non-listed companies.

Source: World Energy Investment 2023 Report, IEA

FIGURE 2

Distribution of cash spending by the oil and gas industry, 2008-2022



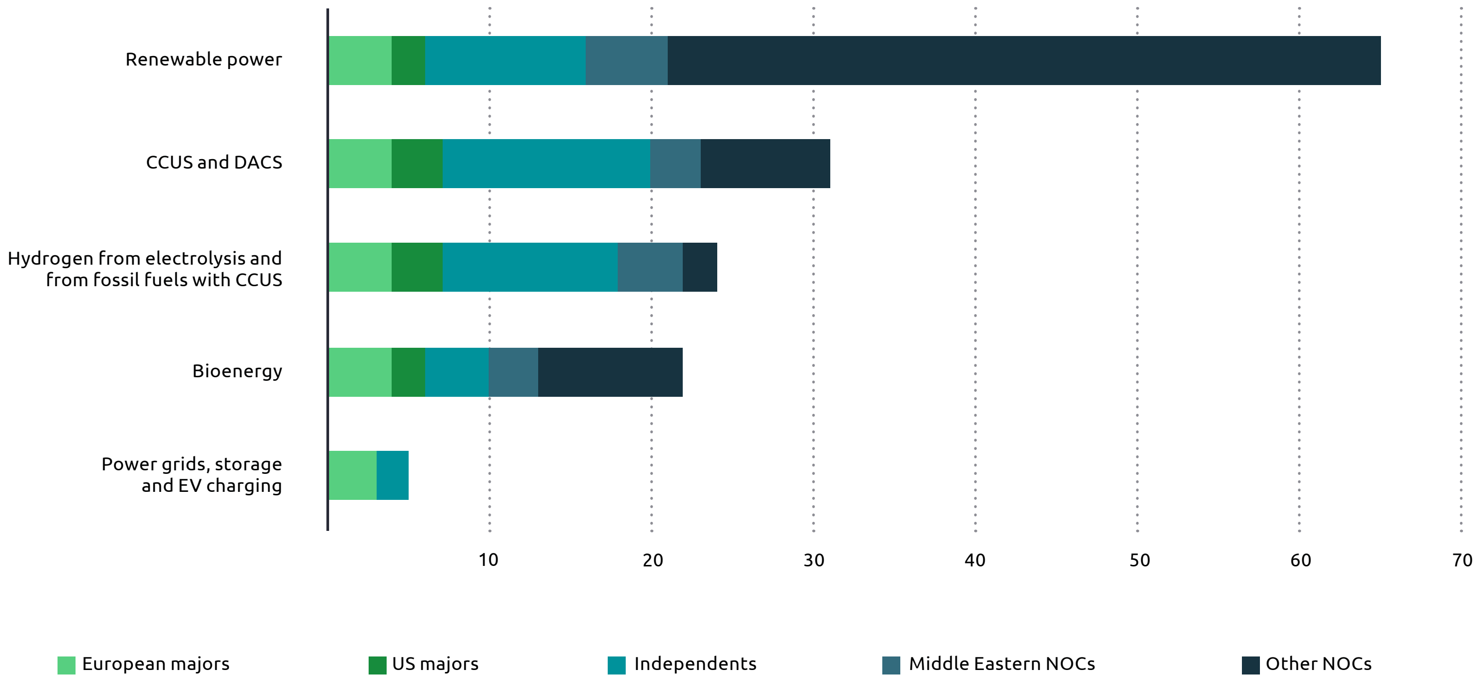
Source: World Energy Investment 2023 Report, IEA

A key insight to understand companies' vision to reduce emissions is analysing how they diversify their business, as they explore other sources and means of supplying energy. IEA's 2023 World Energy Investment report found renewable power to be the main option pursed by most O&G players. This includes a staggering number of NOCs across the globe, which usually see their businesses less inclined towards new ventures. Given their largely exclusive position in E&P within the O&G value chain, independent companies are naturally drawn to Carbon Capture, Utilization and Storage (CCUS) technologies to decarbonise their core activities, and yet less expectedly, many also turn to invest in renewable power and hydrogen.

European IOCs have generally taken more substantial strides towards a diverse portfolio of low-carbon investments, aiming to align with the European Union's ambitious climate targets and public sentiment. European majors such as Total Energies, Equinor, bp and Shell are generally considered at the centre of the transition to fossil fuel alternatives, with substantial investment in bioenergy and EV charging, as opposed to most companies worldwide.

FIGURE 3

Number of oil and gas Companies with Strategic Plans and Realised Investment in Key Low-Carbon Businesses



Source: World Energy Investment 2023 Report, IEA

American IOCs have instead favoured solutions to decarbonise existing business through CCUS, as well as investing in low-emission hydrogen production. Renewable power and biofuels are also considered by some American players, however none of them have shown meaningful interest in entering the EV charging or networks markets. All in all, investment from majors like Chevron and ExxonMobil continue to prioritise safeguarding conventional business lines rather than open up to new opportunities. Unlike their European counterparts, these companies still see their traditional source of revenue as the core pillar of their future business, so efforts are more focused on decarbonising its operations with new technology in the short term.

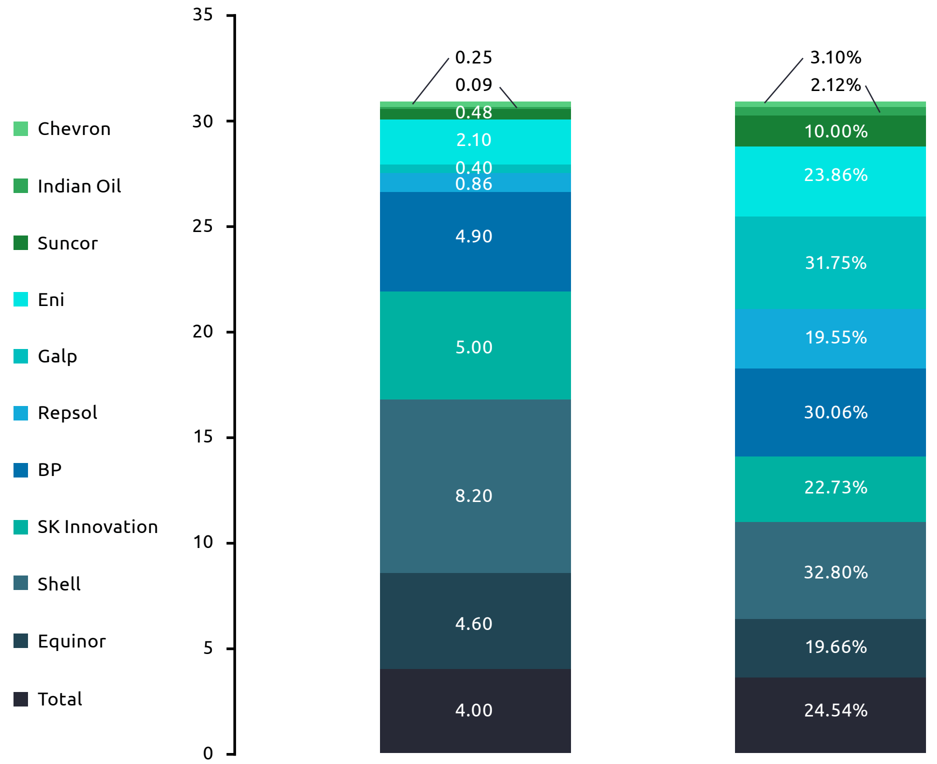
European IOCs continue to demonstrate significant diversification and robust investment in new low-carbon businesses compared to other IOC and NOC competitors

In terms of volume of investment, European IOCs strongly lead the efforts to establish themselves as the main drivers of the energy transition. Our research on selected IOCs shows European majors as the most prominent investors in 2022, in line with previous years. Currently Shell, bp and Equinor have lead the continent in net low carbon investment. However, if clean investment is measured against total investment, Galp surpasses bp, climbing up to a second position behind Shell as the players committing most to the transition. As for Asia, SK Innovation is a clear outlier for the region, as the second biggest IOC investor in volume. It is worth noting companies' definition of low carbon investment is at times challenged, with evolving policies in this space also affecting estimations greatly. For instance, Shell has recently been under scrutiny from Global Witness, an NGO, pointing out its clean investments figures could be greatly distorted by a high level of gas expenditure.

Looking closer at some of the low-carbon investment portfolios of major O&G players, it is clear renewable power has become the most frequent and matured opportunity.

FIGURE 4

Low Carbon Energy Investment by O&G Company in 2022 (Net Amount in billion US$ and % of 2022 Total Investments)



Source: Capgemini Internal Research

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Given the outstanding growth of variable renewable energy sources (VRES) in the last two decades, fossil fuel companies have developed considerable wind and solar PV capacities, both organically and acquiring smaller firms. Total Energies, Galp and Repsol major acquisitions of renewable power producers and retailers, have resulted in high offshore wind capacities in operation as of 2022. The onshore wind spaces is lead by Shell and Orsted, while Total Energies dominates the solar PV landscape among traditional IOCs.

Moreover, hydrogen electrolysers, requiring renewable power to produce green hydrogen, have only seen prominent growth in recent years with the expectation of decarbonizing hard to abate emissions in key industries (e.g. steel, chemicals, agriculture...). Repsol and bp currently operate the biggest electrolyser capacities, however short-term targets from competitors are also quite ambitious.

Biofuel production and EV charging emerge as key opportunities for European IOCs, given considerable synergies with their traditional business lines

Bioenergy has surged in 2022 to over US$ 10 billion in investment from O&G companies (IEA, World Energy Investment 2023), rapidly becoming a new priority to catch up with strict policy in areas like sustainable aviation fuels (SAFs). Shell, Galp and Total Energies seem to be at the forefront of this area.

With regards to EV charging, investment in some cases is held back by consumer adoption and available power grid infrastructure. Nevertheless, companies like Shell, Total Energies and bp have secured a solid footprint in this new market as they transform their convenience and retail stores, going from product-led to service-led businesses.

In the short term, it is difficult for O&G companies to drastically reduce emissions (particularly Scope 3) considering solid demand for fossil fuels worldwide. Swift action is imperative, thus our recommendations for key players are the following:

NOCs/IOCs:

- **Investment –** increase efforts to diversify even beyond wind and solar, towards low-carbon solutions such as bioenergy, EVs and hydrogen.
- **Scope 1 emissions –** leverage available resources and know-how to ramp down emissions from traditional operations.
- **Scope 3 emissions –** as key suppliers of fuel for transport and industry sectors, focus on sustainable alternatives.

Governments/ Policymakers:

- Make new infrastructure available including enhanced power grids for EVs and H2/biofuel ready pipelines.
- Further develop international climate change policy to narrow disparity on incentives/penalties across countries, thus preventing O&G multinationals from avoiding emission reductions

High demand for fossil fuels still challenges society's ambition to get rid of them. Choices made by O&G companies to venture into clean energy or reinvest in its profitable business carry huge significance and impact, and will continue to be a turning point in the fight against climate change.

FIGURE 5

Clean Energy Portfolios in large IOCs (in operation or planned in 2022)

Segment	Total Energies	GALP	ENI	BP	Shell	Exxon Mobil	Chevron	Equinor	Repsol	Orsted
Offshore wind	11 GW	10 GW	0.75 GW (onshore and offshore)	4.4 GW	2.2 GW	-	30 GW (2030 target)	3.3 GW	7.6 GW	2.4 GW
Onshore wind	4.5 GW	0.012 GW		1.7 GW	8 GW	0.5 GW	-	-	1087.6 GWh	3.5 GW
Solar PV	11.7 GW	1.8 GW	1.45 GW	1.6 GW	1.9 GW	0.3 GW	0.02 GW	1.27 GW	820.5 GWh	0.7 GW
Hydro		-	-	-	-	-	-	-	0.7 GW	-
Hydrogen electrolyser	0.05 GW	-	-	2 GW	0.03 GW	28 million m³ per day (planned)	150,000 tonnes per year	1 GW (2027 target)	2.5 MW	1 GW (planned)
Biogas	1.1 TWh	-	50 million m³	16,000 boe/d	3.2 mboe/d	-	2000 barrels per day	-	-	730k tonnes (planned)
Sustainable fuels (inc. Biofuels)	500,000 tonnes	600,000 tonnes	3 million tonnes (by 2025)	27 kb/d	820,000 tonnes	40 kb/d	100k barrels per day (2030 target)	-	250,000 tonnes	-
EV charging points	41,500	5,500	6,500	22,000	150,000	-	-	-	2,000	-

Source: Capgemini Internal Research

RENEWABLES TECHNOLOGY AT SCALE

DAVID PEREZ LOPEZ, SPAIN

ABHISHEK GOKHALE, AUSTRALIA

Energy transition is off-track, but there are lights and darks. With a record 30% share renewable electricity generation is driving the shift in electricity supply. However, renewable-based electricity needs to grow much faster more than double to ensure a fair energy transition.

Renewables will break records in 2023 and 2024

For 2022 solar PV was the only technology to break a record for annual capacity additions, on the other side wind power additions decreased for the last two years in a row. For 2023 and 2024 is expected another record year for global renewables capacity additions, especially solar PV will continue dominating the growth with onshore wind additions rebounding to break the 2020 record[1].

Global renewable capacity additions is expected to reach more than 440 GW in 2023 setting a new mark, 13% more than 2022. However solar PV was the only technology that broke the last year record with new 220 GWs leading the growth leveraged by the global energy crisis. In 2023 onshore wind additions after two years of decline is expected to rebound by 70% to 107GW with all-time record.

Renewable energy investment reached a record $358bn in 2023 H1, up 22% compared 2022 H1 and 36% YoY.

Solar PV grew during the 2023 H1 by 43%, especially driven by China which accounted for half of the investment and followed by the US with an all-time record and 75% increase supported by the Inflation Reduction Act (IRA).

However wind power investment decreased by 8% dragged down by onshore although offshore recorded an increase of 47%[2].

Still renewables investments need to increase by 76% to align with a net zero emissions pathway[3].

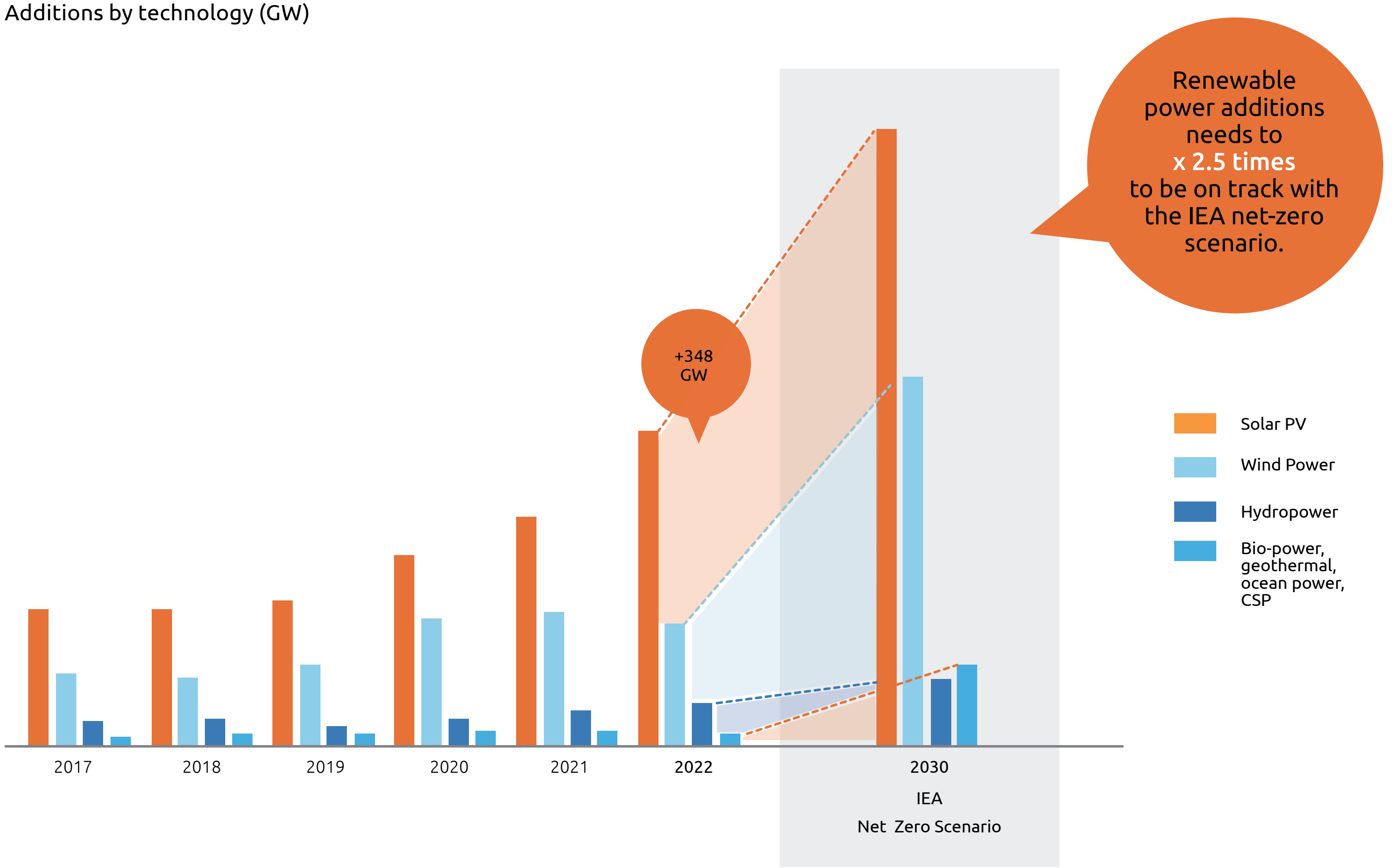
Global renewable capacity additions could reach 550 GW in 2024 in an accelerated case[4], since European countries have introduced key policy and regulatory changes to ease fast permitting setting maximum deadlines for granting permits (should not exceed three months for solar energy projects), upgrading renewable power plants (six months for repowering projects). In certain cases, qualifying projects may be exempted from environmental impact assessment and a presumption of "overriding public interest" for renewable energy projects. This will allow renewable energy projects to benefit from a simplified assessment for some environmental.

1 IEA Renewable Energy Market Update - June 2023

2 BNEF 2H 2023 Renewable Energy Investment Tracker
3 BNEF New Energy Outlook de BNEF
4 IEA Renewable Energy Market Update - June 2023

FIGURE 1

Additions by technology (GW)



Source: IEA Renewables 2023 Gloabl status report

Current annual new renewables capacity addition would need to be accelerated by as much as 2.5 times to achieve the capacity growth required under the IEA scenario for net zero emissions by 2030[5].

The rapid expansion of renewables needs to be accompanied by grid infrastructure, storage and flexibility investments. An increasing amount of electricity generation from wind and solar PV is being curtailed in many markets remaining relatively low ranging from 1.5% to 4%, especially where grid infrastructure and its planning lag behind the deployment of these renewable energies and where there is a lack of storage. IEA estimates that for every $1 invested in renewables, $3 of grid will be required.

5 REN21 Renewables 2023 Global status report

Energy security concerns is spurring the capacity growth

The global shift towards cleaner energy including solar, wind, hydropower, biofuels and others has been accelerating due to the energy security concerns. This is primarily driven by supporting policies, higher fossil fuel prices, declining costs for solar photovoltaics and wind power. These growth driving factors are outweighing the high investment costs, skyrocketing raw material and transport prices, rising interest rates, and supply chain disruptions.

According to the IEA, globally the renewable capacity additions are expected to reach 440 gigawatts (GW) in 2023 and could reach up to 550 GW in 2024 in a favorable case[6].

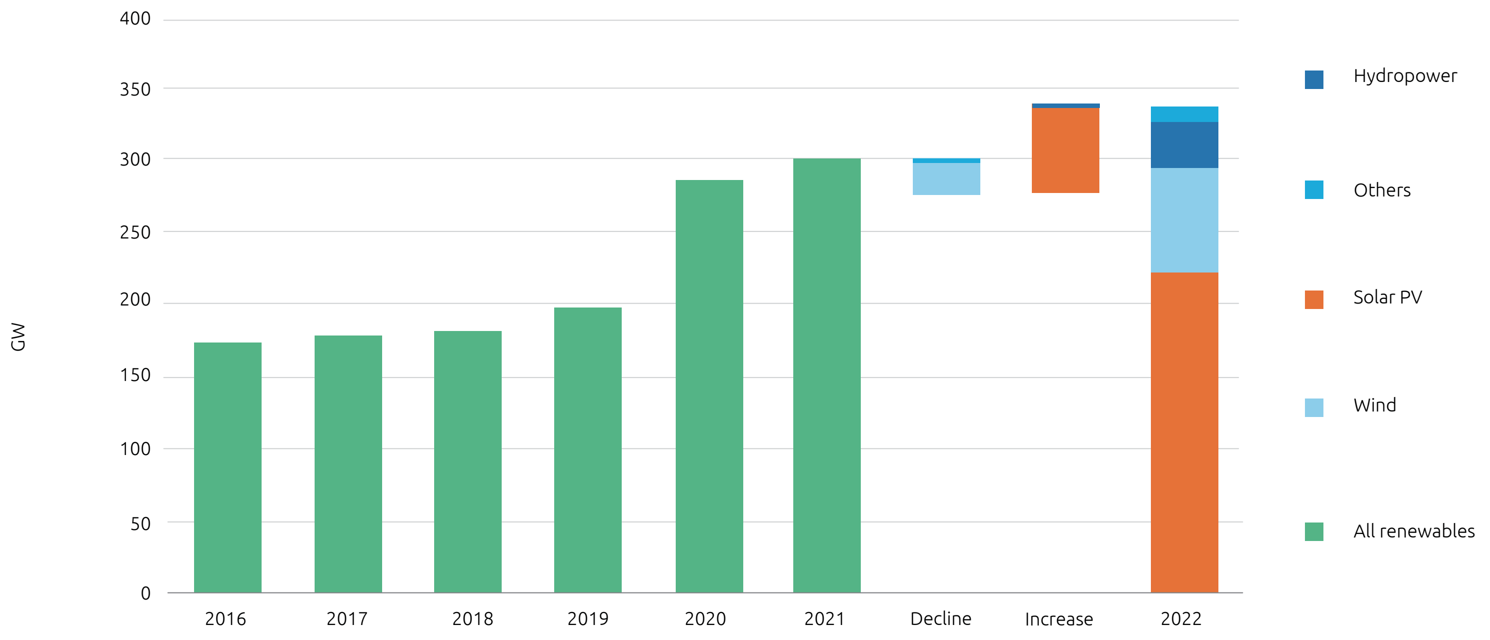
This new capacity addition is equivalent to total power capacity generated by Germany and Spain combined. By the end of 2023 an increasing push in new capacity addition is anticipated, which will take the installed capacity to reach 4,500GW by end of 2024, which will be equivalent of combined power output of China and US.

Renewables, electrification and technology enablers at the heart of Energy Transition

This unprecedented growth needs to be backed by substantial and consistent investments. Scaling up renewables will also demand building new digital technologies that will provide system flexibility.

FIGURE 2

Renewable electricity net annual capacity additions, 2017 - 2022



Economy electrification with renewables and technology enablers such as digitalization of grid, real time smart power plants, AI data-driven, new generation of SCADAs and full IT/OT integration, advanced networks and communications, and cybersecurity will be needed to achieve the objectives.

6 IEA Renewable Energy Market Update - June 2023

Wind Power

In 2022, 77.6 GW of new installations brought the global cumulative wind power capacity to 906 GW, with a year over-year growth rate of 9%[7] compared to 2021.

The slow growth was due to supply-chain issues, inflation and market uncertainty contributed which lead to a decline of nearly 17% in capacity additions. However, China and U.S. jointly accounted more than 52% of global wind output[8].

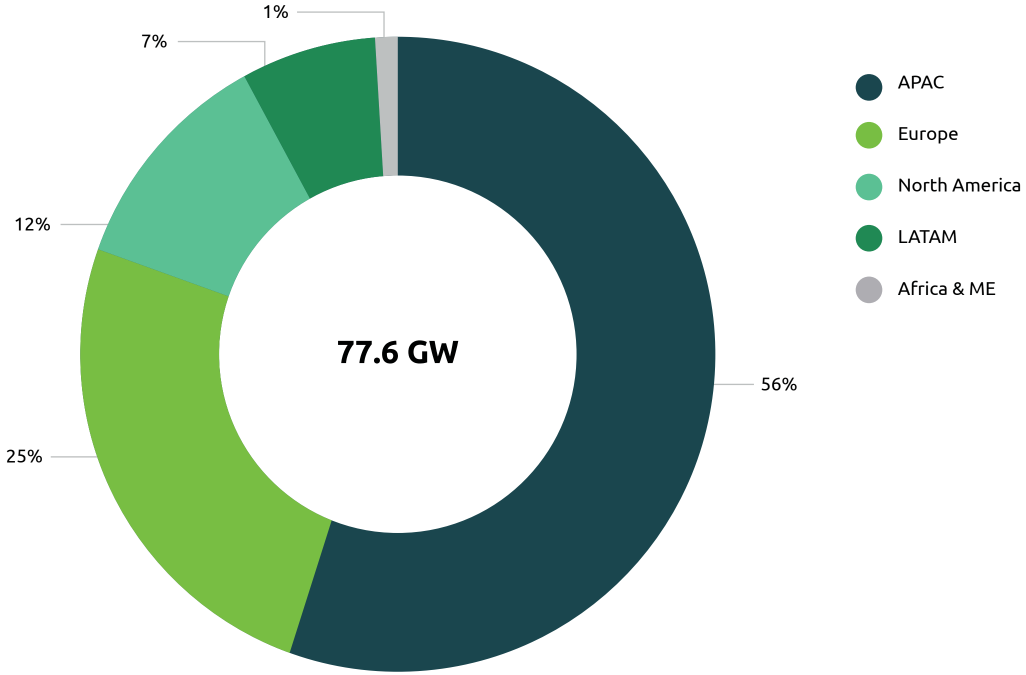
Current rates of installation will have less than two-thirds of the wind energy capacity required to meet the 1.5oC target and achieve a net zero pathway by 2030. The wind market growth rate will need to quadruple to meet net-zero goals.

Lengthy permitting procedures and lack of improvements to grid infrastructure are two main bottlenecks which is slowing down energy transition momentum. This is also posing a greater risk to outlook for developers and investors and potentially disincentivising investment.

Unfortunately the profitability of onshore wind turbine manufacturers has been hampered since several years ago by competition among them, especially in the context of auctions in a "race to the bottom" in costs, even in agnostic auctions against PV, supply chain disruptions, rising and scarce raw material costs, logistical oversight, and for the past year especially by higher inflation, interest rates and capital costs, and quality problems appearing in newer wind turbine fleets. But not only onshore wind turbines, now also offshore are raising alarm bells about a similar situation due to inflation, interest rates and capital costs, and the supply chain.

FIGURE 3

New wind power capacity in 2022 by region (%)



Source: Global Wind Energy Council (GWEC) report 2023

7 IEA Renewable Energy Market Update - June 2023
8 Global Wind Energy Council (GWEC) report 2023

Onshore Wind

In 2022, the onshore wind market added 68.8 GW, making up 88.6% of global wind installed cumulative wind power capacity to 842 GW, with a year over- year growth rate of 8.8%[9]. The global weighted average levelised cost of electricity from onshore wind added in 2021 dropped by 15%

In 2022, Asia-Pacific and North America represented more than two-thirds of global new onshore installations. Asia Pacific lost 3% market share as compared to last year, but Europe saw record installations primarily driven by Sweden, Finland and Poland in 2022 to boost its to 25%. North America retained its third position with growth driven in Brazil and Latin America markets.

Offshore Wind

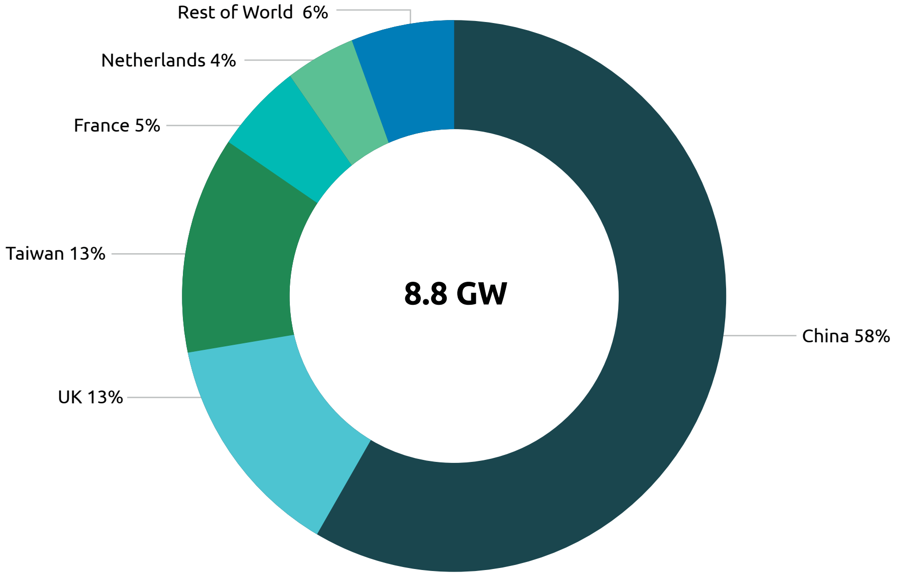
The momentum for offshore wind farms stalled in 2022 with new additions reducing by 58% compared to 2021. This was mainly due to end of national feed in tariff in program for China, modest growth in European markets, and the US didn't installing any new turbines.

A total of 8.8 GW of offshore wind capacity was commissioned in 2022, bringing total global offshore wind capacity to 64.3 GW by the end of 2022. In 2022, China accounted for 63.6% of the global total offshore wind, followed by the U.K., Taiwan, France, and The Netherlands.

The offshore wind market continues to be dominated by four main Chinese manufacturers1. The rest of the market is mostly served by two Danish manufacturers and one American manufacturer. Over the next five years, the CAGR for offshore wind is expected to be 32%, while the market share of new global wind installations is expected to increase from 11% in 2022 to at least 23% by 2027. The decline in commodity prices has led to a 2% drop in costs of new offshore and going down the levelized cost of electricity LCoE on par with coal now.

FIGURE 4

New installation offshore (%)



Source: Global Wind Energy Council (GWEC) report 2023

Offshore wind projects in particular are facing delays owing to rising input costs, slow permitting processes and an increasing shortage of specialized ships needed to install turbine foundations. Recent alarms has appeared since Vattenfall has stopped the development of the major offshore wind project in the UK and will review the entire 4.2 GW as the average cost of an offshore wind turbine is now ~40% higher than it was 2 years ago, mainly due to higher inflation, higher capital costs, and an increasing of the materials average price by ~90% since then.

9 REN21 Renewables 2023 Global status report

Solar PV

Newly installed solar PV capacity in 2022 reached 239GW, an increase of 35% compared to last year. Solar PV continues to be the main source of global investments for transmission and distribution networks and speeding up also the global energy storage market for a 30% annual growth to 2030[10].

It is to be noted that 65% of new capacity additions was led by distributed applications, including residential and commercial systems which account for almost half of global PV expansion. It is expected that Global installed solar PV capacity of 1TW will be added annually by 2030. Lower module prices, more economically attractive distributed PV system uptake for residential and commercial customers and a regulatory policy push for large scale deployment is expected to push the new capacity addition to 286GW by end of 2023 and 310GW by 2024. Apart from solar PV capacity additions, manufacturing capacity for all solar PV production segments is expected to more than double to 1,000GW by 2024, led by China and increasing supply diversification in the US, India and Europe, having enough solar PV manufacturing capacity in 2030 to meet the annual demand under Net Zero scenario.

From 2021 to 2023, the worldwide weighted-average levelized cost of electricity (LCoE) from concentrated solar power (CSP) and utility-scale solar photovoltaics (PV) has increased after a decade of uninterrupted decline. The mains reasons for this increase is the lingering effect of COVID-19 pandemic, increase logistics or shipment costs and inflationary pressure due to the Russia-Ukraine war; however, this does not pose a challenge to cost competitiveness as solar PV technology remains significantly cheaper as compared to other new fossil fuels and nuclear.

China continues to be a dominant player in the solar PV manufacturing industry with investments of almost $50 billion over the last decade. It also continues to control the polysilicon market with a share over 80% with out of the top 10 PV module 10 companies, seven are from China including the top three.

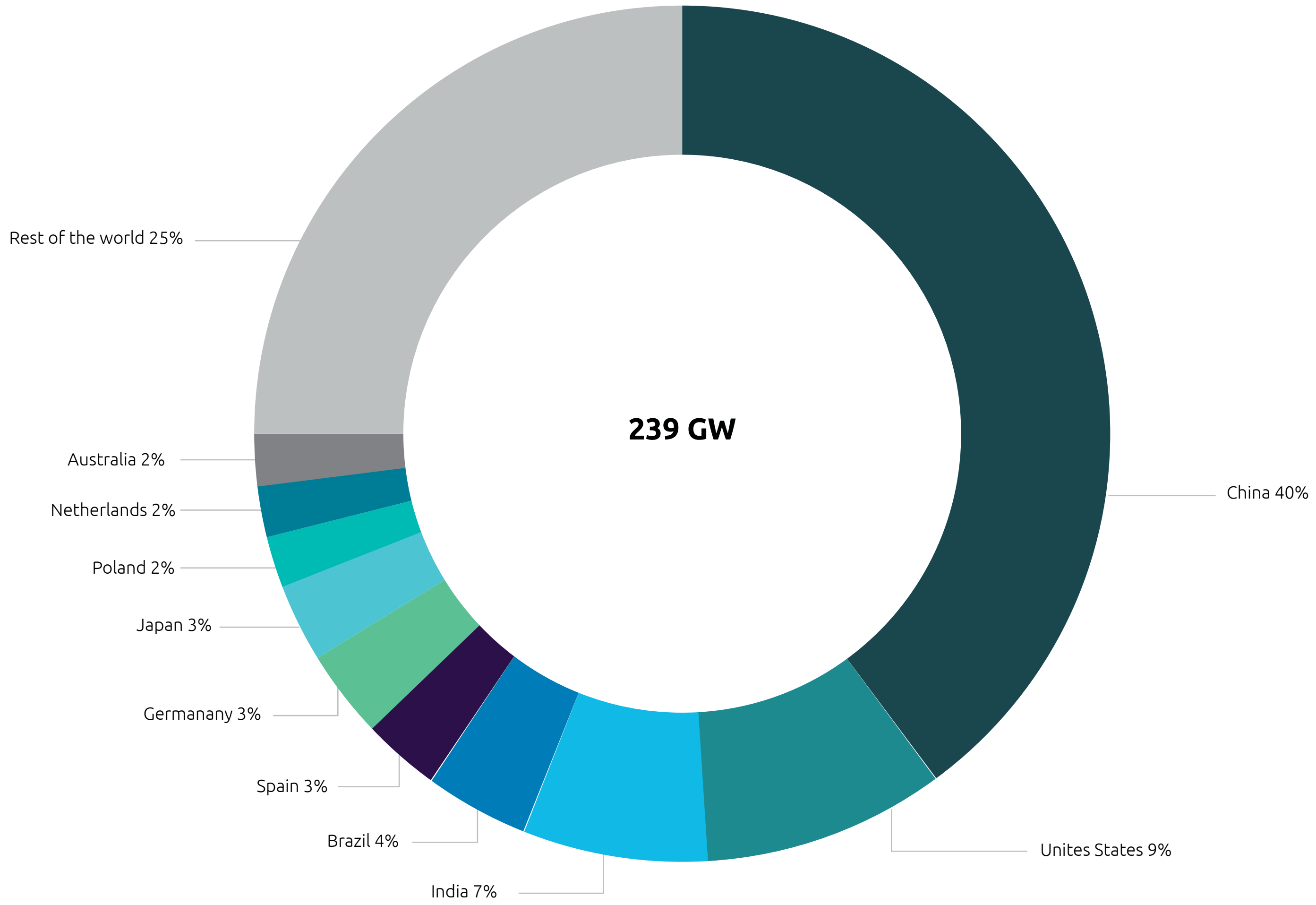
Solar PV panel prices are set to decline for the first time since many months ago for the second half of 2022[11]. A increase in solar shipments due to lower freight costs and increased efficiency in the production of large wafers of 210 mm is also expected to reduce module costs between10% and 15%, with prices dropping.

PV crystalline modules price are declining around 20% for the current 2023 since January to July in all type of modules (high efficiency, mainstream and low cost)[12].

10 Global Wind Energy Council (GWEC) report 2023

11 IEA Special Report on Solar PV Global Supply Chains 2022
12 Price Index - pvxchange

FIGURE 5



Source: Solar Power Europe 2023

Supply Chain Constraints and Disruptions

Since 2021, market has witnessed significant disruptions in global supply chains, increased shipping costs, and Russia-Ukraine war led inflationary pressure have triggered significant price increases.

The energy sector is emerging as a major force in driving the usage of critical materials such as lithium, graphite, arsenic, titanium, selenium, manganese, nickel, and cobalt are vital to battery longevity and performance. Rare earth elements which is essential for permanent magnets for EV motors and wind turbines, and large amount of copper and aluminium to support electrical technologies.

Todays, critical material supply availability and investment reliability is raising concerns for a more expensive energy transition. There is need for the industry to focus on key questions such as how to reduce the material intensity and what are the alternative or substitute materials. It is expected that there will be shortage of supply of these materials by 2030, and high geographical concentration of supplies from China (rare earth elements), Indonesia (nickel), Democratic Republic of the Congo (cobalt) pose risk to the supply chain.

Critical minerals demand is projected more than double under APS[13] but NZE[13] will require almost quadruple[14].

13 IEA scenarios: Announced Pledges Scenario (APS) by 2030 and 2050 and Net Zero Emissions by 2050 Scenario (NZE)
14 IEA Critical Minerals Market Review 2023 report

The market for critical minerals used for the energy transition reached $320 billion last year has doubled in size over the past five years. In 2022, global manufacturing of renewable energy and enabling technologies grew by nearly 40%: solar PV (up 39%), electrolysers (26%), heat pumps (13%), but wind energy manufacturing grew by an insufficient 2%[14].

The Russia-Ukraine crisis has driven the wholesale and retail electricity price across major markets, including China, the EU, the US and India. Additionally, the permitting challenges, unsubscribed auctions, and long development timelines continue to create hurdles in the utility-scale growth. There are a few promising initiatives and focus on policy frameworks which is expected to tap the huge potential of bilateral solar power purchase agreements.

Fast-track renewables permitting will have to address balancing social and environmental interests

The average permitting times in major countries in Europe and United States go from 3 to 7 years[15].

There is a huge gap between renewable energy capacity being built and average permitting times, especially for wind projects and even grid infrastructure, due to slow bureaucratic processes, environmental issues, grid access and other bottlenecks, with major implications for the pace of the energy transition.

15 IIEA Special Report on Solar PV Global Supply Chains 2022

European countries have been waiting for permits to substantial renewable capacity in the pipeline, a new act was passed enabling fast track permitting process to accelerate renewables development introducing specific policy measures with one-stop shops, overriding public interest, including supply chain criteria in public tenders to favour diversification and local economic value, investment in the European labour upskilling, … ensuring a good balance with societal interests, biodiversity protection and others criteria.

China is the leading global supplier of clean technologies holding around 60% of the world's manufacturing capacity for most mass-manufactured technologies (solar PV, wind systems, batteries, 40% of electrolysers[16].

Global solar PV manufacturing capacity is expected to double to nearly 1,000 GW by 2024, enough to meet annual demand in the IEA's 2050 net-zero emissions scenario. In contrast, wind equipment manufacturing is expanding slowly, and Western wind equipment manufacturers are experiencing financial difficulties and may struggle to keep pace with demand growth through 2030.

16 IEA Energy Technology Perspectives 2023 report

A new green tech race? US Inflation Reduction Act and EU Net Zero Industry Act

Multiple policy support packages such as the US Inflation Reduction Act (IRA), the Net-zero Industry Act in Europe, Japan's Green Transformation program and India's Production Linked Incentive scheme have aimed to increase domestic manufacturing capacity of renewable energy and enabling technologies as response to the energy crisis.

In the US, the IRA was approved, with a budget of some US$400 billion over the next decade, which will help consumers and companies with a wide range of support schemes, mostly in the form of tax credits. In response to the IRA, the EU articulated the Green Deal Industrial Plan, which will mobilize €335 billion (€110 billion previously committed) with different funds. Although the EU budget is lower than that of the US, comparatively the effort in terms of % of EU GDP is 2.1% higher than the US 1.6%.

In the 12 months since the IRA was signed, the private sector has announced over $110 billion in new investments in clean energy manufacturing, over 75,000 new jobs created in the battery supply chain, over 80 new or expanded electric vehicle plants, and solar power for 12 million new homes[17].

While the EU approach is not so much protectionist as IRA with the privileging of domestic products over imports, and the need to significantly increase the speed of transition implementation including another key piece such as the Carbon Border Adjustment Mechanism with a level playing field for domestic and non-domestic imports.

Wind and PV generation costs increased for the first time in history but will decline in PV and stabilize in Wind by 2023 being the cheapest electricity source by far

Wind and solar generation costs increased for the first time in history but will decline by 2023 and 2024 remaining 10-15% above their pre-Covid levels in most markets[18] driven by a perfect storm environment in a context of inflation increasing, energy crisis by the Russian gas cut, higher financing costs and interest rates, increasing of raw material and labor costs, and supply chain issues. In spite of it wind onshore and solar PV are the lowest LCoE by far.

Apart from the PV crystalline modules price dropping by 20% since January to July 2023, also a lot of technological progress is taking place contributing to alleviate this situation; renewable technologies are making a great effort in innovation and R&D, improving their final efficiency. PV technology is developing new semiconducting materials for higher efficiency solar cells and larger power panels, using crystalline silicon, CdTe, CIGD, perovskites, multijunction, organic[19]. In the case of bifacials modules new developments based on perovskite solar cells are pointing to higher yields at lower overall costs[20] making solar PV more accessible even. Another like new generation of power electronics inverters with grid-forming features, synchronous generators and grid frequency control. New uses and applications as integrated photovoltaics floating or agrivoltaics uses.

In the case of wind industry bigger and more powerful offshore and onshore wind turbines with new design criteria, smarter control, advanced aerodynamics and aeroelasticity, wakes, materials, digitalization, ….. creating a more efficient technologies and new promising uses as floating offshore wind6. However, looking ahead to 2023, the wind industry is at a particularly complex juncture, as a new generation of wind turbines is facing potential one-off design problems due to new technical challenges and aggressive cost and time-to-market pressures, which could be feared to become a more widespread problem in the industry.

17 U.S. Department of Energy: The Inflation Reduction Act in its first year. Aug 2023

18 IEA Renewable Energy Market Update - June 2023

19 Fraunhofer ISE and US DOE (Department of Energy) Solar Futures Study report

Digitization of energy emerging a new era will trigger the energy transition at scale

Energy transition will be digital or it will not be.

Digital technologies will help increase energy efficiency and smart use from generation to final consumers cutting costs, improving efficiency and resilience, and reducing emissions. In electricity systems, for example, will help integrate higher shares of variable renewables and better match supply and demand from increasingly heterogeneous decentralised sources such as smart charging technologies for electric vehicle and distributed energy resource, or smart and flexibility of demand response requiring a more sophisticated management of electrical grids and final uses in transport, buildings, industry and residential.

Digitization trends are truly dazzling, for example 90% of the world's data has been created in the last two years, growing global investment in software and digital across the electricity value chain by 20% per year in recent years[20].

A new generation of digital technologies (AI for predictive maintenance, analytics, smart self-maintenance, a new generation of SCADAs, full IT/OT integration, 5G, and cybersecurity etc.) are expected to drive the increase in performance and efficiency, resulting in a declines in construction and operational costs.

20 IEA Digitalization and Energy 2023 report

Pure 100% renewable energy based electric system is possible

An energy system based on 100% renewables has emerged to become the goal of many countries beyond 2030 a really efficient cost mainly based on solar and wind energy, hydropower, geothermal, biomass, short, mid and long term energy storage, sector coupling power-to-X and hydrogen-to-X, and direct and indirect electrification of almost all energy demand.

100% renewable energy with a combination of wind, solar, hydro and storage could be like today's energy costs be reached between 2035 and 2050 in 145 countries creating 28 million net new green jobs and decreasing user energy costs in more than 50%[21]. Australia has announced its world leading transition to 100% renewables with wind and solar to meet all grid demand at certain times as early as 2025[22].

Reaching 100% renewables is not a minor issue that requires a solid plan that analyzes many complex issues and crossroads situations, including economic affordability and competitiveness of electricity considering another investments such as e.g. grids investments, security of supply taking into account the cost of storage, baseload, dispatchability, flexibility mechanisms, readiness of future clean technologies, ….and of course sustainability, decarbonization and climate costs. None of the world's major industries would be profitable if it paid for the natural capital it uses

21 Low-cost solutions to global warming, air pollution, and energy insecurity for 145 countries, Energy & Environmental Science. On the History and Future of 100% Renewable Energy Systems Research, IEEE and Stanford
22 Daniel Westerman, CEO at AEMO (Australian Energy Market Operator), Australian Celan Energy Conference 2023, Sydney July 18th,2023

- **For the last year we are made many progresses but not still enough. Energy transition is off-track with lights and darks.**
- **Solar PV is growing significantly but wind power is tackling many issues, other new emerging ones not being massively deployed as heat pumps and storage, and huge expectation in breakthrough hydrogen and CCUS as corner stones.**
- **Many challenges have to be addressed: permitting processes, shorten projects development, rare earth and materials scarcity, investment availability, grid readiness, there is no time to wait.**
- **Acceleration is absolutely needed. Time is now or never. Act.**

CLIMATE CHANGE AND ENERGY SOVEREIGNTY ISSUES ARE TRIGGERING NUCLEAR REVIVAL

DAVID STEIGER, FRANCE

The year 2022 marked the return of nuclear power to favor, thanks to soaring energy prices and the war in Ukraine.

At the end of September 2022, the International Atomic Energy Agency (IAEA) revised its forecasts (in the high case) upwards to 870 GW of nuclear power by 2050. It had previously forecast 790 GW, compared with the current 390 GW.

A strong political will in OECD countries, with investment decisions slow to materialize.

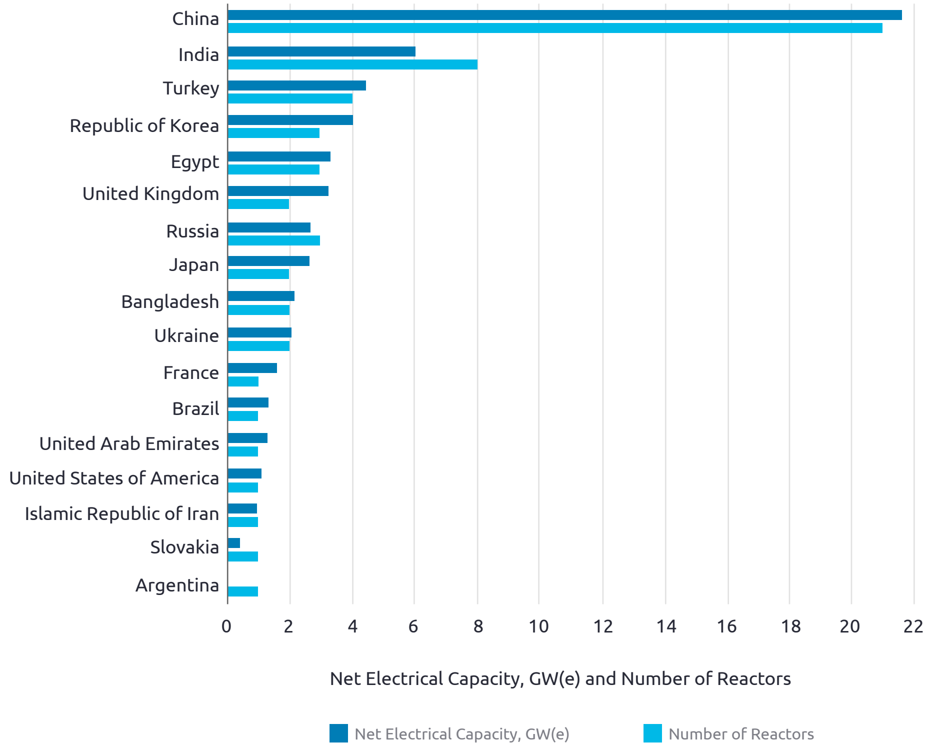
- In Western Europe, the French, British, Dutch and Swedish governments have all taken positions in favor of nuclear power. In some countries, however, investment decisions have been slow to make a clear start to a new positive dynamic. In France, for example, the financing model for the construction of the first 6 EPRs has not yet been decided.
- In Western Europe, the first reactor in 20 years has been commissioned (in Finland) and three power stations are under construction in France and the UK.
- In Central and Eastern Europe, Prague, Bratislava, Bucharest and Budapest, that already operate nuclear plants, have launched new projects. Poland wants to decrease its dependance on coal and is planning to build for the first time, two power stations.
- In Japan, Tokyo adopted a plan in December 2022 to restart its power stations and reach 20% nuclear power by 2030, compared with 7% today.
- In the US, only two units are under construction, with 12 reactors shut down in the last 10 years due to low electricity prices and a lack of political support. However, the government is trying to limit this loss with a €6 billion rescue plan for plants threatened with closure. The inflation Reduction Act (IRA) makes nuclear power eligible for the same tax credits as renewables like wind and solar. A recent report from the Department of Energy (DOE) suggest that America could triple its nuclear power generation, to 300 GW, by 20250, the year by which the Biden administration has pledged to reach net zero carbon emissions.

The development of nuclear construction in Asia remains steady.

- Moscow plans to build 24 reactors to achieve a 25% nuclear share of its energy mix by 2045. However, Rosatom will only be able to rely on its own revenues following Moscow's decision to end government subsidies.
- In China, the 14th five-year plan aims to build around 20 reactors to achieve 70 GW of nuclear capacity by 2025, compared with 53 GW today. China, which built 35 reactors between 2010 and 2020, is still leading the growth of nuclear power worldwide.
- India remains second only to China in terms of nuclear reactor construction. New Delhi hopes to meet its energy needs, which are growing by 4% a year, notably thanks to nuclear power, which currently accounts for 4% of its energy mix. However, its plans are slow to materialise.
- South Korea is following the same path, with the election in March 2022 of a new president Yoon Suk-yeol who is reversing his predecessor's policy of phasing out nuclear power.
- Central Asia is keen to capitalise on the experience it has acquired in its uranium business. In 2022, Kazakhstan and Uzbekistan have selected the sites for their first power stations.
- Finally, after the successful construction of four nuclear power plants in the United Arab Emirates, other countries as Saudi Arabia have nuclear development plans.

FIGURE 1

Reactors under construction



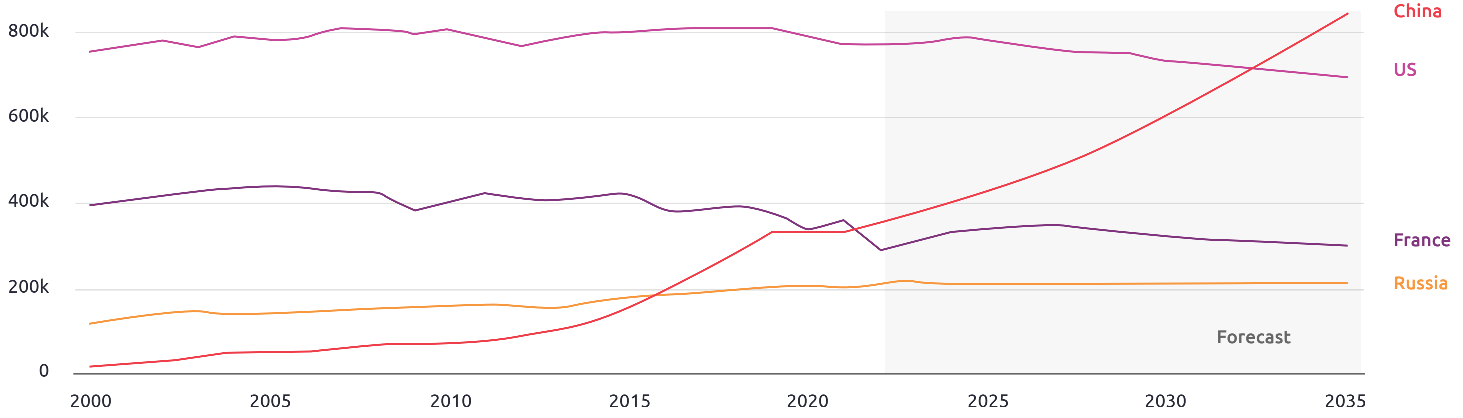
Source: IAEA (PRIS)

The civil nuclear market still dominated by China and Russia while in OECD countries, new nuclear powers construction is disappointing.

- As at 1 January 2023, of the 59 reactors under construction worldwide, 22 were in China and 43 are based on Russian or Chinese technology. This means that four out of every five reactors under construction worldwide are being built by Moscow or Beijing. The only other two countries building reactors abroad are France (in the UK) and South Korea (in the United Arab Emirates).
- Rosatom is still the world's leading builder, with 25 reactors under construction in 9 countries (including Russia). Moscow controls 10% of the uranium extraction market, 36% of uranium enrichment and 22% of fuel fabrication.
- In China, Beijing has made nuclear power a technological showcase. However, its attempts to develop its technology in Europe via Romania and the UK have not been successful. So far China has only exported nuclear plants to Pakistan. All six units operating in Pakistan are of Chinese design.

FIGURE 2

China is set to overtake the US as the biggest nuclear generator by the early 2030s



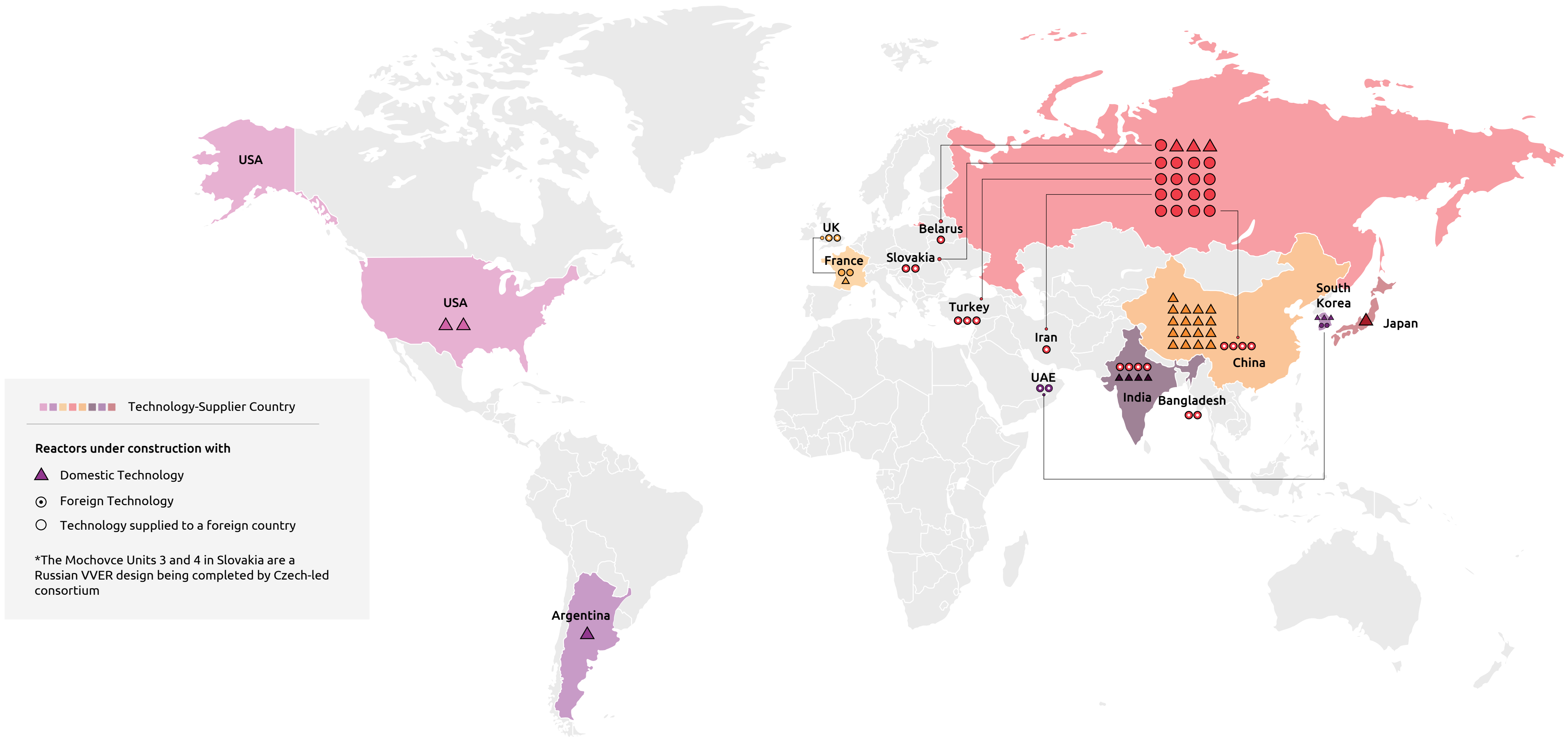
Source: Energy Monitor - Globaldata

- In the United States, Westinghouse's victory over EDF for the construction of a power plant in Poland is evidence of a change of direction, albeit a slight one for the world's leading nuclear power industry. Westinghouse aims to develop in East Europe and notably to take over from Rosatom, the maintenance of the existing VVERs. America's State Department has set up partnership with more than a dozen countries to help them fund and develop nuclear energy programs and eventually small modular reactors.

FIGURE 3

Nuclear Power Reactors Under Construction by Technology-Supplier Country

Units by Technology-supplier Country and Construction County as of 1 July 2022



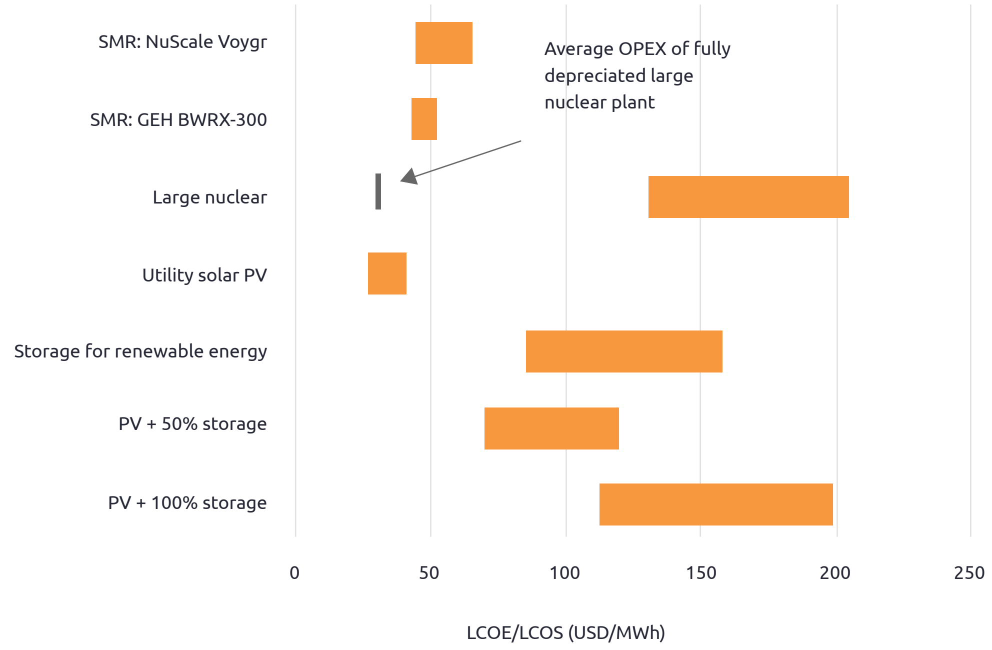
Technological breakthroughs that herald hopes for a nuclear energy faster development.

The promise of Small Modular Reactors (SMRs)

- As a possible complement to the large power reactor systems, smaller reactor potentially using new technological approaches (AMR: advanced modular reactors), are emerging and offering new services going beyond the production of carbon-free electricity. SMRs typically generate less than 300 MW, around a third of the capacity of traditional reactors. These reactors are partially factory-built and aim to make nuclear projects cheaper, enhance their safety and open pathways to new business models.
- SMRs are generally much simpler to engineer than large reactors. In addition to their integrated architecture, by using passive safety systems, they offer a higher level of safety.
- They are also meant to require less fuel than traditional reactors. Power plants equipped with SMRs are designed to refuel every 3–7 years, compared to 1-2 years for large nuclear plants.
- SMRs are factory-built, which means that there should be significant economies of scale when it comes to mass production. As they are transported to their place of operation, they do not require large numbers of skilled workers on the installation site.
- Compared with the territorial location constraints of large reactors and renewable energies, SMRs can easily be installed on smaller sites.
- The financing of SMR construction can be envisaged with smaller amounts and over a shorter period, allowing a faster return on investment.
- Finally, their operating cost should be very competitive. In August 2022, GE Hitachi Nuclear Energy stated that modular SMRs can be developed with a LCOE of around $60/MWh and that they will have a longevity advantage over renewables, between 60 and 100 years, compared with 20/25 years for wind and solar.

FIGURE 4

LCOE/LCOS Ranges of Nuclear Energy vs. Renewables, Storage.



Source: IDTechEx

The challenges of SMRs

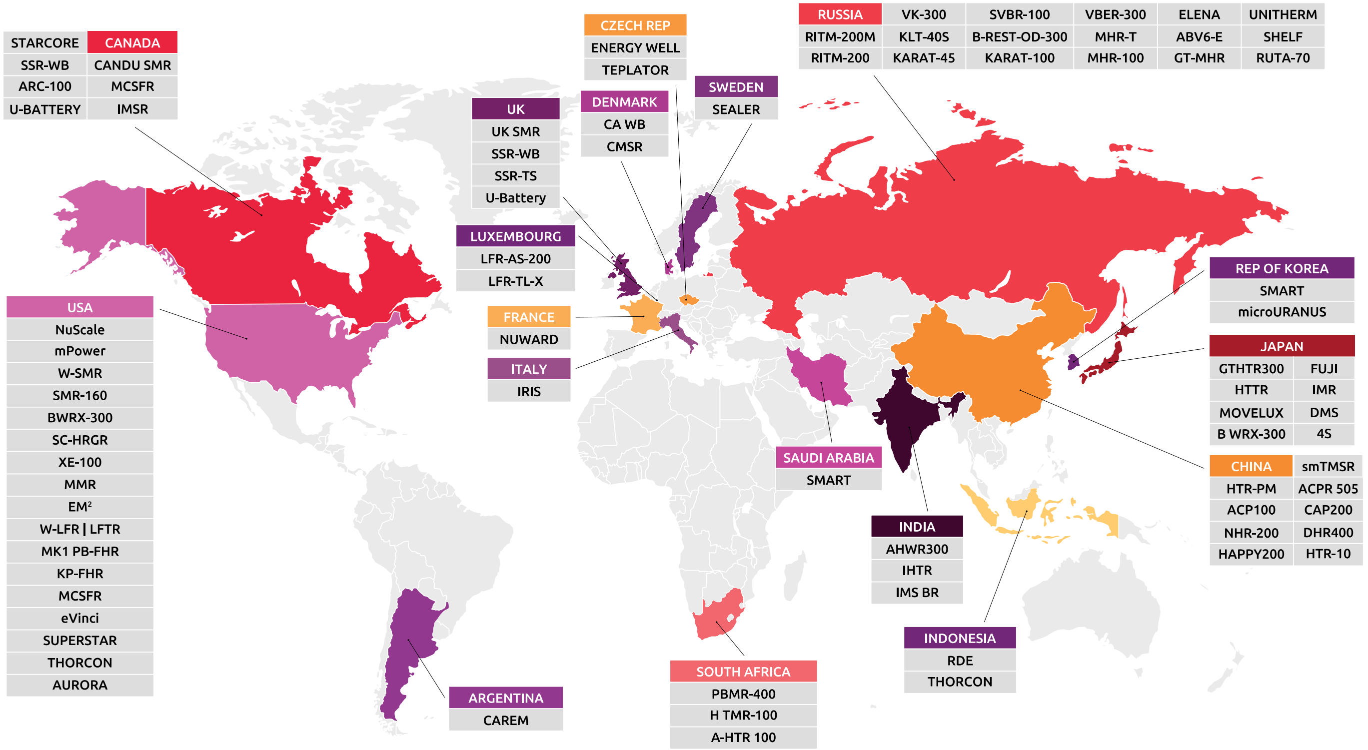
- Despite these competitive advantages, SMRs are still nuclear reactors with little construction experience. However, some small nuclear reactors have been constructed for aircraft carriers and military submarines. In addition, SMRs economic competitiveness is still to be proven in practice once they are deployed at scale.
- Harmonization of regulations and requirements around the world will be essential to support standardization of design, in-factory series production and limited design adaptations to country-specific requirements.
- The next decade is crucial, with some modular reactors due to be commissioned by 2030. Cost overruns, licensing delays and fuel shortages can easily bring construction to a halt. The fate of the NuScale power station in Idaho could be decided this year.

A very dynamic marketplace opening new market opportunities.

- These new generations of reactors are proving extremely popular worldwide. By 2022, the International Atomic Energy Agency (IAEA) will have identified more than 80 SMR and AMR projects worldwide, notably in the United States, Canada, China, Russia, the United Kingdom and France: For example NuScale and Holtec in the United States, Rolls-Royce in the United Kingdom, the Russian RITM-200, the Chinese ACP 100, the Korean SMR model and NUWARD in France. Most of the projects are in the design or licensing phases.

FIGURE 5

Worldwide development of small and medium-sized modular reactors by technology

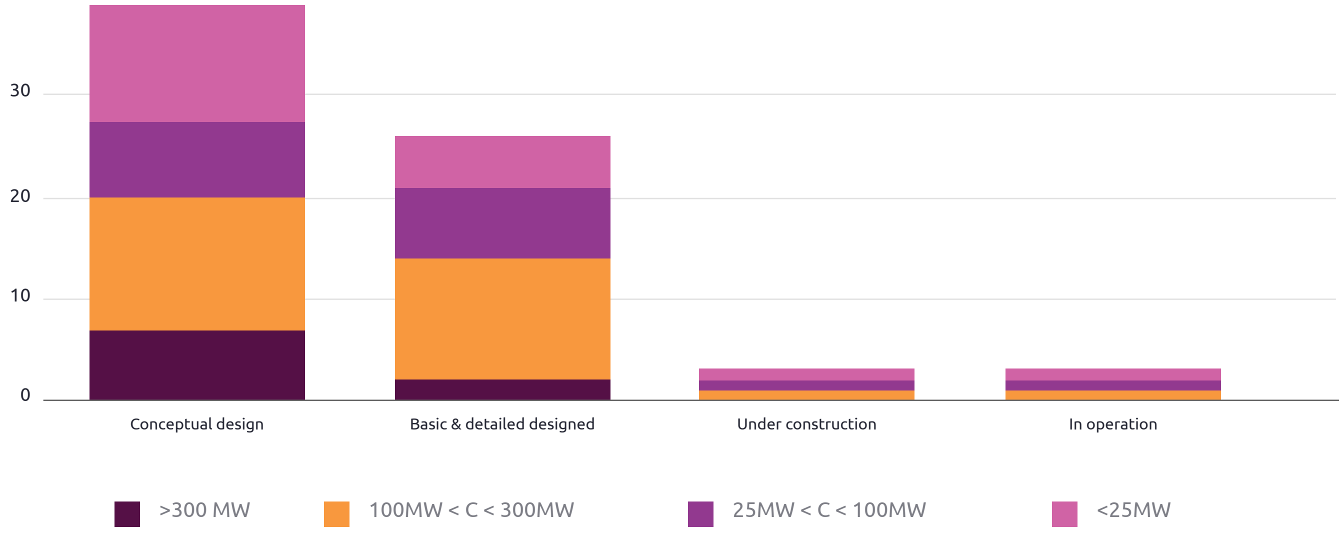


Source: AIEA

- Russia had the first operational SMR, but it is probably China that leads the world in SMR operations, with two SMRs operational on a commercial scale. North America and Europe are other geographical poles of development, although in Europe, projects are at a less advanced stage. Other countries with projects making significant progress are scattered around the world - such as Argentina, which is building the CAREM.

FIGURE 6

Global number of small modular reactor projects by development status, 2022



Source: IEA -Energy Monitor

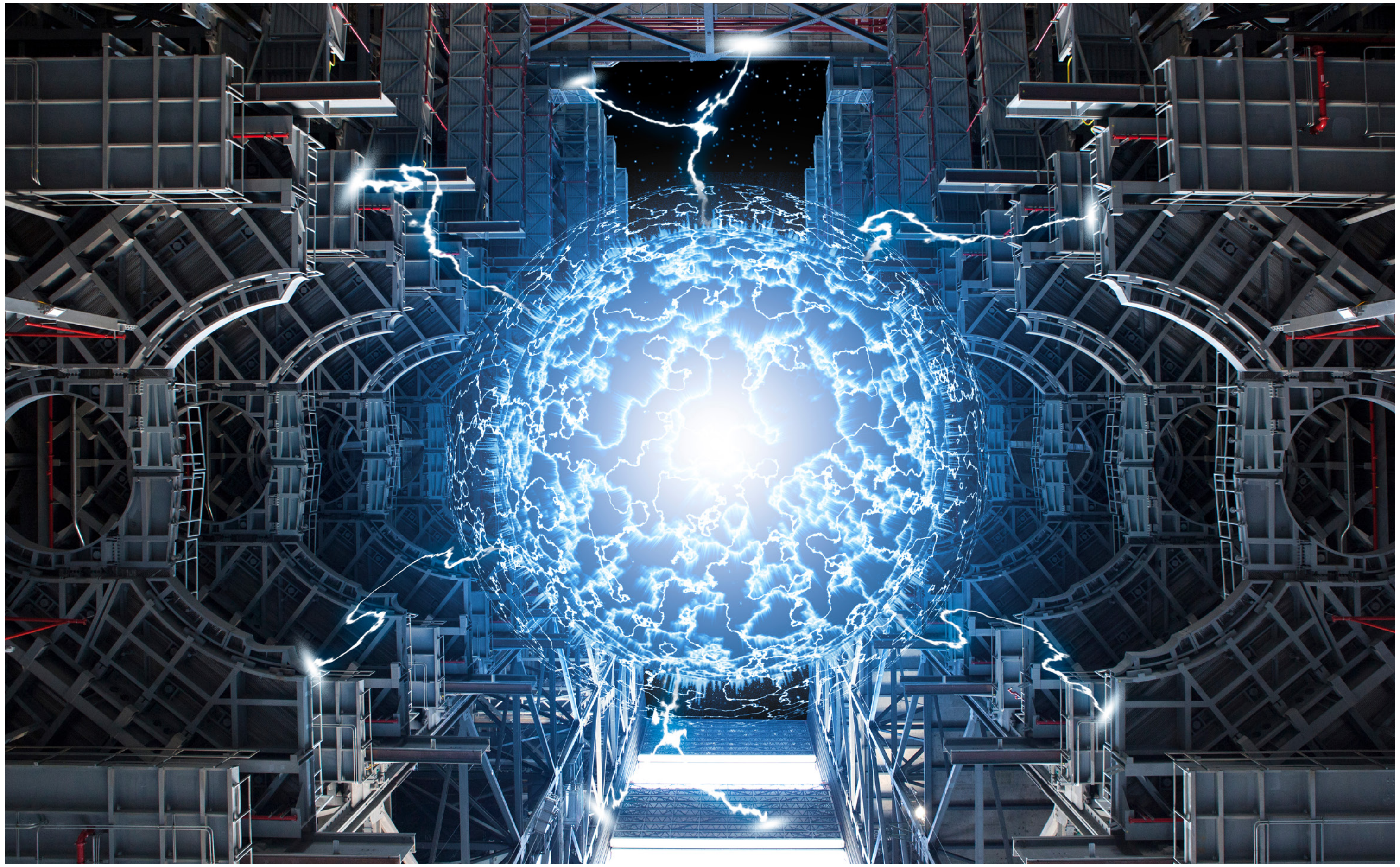
- The market for SMRs and AMRs is huge: in countries open to civil nuclear power, more than 3,300 coal-fired units will have to be replaced by 2050 and SMRs have the right size for that.
- But as well as supplying electricity, these new generations of reactors will have other uses, such as producing heat or supplying electricity for desalination plants, green hydrogen production or synthetic fuels production.

District heating is also one of the possibilities offered by SMRs and AMRs, as shown by the studies carried out in Finland to replace district heating networks with SMRs, thereby reducing the use of fossil fuels.

- The first examples of the most mature SMR models, based on 3rd generation technologies, are expected by 2030. Regarding the AMRs, their industrial and commercial availability will not happen before 2040 or even 2050.
- Many start-ups have invested in SMRs and AMRs. Of the more than 70 SMR models under development, 21 are being developed by a new company.

Fusion is not expected to be implemented before 2050 in the most optimistic scenarios.

- Several projects:
  - Laser-triggered fusion: only 2 places in the world are experimenting with this type of fusion, including 1 based in France (the Laser Megajoule near Bordeaux) and another in the US, where the NIF (National Ignition Facility) laser instrument reached in laboratory the breakeven point on 5 December 2022 proving that controlled nuclear fusion can generate more energy than it consumes.
  - Tokamak: ITER project in France which benefits from international funding, Tokamak EAST in China, which has beaten several records1.
- Still at the experimental stage, nuclear fusion is fueling hopes of large-scale, carbon-free and electricity production with abundant fuel. It should emit little and short lifetime radioactive waste.
- In the same fuel quantities, nuclear fusion could produce 4 million times (versus 1 to 2 million times for fission) more energy than fossil fuels: oil, gas and coal.
- Several technological challenges must be overcome. For example, the tokamak process requires heat confinement of up to 150 million degrees. Reactors must prevent the walls from melting, while maintaining fusion for as long as possible.
- Although nuclear fusion reactors are promising and could hold a key role in our energy future, they are not expected to be in industrial operation before 2050 at the best.



Main issues to sustain and drive the nuclear development.

Main issues to sustain and drive the nuclear development.

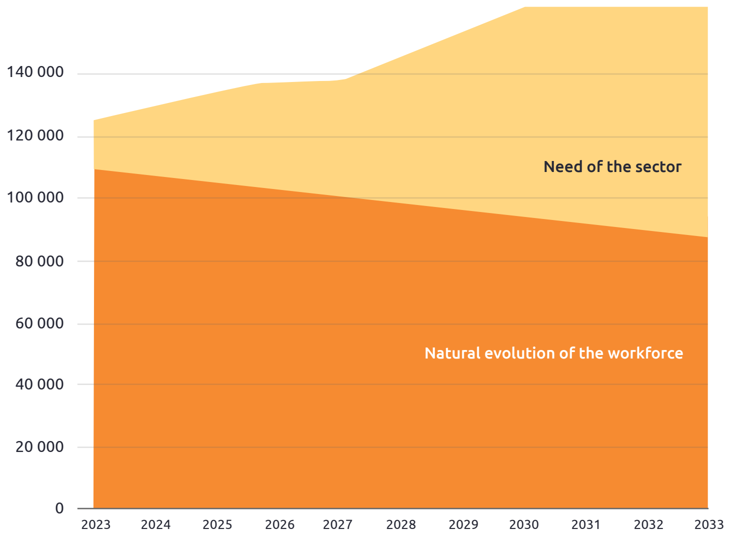
- Because their design is highly technical and safety issues are crucial, it takes years to be get nuclear plants design and construction approved. They are thus expensive to build while their fuel and operation cost are relatively low. The US Department of Energy (DOE) estimates that nuclear reactors should cost around 3,600 dollars per kilowatt to allow quick development in the country. However, the first reactors of this type cost between 6,000 and 10,000 dollars per kilowatt.
- A period of high interest rates will lead to higher construction cost.
- To encourage nuclear development despite these difficulties, innovative approaches to financing and support policies are being pursued, including partial investment or loan guarantees from the government.

Unprecedented need for workers, a major source of employment.

- Finding enough workers to build and operate new nuclear plants is a real challenge.
- The DOE estimates that US will need an extra 375,000 workers to meet the 2050 target. "The very near term is going to require the skilled trades: electricians, metal workers, fabricators, construction" says Kathryn Huff, the head of the DOE's Office of Nuclear Energy. The need for reactor operators and nuclear engineers will come later. "This is a blue collar blueprint to rebuild America" said President Biden.
- In France, in April 2023, the" Groupement des Industriels Français de l'Énergie Nucléaire "2(GIFEN) presented the government with the "MATCH" program, which sets out the capacities and requirements of the nuclear industry over the period 2023-2033, as it prepares to relaunch itself. Extrapolated to all 220,000 jobs in the nuclear industry, the foreseeable need would be around 100,000 full-time equivalent recruitments.
- But in a tight labor market it is unclear where all those workers will come from.

FIGURE 7

Estimated FTE requirement (French nuclear field)



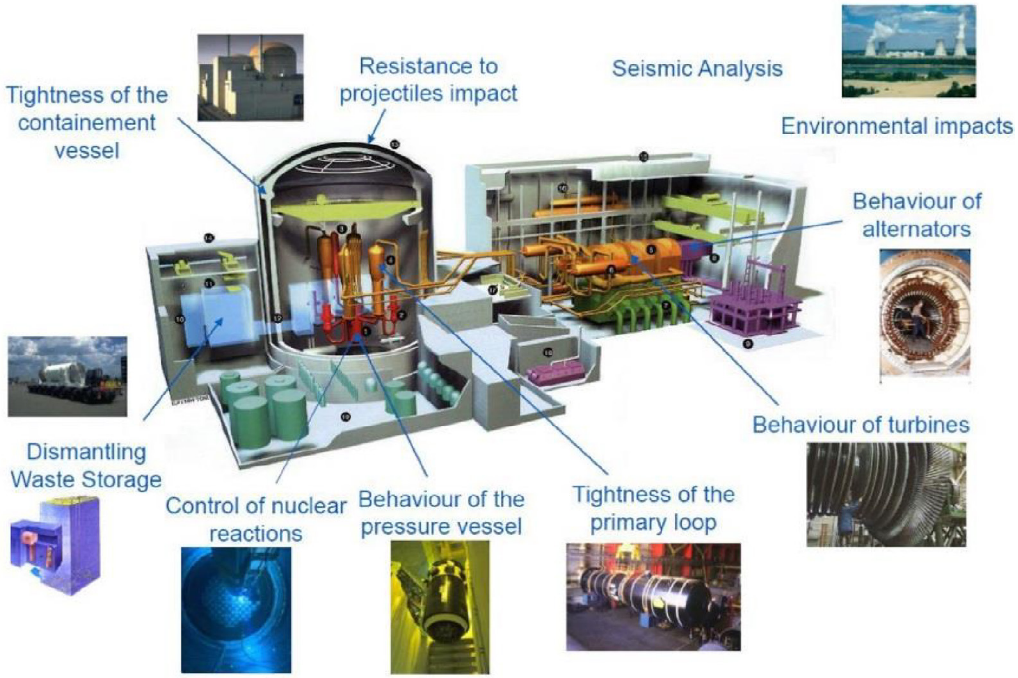
Source: Match Report

Digital technologies are a strategic lever for productivity, performance, quality, and nuclear safety.

- Digital technologies are now reaching maturity and are considered as key enablers. Numerous initiatives by companies of all sizes, including startups, are now underway at every stage of the life cycle of nuclear facilities, including design and simulation, construction and manufacturing, operation, and maintenance, dismantling and waste management, and safety.
- Like EDF, the nuclear industry has embarked, at a more or less sustained pace, on an in-depth transformation that requires joint improvements to material flows (industrial processes, management of manufacturing deviations, etc.) and information flows (document exchanges, fault analysis, widespread use of 3D models, etc.), all supported by digital transformation (PLM, MES3, etc.).
- Ultimately, these investments will enable to control safety requirements, costs and “lead times.”
- They will go hand in hand with the standardization of components and processes and contribute to better management of equipment performance.
- They will also enable each country to strengthen its competitiveness and win export contracts - with major benefits in terms of the balance of trade and high value-added jobs.
- Digital technology can make a major contribution to sharing the information needed to carry out security checks in a way that is both safer and more efficient, or to supplement these checks with artificial intelligence tools.

FIGURE 8

EDF has developed for 30 years its advanced simulation capacity, methodology and in-house software.



Source: EDF

Conclusion

- The growing urgency of the climate change impact and, more recently, the energy crisis has wakened-up a global interest in nuclear energy.
- China is still leading the construction market with by far the most reactors under construction. However, Chinese companies are currently not building reactors outside their country. Russia is still largely dominating the international market as a technology supplier.
- In the OECD countries, more and more countries are announcing the launch of new programs or the desire to relaunch the nuclear industry. Beyond the challenges of decarbonizing society, these programs also aim to re-industrialize countries and consolidate their energy sovereignty.
- To that end, there are many challenges to be met, particularly in terms of resource requirements, financing in an era of increasing interest rates and controlling costs and deadlines.
- Industries have embraced the issue and are using digital technologies (typically digital twin programs) throughout the lifecycle of a reactor to improve performance and safety and reduce costs and lead times.
- There is much expectation surrounding the SMRs development, a new generation of nuclear reactors that are being marketed as the solution to nuclear power's previous shortcomings. The proliferation of initiatives worldwide, the unprecedented volume of investment and the competition between developers will lead to technological breakthroughs and a possible acceleration of the design and development phases.
- In addition to technology improvements a successful nuclear renaissance implies: a strong political will, available financing, public opinion (national and local) acceptance and approval processes acceleration.

IS THE BATTERY INDUSTRY READY TO SUPPORT THE ENERGY TRANSITION?


TIM GERKENS, GERMANY


SIMON SCHÄFER, GERMANY


MANUEL CHAREYRE, FRANCE


RICHARD BIAGIONI, FRANCE

Batteries are key – can they deliver?

Electrification, combined with the usage of green energy, is a key lever to meet future CO_2 targets and transform industries towards climate neutrality. The expected growth of green technologies, such as electric cars or trucks, is extremely high and rapid. The fluctuation in renewable energy generation requires ramping up stationary battery energy storage systems for grid stability.

This shift causes the need for a significant increase in battery production. Can we meet the demands in time? Will the costs be bearable? Is the supply chain sustainable? Is there enough raw material accessible? Can the industry deliver what is needed?

The battery race is on

The race is on for the gigafactory and battery industry. The key to success is providing the required number of batteries quickly, at competitive cost and at scale.

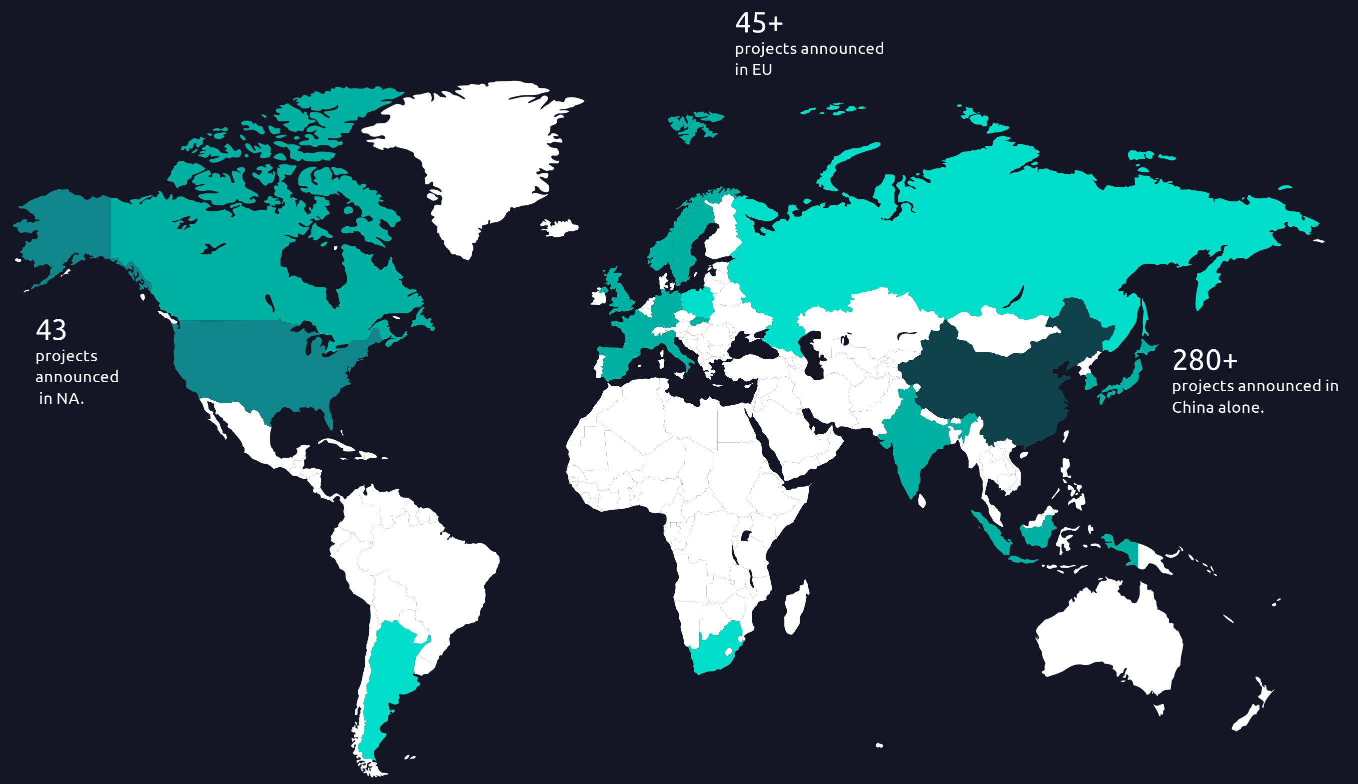
Major challenges in the battery industry include rapid scrap rate reduction, high and consistent quality, and increased throughput on the technical manufacturing side. But also, the war for talent, the need for sustainability across the entire value chain, and traceability to meet regulations are equally important. It is crucial to foster data for product and manufacturing improvements, as well as to successfully create new services and business models in order to remain competitive.

More than €300 billion in investments into gigafactories have been announced until 2030 already. More than 6.8 TWh are currently announced for 2030, covering the need of 3.5 TWh (APS scenario), which is six-fold today's capacity. However, being on the edge of meeting the net zero emissions (NZE) scenario requires 5.5 TWh if an 85% utilization is considered[1,2].

1 Global EV Outlook 2023, IEA, Paris, p.121ff NZE Net Zero Emissions Scenario APS Announced Pledges Scenario
2 Benchmark Minerals Intelligence (2023) IRA supercharges USA's gigafactory capacity pipeline as it overtakes Europe for first time, Company Announcements
T&E (2023) Two-thirds of European battery production at risk, Company Announcements

FIGURE 1

Announced battery production sites until 2030



400 PROJECTED & RUNNING BATTERY PRODUCTION SITES UNTIL 2030

- **In 2022, companies announched more than $73 billion in US projects - 3x 2021**
- **More than two-third of battery production announced in Europe is at risk due to IRA subsidies in the US**
- **Chinese battery firms have announced investments in Europe worth $17.5 billion since 2018**

Source: IAEA (PRIS)

Digital, data, artificial intelligence (AI) – Driving the step change

Producing batteries and their components is costly and highly complex, and as a multitude of new organizations race to market, even the incumbent players have acknowledged they need to modernize and transform their operations. All players in the battery industry are facing a multitude of challenges. Two main ones are:

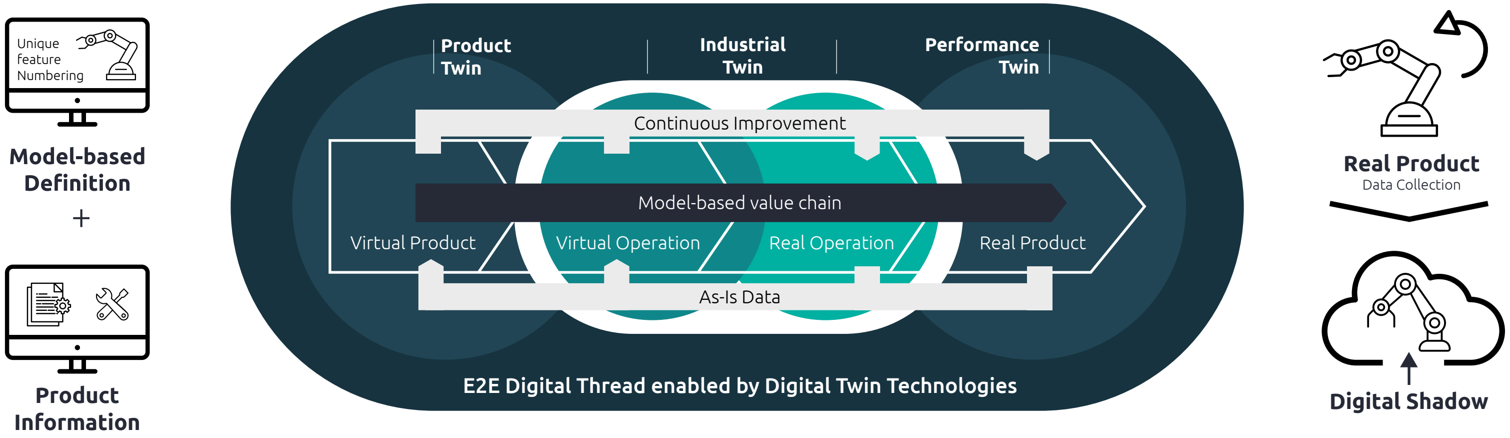
Challenge #1: Time-to-Market: It takes about five years from a small-scale pilot factory to the completion of a gigafactory with stable production. Given the current demand for battery and battery components, manufacturing organizations need ways to streamline their processes to get gigafactories up and running faster at scale and quality to remain competitive.

Companies that do not produce in a short time at scale & at cost will not survive

Challenge #2: High scrap rate: It is not enough to quickly start production in a gigafactory. Today, gigafactories suffer from a high scrap rate of up to 30% in the ramp-up phase. Such waste and its associated costs are unsustainable from a business perspective, as a 10% scrap rate reduction can save $200-$300 million per annum for a 30 GWh factory[3]. Furthermore, gigafactory high scrap rates result in increased energy consumption and more waste, not to mention costly delays in production.

FIGURE 2

Digital Twin enables continuity between R&D and operations to accelerate the commissioning and ramp up



3 Battery Power (2023), *The Cost Benefits Of Investing In Solutions To Reduce Battery Waste And Scrappage In Gigafactories, Hitachi High Technologies*

Enabling a step change through digital and data

So, how can the industry overcome these challenges? How can a step change be made? Certainly not by optimizing the traditional approach, but by adopting a data-driven battery development and production method.

Taking a simulation-first approach to gigafactory development: By leveraging digital twins of the cell, pack, and manufacturing process, as well as the gigafactory as a whole, organizations can virtually design and commission optimal production lines, thus minimizing extensive prototyping and avoiding costly changes on the factory floor. The right combination of digital solutions and services is believed to bring the required acceleration in production ramp-up in the battery industry.

Connecting the digital and physical manifestations of gigafactories: By integrating data from virtual and physical facilities, organizations can facilitate end-to-end integration of the production process and accelerate physical commissioning. Combining virtual and physical data can identify and help organizations address potential quality or production issues early. Teams on the shop floor can act fast, assisted by data-driven automation and decision aiding, to accelerate manufacturing ramp-up and operations at scale.

Developing and deploying a data-driven operations strategy: Data and the use of AI are the backbone of a step change in gigafactory performance. Organizations can leverage data from the Industrial Internet of Things (IIoT) to identify potential quality issues and make changes to meet market needs. It is recommended to start from a data-centric architecture blueprint for the battery industry and associated ontologies, tailoring it to the client's best fit and requirements. An end-to-end solution and deployment of hardware and software solutions and services from the enterprise level to the shop floor is needed. The key is to enable a fully data-driven and closed-loop operation based on a highly scalable, flexible, and interoperable architecture. This helps organizations develop a solid data platform and a standardized data model that permits interoperability from different sources to access and analyze the information they need. Based on proof of concepts with clients and industry, companies can achieve scrap rate reduction significantly faster with data-driven manufacturing solutions and services.

Upstream supply chain – is the raw material supply sufficient?

Lithium prices are expected to remain high in the mid to long term as capacity shortages are announced. Scenarios considering varying future cell technology show that the need for lithium is growing by a factor of around 40 between 2020 and 2040, leading to potential supply risks[4].

Challenge #1: Global transformation: The extraction and transformation of metals carry a high social and environmental cost. Metal supply is becoming increasingly critical, commercial tensions between miners and their industrial customers are growing, and regulations are creating new constraints.

Challenge #2: Complex Sourcing: The extension of the battery metals sector is slow. Difficulties and delays are evident in industrializing innovative new plants, whether upstream for metal production and refining or downstream for battery production. Multi-sourcing will be imperative for several years to come, in order to guarantee supply quantities and lead times.

Challenge #3: New Logistics: Requirements of gigafactories are modest in individual terms, but micro-batch logistics need to be invented by miners, wholesalers, logisticians, and traders, who are more accustomed to managing bulk quantities of ores and metals.

Challenge #4: Legislative: The regulatory requirement for end-to-end traceability of battery quality and corporate social responsibility (CSR) certification of the metal extraction and transformation process demands the implementation of many digital services and complex electronic exchanges between all players in the value chain.

Challenge #5: Up-front Financing: The lack of a strategic vision by public authorities in the past meant that mining players were unable to find the support needed to obtain financing.

Coalitions of interest and digitization can turn things around

Studies show that today, the metals and mining industry qualifies as a data-poor environment and can be described as less digitally mature than comparable industries, such as automotive or chemicals[5]. However, by accelerating digital transformation, metals and mining players can boost throughput, simplify processes, lower costs, improve metal recovery and yield, save energy and reduce supply chain complexity. This can give economically viable access to more battery metals. Many companies are willing to embrace a digital strategy and reap its benefits. However, when it comes to conversion, there is a gap that exists due to specific industry requirements and old-fashioned ways of doing things.

The mining companies are forced to change. As outlined, regulations like the European battery passport require the change to digital and improved traceability. This opens unique opportunities to use the regulatory required data and the necessary infrastructure, enrich it with additional data, and run specific intelligence for real-time and long-term insights and decisions.

Also, systems need to be set up to ingest and use data to be fully connected to the ecosystem and make use of its digitization efforts. Conversely, it is imperative to incorporate third-party market services and platforms into the comprehensive digital strategy to optimize their utilization.

For Europe and North America, it is a chance to take the lead by defining and agreeing on a governance structure, marketing methods, associated services, and technological underpinnings for a unified solution.

Can circularity fill the gap? Or new chemistries?

Currently, the recycling industry cannot provide significant additional volumes, which means it cannot fill the gap in battery metal supply immediately. This is due to a shortage of recycled batteries, the immaturity of the recycling process due to product complexity, and the availability of recycling facilities.

The continuous innovation in the chemistries for battery cells is trying to lower the dependency on rare metals such as cobalt or lithium. How quickly these new concepts can really change the predicted demand for scarce resources needs to be proven. Still, in other industries, emergencies have accelerated such processes.

4 IEA (2021), *The Role of Critical Minerals in Clean Energy Transitions, IEA, Paris*
5 Rockwell (2021) *The Connected Mine Evolution*
WEF (2023) *Connected, Safe, Intelligent – Mining in Modern Age*
BGR (2020) *Assessment of the Effects of Global Digitalization*

Recycling of batteries – starting with gigafactory scrap

The topic of recycling is becoming increasingly important. While in the short term, most gigafactory scrap is used in recycling. Within this decade, the recycling market will grow to an estimated market size of $19-22 billion by 2030[6]. A growing number of batteries are on the market, and they will reach end-of-life. Therefore, significant growth opportunities in the recycling space are emerging.

Within the recycling market, several challenges regarding technology, profitability, logistics, and safety need to be solved:

Challenge #1: Changing battery designs: Evolving and diverse battery designs and materials create a need for automated sorting and design for recycling.

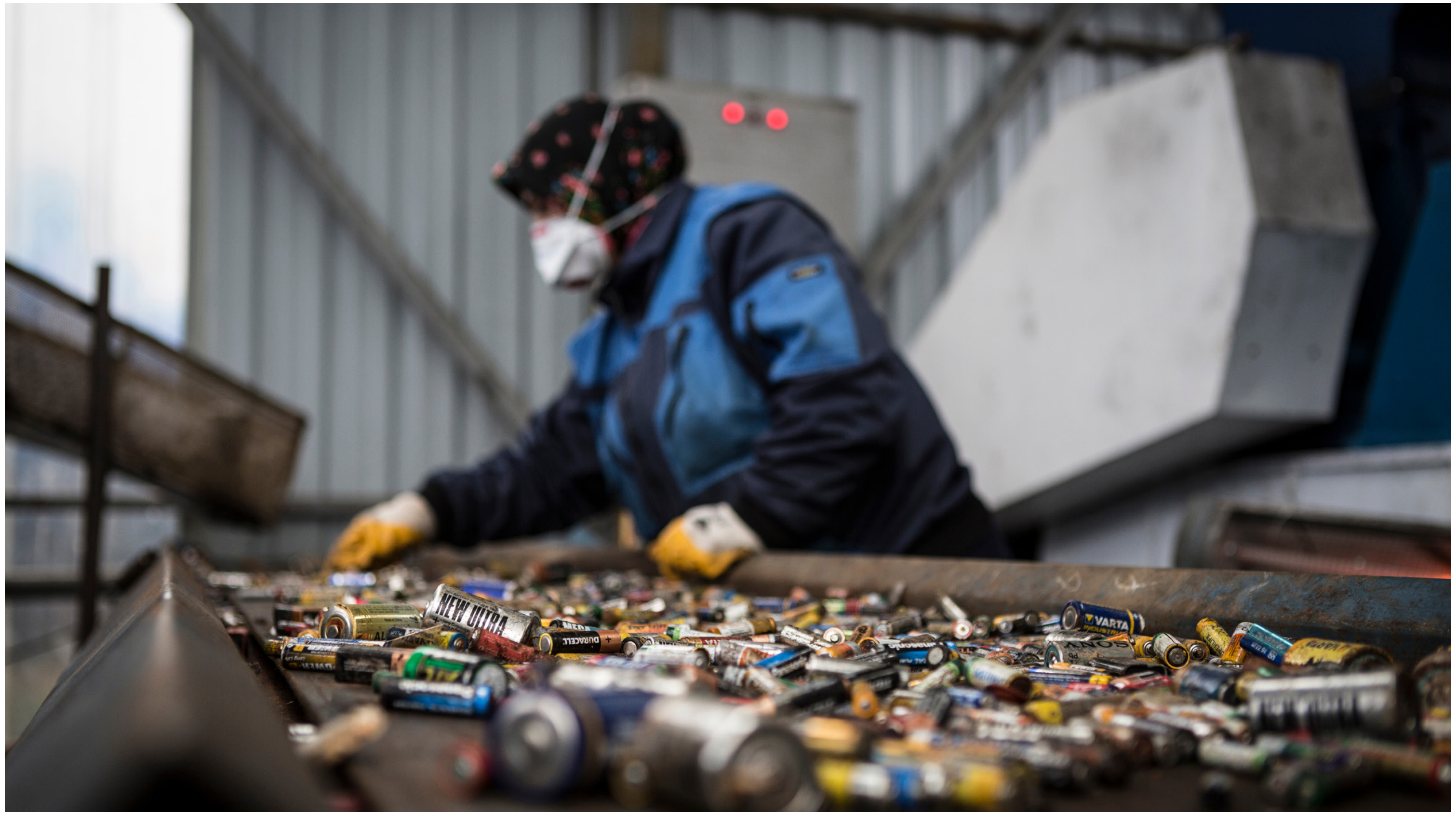
Challenge #2: Safety hazards and manual effort: Separation of components is technically challenging with safety hazards and requires manual work.

Challenge #3: Scalability and ramp up: Scaling up and industrialization of recycling technologies is necessary to handle gigafactory scrap, but also to be ready for future recycling volumes.

Challenge #4: Commercial impact: Maintaining economic viability is challenging as it is cost- and energy-intensive.

Challenge #5: Traceability in recycling: Complex supply chains and a lack of standardization has led to challenges. Transparent information about the battery's health and used materials must be available digitally at end-of-life.

Challenge #6: Collection and transportation: A lack of efficient collection and transportation systems for used lithium batteries leads to increased costs and challenging business cases.



6 Marketresearch Future (2023), *Lithium-Ion Battery Recycling Market*,
EMR (2023) *Global Battery Recycling Market Outlook*

The race is open to seize a fast-growing market

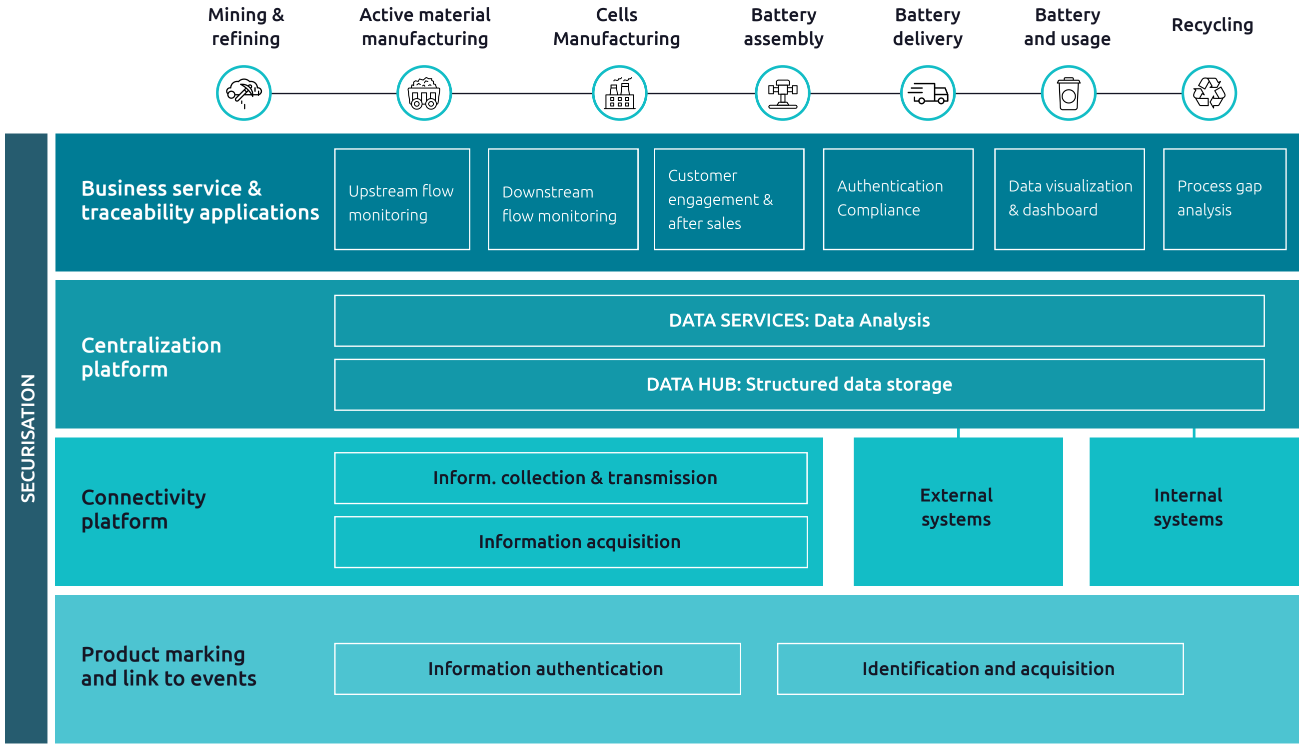
Due to the current lack of batteries to be recycled at scale, it is a different situation than in the battery manufacturing industry, where demand is high. But at some point, the industry must be ready to follow the ramp-up of electric vehicle (EV) battery production. Until then, use the time to develop the technologies and digital enablers to ramp up quickly. The processing of the scrap produced during cell production and battery assembly is therefore where innovations can be developed and tested already.

How digital tools can enable the circular economy for batteries

To cope with the various challenges of the recycling industry, there is a need to leverage data and implement digital tools. Digital continuity and traceability powered by digitization provide better information about a battery when it comes in for recycling. As a result, disassembly of physical and chemical components can be automated and made safer, faster, and cheaper. The digital twin of batteries assists in algorithm training and facilitates virtual testing for machine-driven innovations in battery design for simplified recycling. This occurs prior to physical implementation, resulting in expedited and cost-effective development and improvements. Such models and processes capture knowledge for faster replicability and efficient scaling-up of recycling capacity. Integrated into the overall (extended) enterprise, information technology/operational technology (IT/OT) architecture, scrap and recycling management becomes automated and efficient, providing additional data from the analysis that can flow back into the manufacturing process and product improvements.

FIGURE 3

E2E traceability is enabled by a multi-technological ecosystem



Who will design, produce, and recycle all these batteries?

In this rapidly expanding industry, which is projected to maintain a compound annual growth rate (CAGR) of over 29% in the next decade, both, well-established companies and newcomers, are vying for a highly skilled workforce.

Challenge #1: Lack of talent: There is a surge for specific battery skills in the market, but the market cannot deliver the needed expertise or the quantities required. A wide range of experts are needed to successfully ramp up new battery development and gigafactory production, ranging from electrochemists, system engineers, process engineers, and digitalization specialists, as well as large amounts of qualified blue-collar workers for the production. By 2025, about 800,000 workers must be upskilled, trained, or reskilled to meet the growing workforce demand[7]. Companies must find a way to be very efficient in training the workforce, and to be an employer of choice to retain employees.

Making it simple is key

Challenge #2: Limited time to train & gather experience: Although there is a need for a rapid ramp-up in operations, the time available to train people is limited. This limitation, combined with the shortage of skills, can only be addressed when the amount of training needed is reduced. Therefore, the work needs to be simple, straightforward, and easy to understand while being safe, effective, and attractive to keep talent.

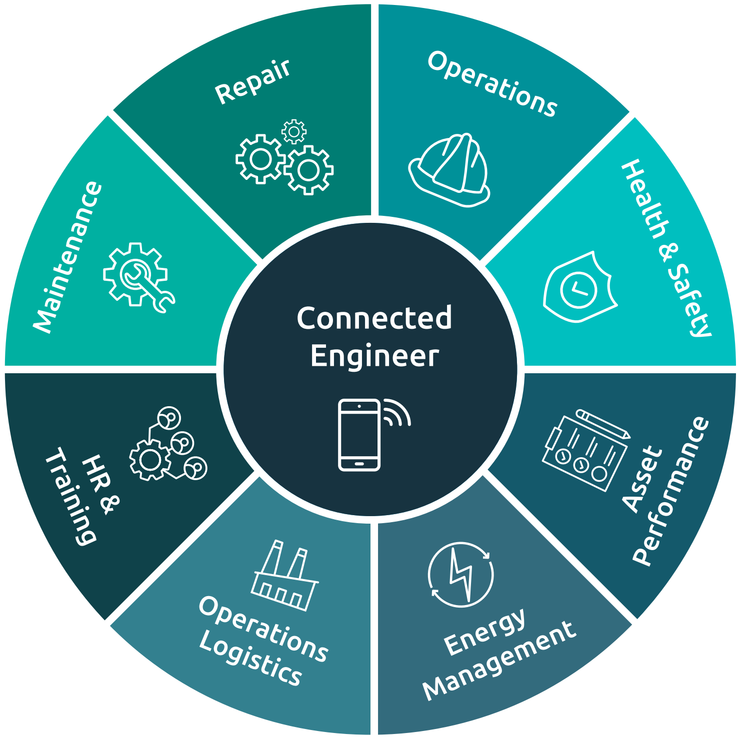
The new way of working is a digitally enabled operator

To address these challenges, it is necessary to implement innovative and intelligent methods for training, support, and operations. The opportunities that digitization and data bring to the table need to be leveraged to the maximum potential.

To achieve a high plant efficiency quickly, a skilled workforce is essential. Higher automation, more autonomous decisions, and AI-based decision aids will reduce the needed skill level in the workforce, leaving specific knowledge to a smaller group of specialists. It is crucial to capture and formalize specialist knowledge, making it available to the workforce through automation/decision aids and agile training elements. Ontologies, natural language processing, and generative AI, all smartly combined, are a means to realize such knowledge capture and the basis of making it available again.

FIGURE 4

Future Operator: Connected or Augmented Worker solution to maximize organizational performance



7 EIT Inno Energy (2022) *European Commission set to grant EIT InnoEnergy 10 million Euros to bridge growing skills gap across battery value chain*

Levers for talent upskilling

Making training as real as possible, ensuring continuous lessons learned flow into training, and reacting to the latest changes, advancements and insights are key. Hence, it is imperative to integrate the training system into the operational system, ensuring connectivity to a single source of truth. This enables the seamless linkage of operational changes and insights directly into training and expert support, facilitating immediate feedback and improvement. It also provides the opportunity, using tools like augmented reality/virtual reality (AR/VR), to offer training during regular operations for continuous skill enhancement, including real-time corrections and support.

Basic training shall be real, interesting, and to the point. Digital twins and synthetic environments are a means to train a larger staff, regardless of location, which is also essential when replicating gigafactories worldwide. Just as the factories are to be network-managed, so too will the training. Variations across locations and production lines are pinpointed through end-to-end traceability across products, processes, and factories, allowing for the management of their impact on training.

The future of work lies with connected and digitally enabled operators, making things easier and more efficient, as well as safer, more enjoyable, and rewarding for the workforce.

Conclusion

Battery players need to holistically embrace digital and data to win the gigafactory race

Data-driven business agility is the core of successful gigafactory design, industrialization, and operation. A holistic enterprise architecture designed for a fully digital and data-driven system provides the framework needed while ensuring digital continuity.

This approach not only yields benefits in product, process, and factory engineering but also offers advantages in terms of time to market and cost. Moreover, adjacent disciplines should seamlessly integrate, utilize a common single source of truth, and harness the generated data to maximize their effectiveness. Supply chains driven by upcoming regulations and training must be fully digitally integrated to improve company performance and address current challenges.

With recycling being an integral part of a factory and an important piece of the value chain, the gigafactory must be entirely digitally integrated, both internally and externally, for effective battery production at cost and scale.

The battery industry is a closed-loop ecosystem with high investment, many challenges, and potential risks, but also great opportunities. Going digital by design across the whole value chain is mandatory to be successful.

FIGURE 5

Accelerating in overcoming challenges is crucial for market success

ELECTRIC VEHICLES: MARKET REVIEW AND RECENT TRENDS

MATTHEW MORRIS, UK

MIKE LEWIS, UK

Trends in electric vehicle markets

Trend Category	Major Trends	Additional comments
Trends in electric light-duty vehicles	Electric car sales continue to increase, led by China	In 2022, China was the frontrunner once again, with **China accounting for around 60%** of all new electric car registrations globally
	Over 26 million electric cars were on the road in 2022, up 60% relative to 2021 and more than 5 times the stock in 2018	The increased sales resulted in **more than 26 million electric cars** on world's roads in 2022, representing a 60% uptake from 2021
	The number of electric car models rises, especially for large cars and SUVs, at the same time as it decreases for conventional cars	The race to electrification is increasing the number of electric car models available on the market. In 2022, the number of available options reached 500, up from below 450 in 2021 and more than doubling relative to 2018-2019
	Emerging markets see encouraging growth	China, Europe and the United States , the three major markets for electric cars , accounted for about **95% of global sales in 2022**
	Sales of electric light commercial vehicles continue to increase, catching up with electric car sales	Electric light commercial vehicle (LCV) sales worldwide nearly doubled in 2022 relative to 2021 to more than 310 000 vehicles, even as overall LCV sales declined by more than 10%
	Electric two-wheeler sales declined in China while global electric three-wheeler sales continued to rise	Global electric two-wheeler sales totalled **about 9.2 million** in 2022, a drop of nearly 18% from 2021. This drop is almost entirely attributable to the dip in sales of electric mopeds and motorcycles in China, which fell from 10.2 million in 2021 to under 7.7 million in 2022, even as the overall two-wheeler market there continued to grow
Trends in electric heavy-duty vehicles	Electric truck and bus sales shares	In 2022, **nearly 66,000 electric buses and 60,000 medium- and heavy-duty trucks** were sold worldwide, representing about 4.5% of all bus sales and 1.2% of truck sales worldwide.
	Zero-emission vehicle model availability expanded in 2022 in the medium- and heavy-duty truck segments	The number of models on offer for zero-emission trucks has continued to expand in 2022, with nearly 840 current and announced medium- and heavy-duty vehicle models in the Global Drive to Zero Emission Technology Inventory (ZETI) database
	China dominates heavy-duty battery production	European and North American electric bus and truck makers rely heavily on Asian battery makers. Given their dominance in lithium iron phosphate (LFP) battery chemistries, China's CATL produces the vast majority of batteries for trucks

EV sales in 2022

	Cars	Buses	Trucks	Vans	Total
Global	**10,200,000**	**65,400**	**59,500**	**307,900**	**10,632,800**
China	5,900,000	54,300	51,500	131,500	6,137,300
Europe	2,600,000	4,770	2,815	92,200	2,699,785
North America	1,112,400	NA	NA	NA	1,112,400

Source: IEA

- Electric car sales exceeded 10.6 million in 2022, with a total of 14% of all new cars sold were electric in 2022, up from around 9% in 2021 and less than 5% in 2020
- This resulted in more than 26 million electric cars on world's roads in 2022, representing a 60% uptake from 2021
- Battery electric vehicles (BEV) accounted for over 70% of total annual growth, as in previous years
- Three markets, viz. China, Europe and the United States dominated the global sales.
- China was the frontrunner once again, accounting for around 60% of global electric car sales. More than half of the electric cars on roads worldwide are now in China and the country has already exceeded its 2025 target for new energy vehicle sales
- In Europe, the second largest market, electric car sales increased by over 15% in 2022, which implies that more than one in every five cars sold was electric
- Electric car sales in the United States , the third largest market, increased 55% in 2022, reaching a sales share of 8%

Cumulative electric vehicles sales (2010-22)

Year	Buses	Cars	Trucks	Vans	EV - Grand Total
2010	2000	7570	24	1600	**11194**
2011	1010	48000	300	3700	**53010**
2012	2600	118000	450	11011	**132061**
2013	5700	201000	910	11005	**218615**
2014	16300	330000	380	11020	**357700**
2015	121000	550000	17000	27780	**715780**
2016	106000	750000	15005	23170	**894175**
2017	91530	1180000	81000	86140	**1438670**
2018	98600	2050000	57600	80190	**2286390**
2019	81700	2080000	38400	59280	**2259380**
2020	73700	2970000	34420	86500	**3164620**
2021	56900	6500000	41000	156300	**6754200**
2022	65400	10200000	59500	307900	**10632800**
EV - Grand Total	**722,440**	**26,984,570**	**345,989**	**865,596**	**28,918,595**

Electric Vehicles-Three Major Markets

China, Europe and the United States - the three major markets for electric cars , accounted for about 95% of global sales in 2022.

China

- In 2022, China was the frontrunner once again, with China accounting for **around 60% of all new electric car registrations globally**
- Half of the world's electric cars are in China, with more than 50% of all the electric cars on the world's roads, a total of **13.8 million**
- In 2022, battery electric vehicles (BEV) sales in China increased by 60% relative to 2021 to reach **4.4 million,** and plug-in hybrid electric vehicles (PHEV) sales nearly tripled to **1.5 million**
- In 2022, the share of electric cars in total domestic car sales reached 29% in China, up from 16% in 2021 and under 6% between 2018 and 2020. China has therefore achieved its 2025 national target of a 20% sales share for so-called new energy vehicles (NEVs) well in advance

Europe

- Europe accounted for **10% of global growth** in new electric car sales
- In Europe, electric car sales increased by more than 15% in 2022 relative to 2021 to reach **2.7 million**
- Despite slower growth in 2022, electric car sales are still increasing in Europe in the context of continued contraction in car markets: total car sales in Europe dipped by 3% in 2022 relative to 2021
- Europe remained the world's second largest market for electric cars after China in 2022, accounting for **25% of all electric car sales and 30% of the global stock**
- European countries continued to rank highly for the sales share of electric cars, led by Norway at 88%, Sweden at 54%, the Netherlands at 35%, Germany at 31%, the United Kingdom at 23% and France at 21% in 2022.
- In volume terms, Germany is the biggest market in Europe with sales of **830,000 in 2022, followed by the United Kingdom with 370,000 and France with 330,000.**
- Sales are expected to continue increasing in Europe, especially following recent policy developments under the **'Fit for 55' package.**

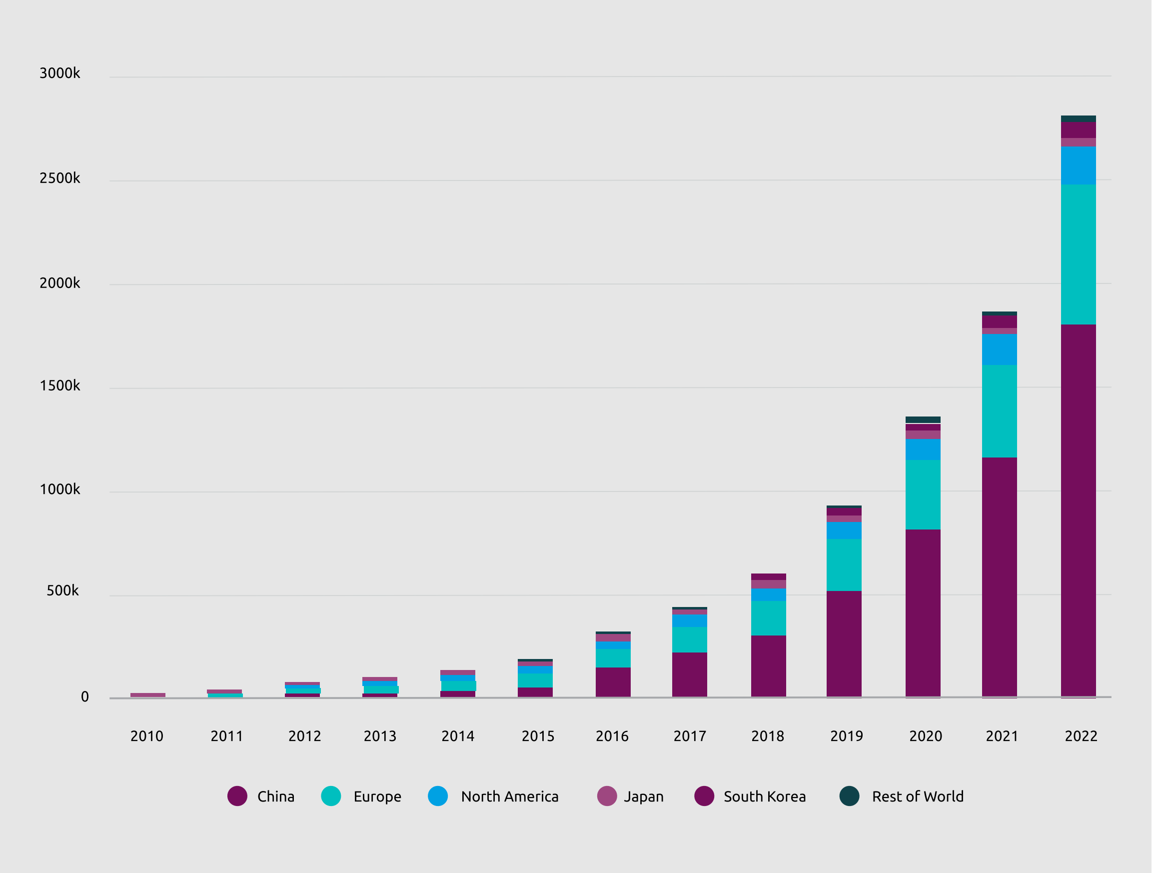
United States

- In the United States, electric car sales increased **55% in 2022** relative to 2021, led by battery electric vehicles (BEVs)
- **Sales of BEVs increased by 70%,** reaching nearly 800,000 and confirming a second consecutive year of strong growth after the 2019-2020 dip.
- Sales of plug-in hybrid electric vehicles (PHEVs) also grew, however by only 15%
- Overall, the United States accounted for **10% of the global growth in sales**
- The total stock of electric cars reached 3 million, up 40% relative to 2021 and accounting for 10% of the global total.
- The Inflation Reduction Act (IRA) has triggered a rush by global electromobility companies to expand US manufacturing operations
- Between August 2022 and March 2023, major EV and battery makers announced cumulative post-IRA investments of **USD 52 billion in North American EV supply chains,** of which **50% is for battery manufacturing,** and **about 20% each for battery components and EV manufacturing**

EV charging infrastructure

FIGURE 1

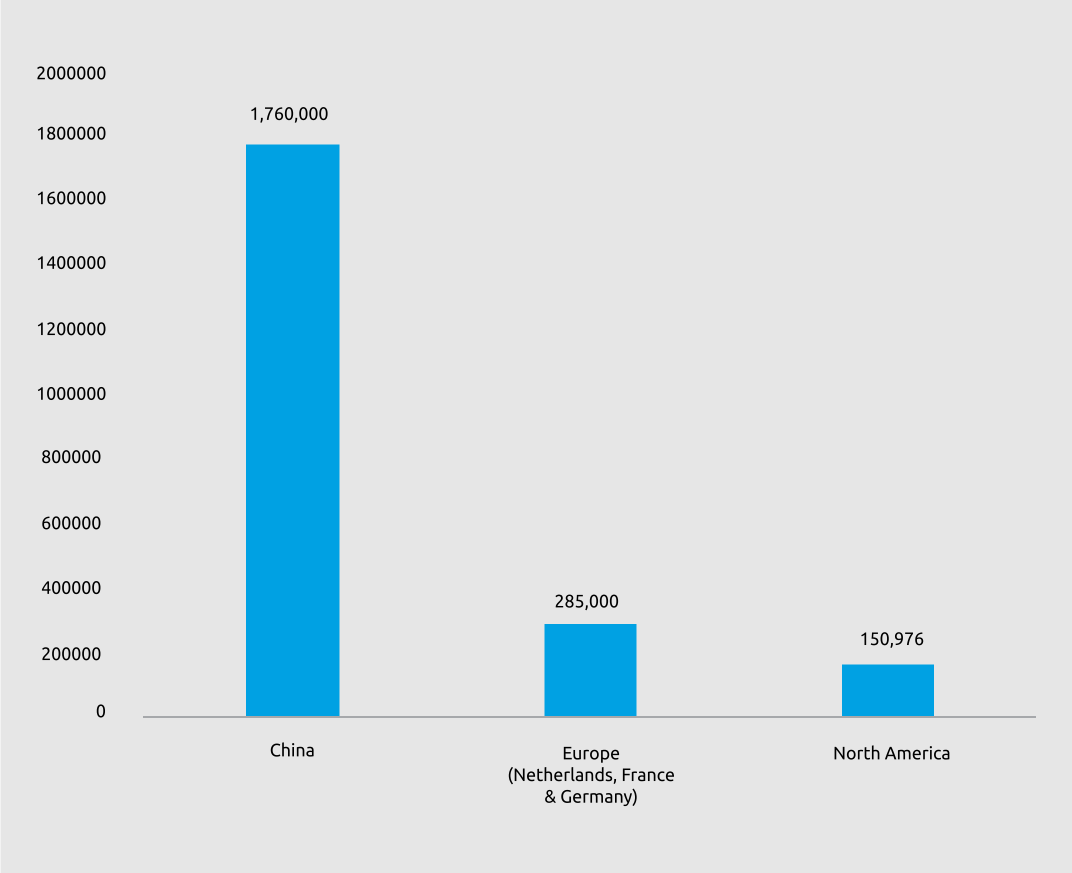
EV charging infrastructure (2010 - 2022)



Source: Bloomberg NEF

FIGURE 2

EV charging points (2022)



Source: IEA

At the end of 2022, there **were 2.7 million public charging points worldwide,** more than 900,000 of which were installed in 2022, about a 55% increase on 2021 stock

Slow chargers:

- Globally, more than 600,000 public slow charging points were installed in 2022, 360,000 of which were in China, bringing the stock of slow chargers in the country to more than 1 million
- At the end of 2022, China was home to more than half of the global stock of public slow chargers
- Europe ranks second, with 460,000 total slow chargers in 2022, a 50% increase from the previous year
  - The Netherlands leads in Europe with 117 000, followed by around 74 000 in France and 64 000 in Germany
- The stock of slow chargers in the United States increased by 9% in 2022, the lowest growth rate among major markets

Fast chargers:

- The number of fast chargers increased by 330,000 globally in 2022, though again the majority (almost 90%) of the growth came from China; China accounts for total of 760,000 fast chargers
- In Europe, the overall fast charger stock numbered over 70,000 by the end of 2022, an increase of around 55% compared to 2021
- The United States installed 6300 fast chargers in 2022, about three-quarters of which were Tesla Superchargers. The total stock of fast chargers reached 28,000 at the end of 2022.

Electric Motorcycles and Trucks

FIGURE 3

Electric Motorcycles and Trucks

	China	ASEAN[4]	North America and Europe	India	Other South Asia	Latin America	Africa
2021 market size,[1] million units	~15.0	~12.0	2.1	15.1	2.3	~2.8	~1.0
Estimated CAGR 2021-30, %	0-1	4-5	5-6	6-7	5-6	5-6	12-14
Moped/ Bebek,[2] %	–	15-20	–	3-4	0-5	15-20	0-5
Scooter, %	80-85	70-75	25-30	28-30	25-30	0-1	0-1
Light motorcycle, %	0-5	5-10	10-15	60-65	65-70	70-75	90-95
Heavy motorcycle,[3] %	0-5	0-5	50-60	4-5	0-5	0-5	0-5
Electrification level, %	~15	~2	~8	~4	<1	<1	<1

Source: McKinsey & Company

Electric Motorcycles:

- It is predicted that electrification could also transform two-wheelers, viz. the mopeds, scooters, motorbikes, and motorcycles that account for about 30% of global mobility
- These vehicles are an essential link in the transportation network, especially in China, South Asia, and Southeast Asia, with about 45 million units sold in fiscal year 2021
- The global two-wheeler market is projected to have a compound annual growth rate of 8.7 percent through 2029 when it will reach a value of about $218 billion
- While China and the developing world concentrate on smaller, typically work- or transportation-focused machines; North America (excluding Mexico) and Europe are more bifurcated, with premium brands selling more than 500 cubic capacity products

Electric Trucks:

- In 2022, around 60,000 medium- and heavy-duty trucks were sold worldwide, representing about 1.2% of truck sales worldwide
- In 2022, an estimated 52,000 electric medium- and heavy-duty trucks were sold in China, representing 4% of total sales in China and about 85% of global sales
- In addition, many of the trucks being sold in Latin America, North America and Europe are Chinese brands
- Electric trucks sales shares remain low across most major markets. With the exception of China, cumulative electric medium- and heavy-duty truck sales to date number in the hundreds in most countries (just under 2000 electric trucks were sold across the entire European Union in 2022)

Accelerating to net zero

Through a combination of government incentives, regulations evolutions, technology improvements, and the potential for cost savings, the past five years have seen a significant increase in the adoption of electric vehicles (EVs) by private citizens and businesses alike.

Between 2019-23 global EV growth rose from 2m vehicles to 11m. Similarly, electric vehicle charging facilities grew from 500,000 sites to over 2 million in the same period.

The next five years will be critical to supporting the global energy transition and revealing if electricity can be the long-term fuel for road transportation.

We see 5 technological that must mature within the time period:

Challenge #1: Expansion of public charging infrastructure
As the demand for EVs continues to grow, it must be supported by rapid growth of the public charging infrastructure

Challenge #2: Home charging solutions
Home charging options must become more diverse and accessible. EV owners will have a range of choices, from standard AC charging stations to faster Level 2 chargers and even more advanced Level 3 DC fast chargers installed at residences.

Challenge #3: Smart-Grid Integration
Vehicle-to-Grid/Home/Buildings (V2G/H/X) technology: In support of smart-grid evolution, V2G technology will be critical in smoothing the demand curve and the load-demand balance for the electric system.

Challenge #4: Wireless charging technology
Wireless charging technology is already proven to work, and will continue to advance and gain popularity in the coming years.

Challenge #5: Digital Customer Experiences
Enhanced user experience through digital solutions: Of all the technological forces within the EV and charging ecosystem, it is the area of delivering digital customer experiences which has made the least relative progress.

Challenge 1: Public charging infrastructure

As the demand for EVs continues to grow (forecasts suggest over 110m units produced worldwide by 2028 1), it must be supported by rapid growth of the public charging infrastructure. Governments, utility companies, generators, and regulators, as well as private entities, will need to coordinate, cooperate, and invest in building charging stations in centers of population and across the road network. The goal of eliminating range anxiety and establishing a dependable, widespread charging infrastructure aims to enhance the accessibility and convenience of EV charging for both current electric vehicle drivers and prospective first-time buyers.

Public charging infrastructure – which will need to be a network or networks provided by incumbent fuel retailers, dedicated EV charging companies, or small-scale local public interest groups – will need to provide a combination of low-power and high-power fast-charging networks to suit the needs of different driver scenarios.

The prevalence of high-power fast-charging networks will accelerate, enabling EV drivers to charge their vehicles rapidly. However, while they drastically reduce charging times, advanced charging technologies such as 350 kilowatts (kW) place a higher load on the overall power grid.

To enable electric vehicles for long-distance travel to rival the convenience of internal combustion engine vehicles, we must effectively utilize a blend of battery storage and advanced smart grid methods, ensuring drivers have reliable access to the power they require precisely when they need it. IE 2 have noted in most countries as the number of EV's on the road increases, the number of publicly available charging points is decreasing.

Challenge 2: Home charging solutions

Home charging options must become more diverse and accessible. EV owners will have a range of choices from standard AC charging stations to faster Level 2 chargers, and even more advanced Level 3 DC fast chargers installed at residences. Smart charging systems will integrate with renewable energy sources and allow for optimal charging times to reduce costs and maximize efficiency.

Challenge 3: Smart grid integration

In support of smart grid evolution, V2G technology will be critical in smoothing the demand curve and the load-demand balance for the electric system by allowing EVs to not only consume electricity but also feed it back to the grid or the home when needed. This capability will need to become more widespread, perhaps as part of future home charging solutions. Creating a two-way flow of electricity between vehicles and the power grid also requires modifications to most domestic electrical systems. EV owners may need incentives to participate in demand response programs to support utilities in using the stored energy in EV batteries to balance the grid during peak demand periods.

Challenge 4: Wireless charging technology

Wireless charging technology is already proven to work and will continue to advance and gain popularity in the coming years. As with all aspects of EV and smart grid, the ability to access the benefits of this innovation is dependent on the speed at which it can be added to national infrastructure.

Challenge 5: Digital customer experiences

Among all the technological facets within the EV and charging ecosystem, the aspect that has shown the least relative advancement is the delivery of digital customer experiences.

If the growth in physical charging networks and EV vehicle adoption can be described as rapid, the evolution of digital experiences to access such services has been sedentary. For years, drivers have had up-to-the-minute information on traffic conditions, the location of the nearest open supermarket, the location of the closest fuel station with the most competitive price, and the estimated time of arrival from within a single mobile app.

The opportunity to design for the needs of EV drivers and shape how EV drivers interact with charging infrastructure elements will become the next competitive edge for suppliers of charging services. Providing aggregated mobile apps and platforms to provide real-time information on the availability of charging stations, charging rates, and even reserve a spot in advance, will be differentiators for those suppliers who can get it right.

Crucially, it will be the digital identity of the EV driver that will incorporate personalized recommendations and loyalty programs, which is the ultimate prize for those suppliers wishing to have a long-term presence in the market.

Customer needs include:

Network coverage

Seamless charging network access is one of the primary challenges EV drivers face. Digital solutions should provide a seamless process for finding and accessing charging stations. This includes real-time availability information, intuitive maps, and user-friendly interfaces that allow drivers to easily locate and navigate to the nearest charging station.

Network roaming

App integration and interoperability must exist between different charging networks and charging station providers. EV drivers should be able to use a single app or platform that integrates with multiple charging networks, eliminating the need for separate accounts and payment systems. This unified experience will simplify the process and reduce friction for EV drivers.

Network availability

Real-time charging information is crucial for EV drivers. The digital customer experience should offer accurate details on charging station availability, charging speeds, and estimated charging times. Additionally, integrating dynamic pricing information can help users make informed decisions based on cost and optimize their charging experience.

Integrated payment systems

Simplifying payment processes is crucial for a seamless digital customer experience. Ideally, EV drivers should be able to make payments through a single app or platform, eliminating the need for multiple accounts or payment method, the suppler should take care of all of that. Secure and easy-to-use payment systems, including options for contactless payments and automatic billing, can greatly improve the user experience.

Personalization and recommendations

Digital platforms can leverage user data to provide personalized recommendations and suggestions to EV drivers. By analyzing driving patterns, charging preferences, and historical data, the system can offer tailored charging solutions, such as recommending nearby charging stations, suggesting optimal charging times, or even predicting charging needs based on upcoming trips.

Customer support and feedback channels

A robust digital customer experience should include easily accessible customer support channels. EV drivers should have the option to reach out for assistance, report issues, or provide feedback directly through the digital platform. Prompt and responsive customer support is crucial for addressing any concerns or technical difficulties that drivers may encounter.

Enhanced communication and notifications

Clear and timely communication is essential for a positive digital customer experience. EV drivers should receive notifications about charging station availability, charging progress, completion alerts, and any relevant updates or changes. These notifications can be delivered via mobile apps, SMS, or email, ensuring that drivers are well-informed and can plan their charging accordingly.

Integration with smart home and smart grid technologies

The digital customer experience can be further improved by integrating EV charging with smart home and smart grid technologies. This includes features like remote monitoring and control of charging sessions, integration with renewable energy sources, and optimizing charging schedules based on electricity prices and grid demand. These capabilities empower EV drivers to make eco-friendly and cost-effective charging decisions.

ELECTRICITY CONNECTIONS: IS THE IMPACT OF ELECTRIFICATION HOLDING BACK DECARBONISATION?


MICHAEL TAYLOR, UK


RENE KERKMEESTER, NETHERLANDS


PHILIPPE VIÉ, FRANCE


RANBIR SINGH, UK

The Electrification Problem

It is widely recognised that a major part of the global decarbonisation effort will be shouldered by the adoption of renewable power generation and the electrification of transportation, industrial and domestic sectors. As investment in low carbon technologies soar, global electricity networks are increasingly unable to keep pace with connection applications.

Electrification is causing a strain at all levels across electricity networks. In most cases, the transition to a low carbon power system is driven through the installation of renewable generation options. This adds significant transmission network strain as large volumes of usually intermittent generation sources are connected. Furthermore, the decarbonisation of the SME industry and domestic sectors will increase distribution network strain through the mass adoption of Electric Vehicles (EV), embedded generation and electric heat options, such as heat pumps.

Connection speed and network reform are increasingly recognised as a pace setter for the energy transition, such that the success, or failure in achieving decarbonisation targets ultimately hinges on the rate that nations are able to progress electrification.

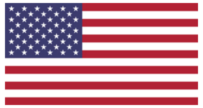
What is holding back electricity network connections?

The upgrading of the electricity network is a critical part of enabling electrification and eventually meeting net zero targets. Whilst electrification presents unique challenges at a national level, as a result of national system design, there is commonality across key challenges which present an excellent opportunity for shared learnings. These include:

- **Central regulatory reform:** essential in ensuring market and network rules promote the right behaviours from network operators and provide clear signals to investors
- **Utilising Distributed Energy Resource Management (DERMS):** improve connection planning and network development
- **Connection application management and prioritisation:** ensure connections contribute to network resilience and deliver positive consumer outcomes

In this article, we will explore a series of case studies to discuss how electricity connection speeds can be increased.

Case Study – Connection Processes Reform: US, UK and Australia



Network Reform to Unlock Connection Speed

On August 16th 2022 the US announced the Inflationary Reduction Act (IRA), offering nearly $400bn in tax credits for clean energy, climate mitigation & agricultural projects[1].

The Department of Energy (DOE) report that the US will need to expand its transmission systems by 60% to meet 2030 targets, whilst also needing to triple the current capacity to achieve the 2050 target of a decarbonised economy[2]. In response, the DOE has committed up to $20 Billion of federal investment to improve electricity networks, through a series of programs, including[3]:

- **Grid Resilience Utility and Industry Grants ($2.5bn):** fund network technology solutions improve grid resilience
- **Smart Grid Grants ($3bn):** increase flexibility and efficiency of power systems, targeted at domestic entities (state/local governing institutions)
- **Grid Innovation Program ($5bn):** provide financial assistance to governing institutions and grid owners for innovative solutions that improve grid resilience and reliability
- **Transmission Facilitation Program ($2.5bn):** innovation fund to support transmission system developments through application of capacity contracts (purchasing up to 50% of maximum capacity) to de-risk inflight, or pipeline projects

Given the IRA and 'Building a Better Grid' are still relatively recent initiatives, its unclear whether the federal investment has been sufficient to manage the high volumes of electricity projects being connected to the grid. Furthermore, it is unclear whether the decision to manage stimulus through schemes, which can often include lengthy application and vetting processes, will be able to keep pace with the simplicity of the IRA tax credit model.

1 https://impact.economist.com/sustainability/circular-economies/go-green-or-bust-could-a-green-industrial-revolution-spark-an-American
2 https://www.energy.gov/gdo/building-better-grid-initiative
3 https://www.energy.gov/articles/biden-harris-administration-announces-13-billion-modernize-and-expand-americas-power-grid

Ofgem launch connections review

In May 2023, UK Energy Regulator (Ofgem) launched its review into an electricity connections reform[4].

The review was instigated under the backdrop of news headlines quoting transmission connection times in excess of 15 years[5]. Failure to address these prolonged connection wait times introduces significant risk to the UK's net zero targets for both the power system in 2035 and the whole economy by 2050.

The failings of first-come-first-served

The UK operates on a 'first come first served' basis for electricity connection applications at the transmission level and through much of its distribution networks. At the transmission level in particular, the formation and scale of the connection queue and the overall size indicates severe market distortion, with demand outstripping connection capacity. Furthermore, there is a distinct lack of queue prioritisation, resulting in potentially higher priority projects being delayed at the expense of lower priority activities.

4 https://www.ofgem.gov.uk/publications/open-letter-future-reform-electricity-connections-process
5 https://www.current-news.co.uk/industry-calls-on-beis-to-solve-network-constraints-with-delays-of-up-to-15-years/

The queue length is compounded by the application process, which allows for investors to speculate on prospective projects, to ensure their place in the line, regardless of project maturity.

In addition, there has historically been little scrutiny on project maturity for connection applications, which can result in the approval of projects that have outstanding, critical dependencies, such as planning permission. This results in 'zombie' projects populating the queue, holding back high priority projects. This ultimately reduces the accuracy of generation capacity projections, and further complicates network planning.

Connections Reform Initiative

The Clean Energy Council (CEC) mobilise the industry to ramp up generation connection to grid times through the Connections Reform Initiative (CRI)[6]

The CRI has brought together a diverse set of Australian energy market stakeholders to address concerns around delays and the increased complexity in the connections process.

The first phase of the CRI activity focused on introducing collaborative, cross-industry ways of working, simplifying regulatory change processes and introducing a more flexible approach to minimum standards to better reflect network capability. Solution outputs within these target areas were consolidated into a collective delivery roadmap, outlining when review recommendations would be implemented[7].

The CRI's roadmap recently went through its second iteration, where the emphasis shifted from ideation/planning to implementation. However, there were some notable shifts in short term strategic direction, as demonstrated by the reallocation of the connection 'batching' workstream into the Streamlined Connections Process (SCP)[7].

6 https://www.cleanenergycouncil.org.au/advocacy-initiatives/energy-transformation/connections-reform-initiative
7 Connections Reform Initiative (CRI) – Connections Reform Roadmap: Version 2 (May 2023)

The decision to reform the connection 'batching' workstream into the SCP was due to 'batching' recommendations being unable to progress because of cross review dependencies. The SCP focus shifted into undertaking a end-to-end system review and identifying near term initiatives to trial through regulatory sandboxing[7].

Whilst the success rates of the CRI are currently unknown, the roadmap approach is allowing for long term planning, whilst retaining the agility to respond to near-term review developments.

Unblocking electricity connection processes through central reform

Central reform is a critical aspect of increasing the pace of electricity connection processes. Whilst the approaches adopted by the US, UK and Australia differ, they all beg the question 'are we building the systems of tomorrow, with the frameworks of yesterday' and how can central reform promote electrification?

Adopting whole system approach to energy system reform

Energy systems are fundamentally linked and it is therefore critical that reviews considered the wider flow of energy, money, data and agreements through the entire system. Failure to consider the wider landscape when undertaking regulatory reform initiatives increases the likelihood that transitional 'debt' is incurred, resulting in unnecessary future rework.

Ramping up pace of regulatory change and simplification

Energy system requirements are evolving at a pace that central regulation systems are struggling to adapt. Increasing the pace of change will be critical in adapting to a framework that supports efficient implementation of innovative projects and achieving the necessary future targets.

Effective planning for near, medium and long term success

Successful energy system evolution will require robust mechanisms for identifying where connections are required to provide clear signals for investment. Leveraging development roadmaps can be an effective tool, providing they are regularly reviewed to respond to near-term events.

Case Study – Utilising DERMs and ADMS to Improve Network Management

Adopting and integrating emerging DERMS and ADMS Technology can help DSOs realise efficiencies in network and connection management

Electrification is fundamentally changing the distribution network landscape, as increased penetration and volume of distributed assets increases the need for flexible and responsive system management. This is pushing the traditional Distribution Network Operator (DNO) to transform into a Distribution System Operator (DSO), but what technologies can help enable this transformation?

Distributed Energy Resources Management Systems (DERMS)

DERMS are control systems that allow for management and optimisation of Distributed Energy Resources (DERs) within electricity networks, such that DSOs can dispatch and control DERs in near-real time[8].

DERMS common 'use-cases' include Volt/Volt Ampere Reactive (Volt/VAR) optimization (VVO), power quality management, and the coordination of DER dispatch (when possible) to support operational needs. DERMS platforms can also offer clients a variety of benefits which are defined by the following use-cases[9]:

Asset Management and System Planning

- Precision Demand Response and DER Management
- Telemetry and Control
- Dynamic Network Topology
- Alarms, dashboard, single line diagram, audit logs, user manual
- Control strategy management features
- Optimal DER Plan Creation
- DER Fleet Management
- Volt VAR Control
- Network/Resource Constraint Management Utilizing DERs
- Energy Arbitrage and Usage Optimization

Analysis and Forecasting

- Energy Arbitrage and Usage Optimization
- Precision Demand Response and DER Management
- Telemetry and Control
- Dynamic Network Topology
- DER and Load Forecasts
- DER Situational Awareness
- DER Analysis to inform planning Internet of Things (IoT) aggregation functionalities
- Alarms, dashboard, single line diagram, audit logs, user manual
- Control strategy management features

8 DERMS Requirements and Considerations: A Utility Perspective (Arizona Public Service)
9 DERMS Solutions – BESC Research Services (March 2021)

Advanced Distribution Management Systems (ADMS)

ADMS Platforms are designed to effectively monitor, control and optimise distribution of electricity across a network. The primary function of ADMS is to improve efficiency and reliability of distribution networks through real-time monitoring; fault detection and restoration; outage management; and grid optimisation. However, ADMS are not typically designed to support many millions of SCADA points, or act as a holistic customer enablement platform[10].

Integrating DERMS and ADMS technologies

The integration of DERMS and ADMS offer a number of advantages in transitioning traditional distribution networks towards flexible, resilient future systems. One example is in the management of Virtual Power Plants (VPPs), which aggregates and coordinates a fleet of DERs to act like a single power plant. DERMS and ADMS can play a role in VPP, where:

- DERMS plays a critical role in monitoring, controlling and optimising the individual DERs, ensuring they responding to real-time signals, working effectively and contributing the required capacity to the VPP
- ADMS ensures the VPP integrates with the wider network infrastructure and can coordinate its activities with other network assets and network operations to promote network resilience and reliability

Overall, integrating DERMS and ADMS should drive a reduction in electricity cost through increasing asset output, maintenance and life-span. They should also increase the uptake of DER which tend to be low-carbon sources of electricity, such as wind and solar, reducing the carbon intensity of electricity used to power our homes and businesses[10].

UK energy networks ramp up application of DERMS

In the UK, implementation of DERMS currently only exists in small pockets of the network, however DERMS adoption is ramping up as all major UK DNOs are setting up frameworks to enable DERMS.

Furthermore, the UK is designing its electricity markets to reward flexible Distributed Energy. As such, starting in 2023, any capital grid upgrade that costs more than £1 million ($1.34 million) will need to prove that a flexibility based alternative solution, such as a VPP, is not a reasonable alternative option to meeting the system need.

This is a departure from the traditional "cost of service" structure for UK utilities, which typically determine their grid upgrade needs based on future load growth forecasts and earn guaranteed rates of return on the resulting capital investments.

10 The Interconnected Roles of DERMS and ADMS – A deep dive into complementary management systems

Case Study - Application Request Management

Our approach leverages deep Australian electricity distribution connections process knowledge and solution templates

BETTER CONNECT MVP

Context and Challenges

Essential Energy is a NSW Government owned corporation with responsibility for building, operating and maintaining Australia's largest electricity network, spanning 95 per cent of New South Wales and parts of southern Queensland

Essential Energy receive around 60,000 applications a year for low voltage connections. Effectively managing and actioning such a large volume of connection applications comes with series of challenges, which were as follows[11]:

FIGURE 1

Manual

Connections process facilitated in largely manual environment using workflow management tool, and access Database platform to record and store information

Visibility

Minimal or no visibility of the project lifecycle for the customers and convoluted internal processes resulting in delays for processing of design stage

Data

Transfer of the critical project data between Essential Energy teams and the systems needing to be handled manually, creating rework

11 Ausgrid Capgemini End to End Connections (Dec 2021)

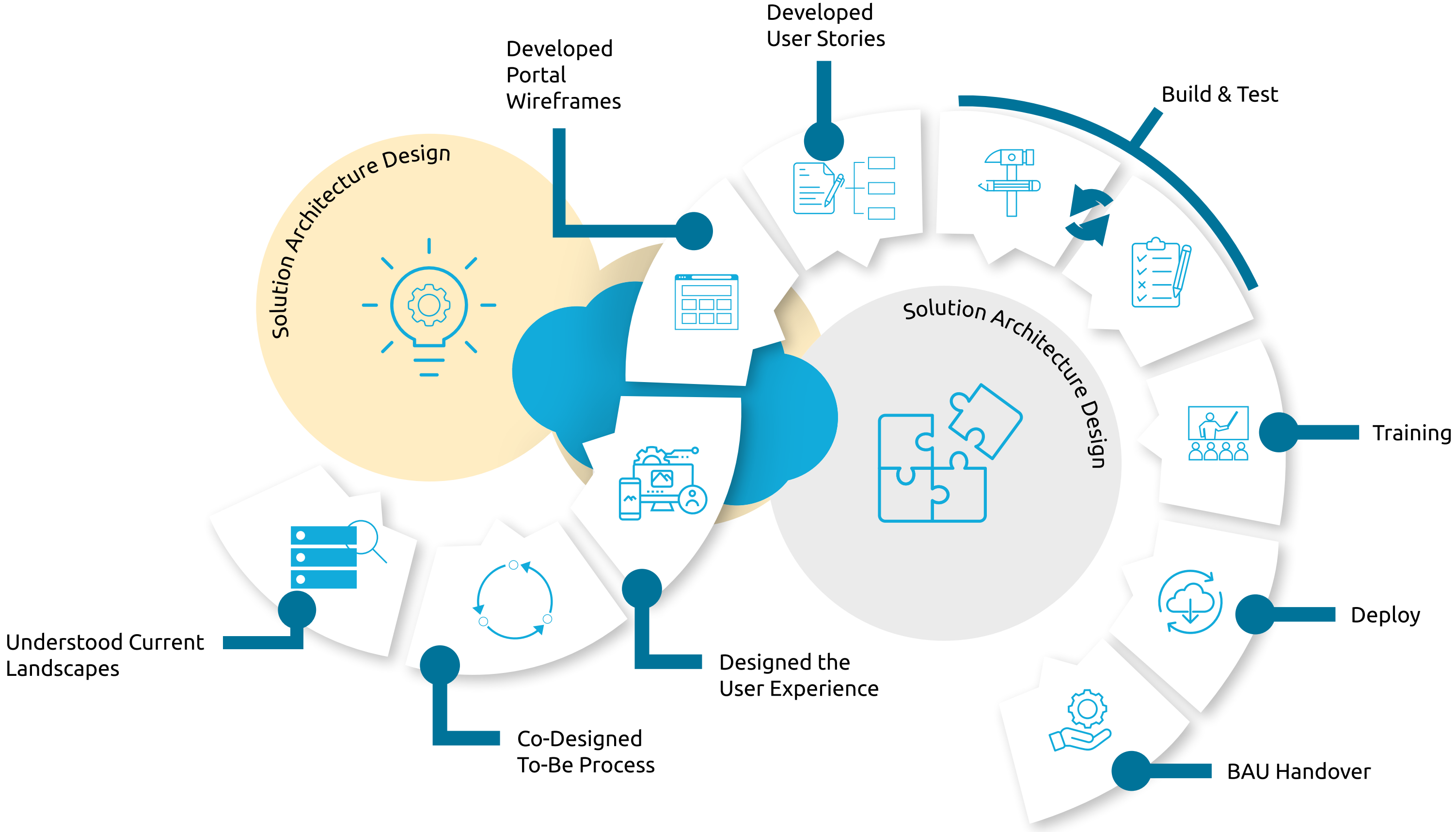
Solutions and Benefits

Capgemini delivered a solution to enable automation of Design sub process for the customer connections process. This was achieved by:

- Using Salesforce Service Cloud for internal console and Community Cloud for the front end portal to submit and track work request
- Defining requirements by utilising an accelerated, collaborative 'discovery' phase that focused on process design, user journeys, and internal/external personas
- Implementing agile approach to change management, design, build and test salesforce functionality
- Interactive train the trainer sessions, empowering SME's within the organisations to provide end user training and supporting delivery of end user sessions

This has ultimately led to faster, easier, more efficient lodgement of work requests. Automated workflows allow segmentation, and allocation of work, reducing manual administration and elimination of 90% data entry requirements for design and certification processes

FIGURE 2



Case Study - Connections Management

Capgemini Engineering Support Enedis in Accelerating it's Grid Connection Activities

Approach and Solutions

- Clear scope of service based on four work packages (Coordination, Study Monitoring and Control, Service Providers Monitoring and Control, Acceptance of Work/ Commissioning)
- Performance based on KPIs built together by Enedis and Capgemini
- Teams of 6-7 project managers organised around a senior technical expert on each regional branch with the support of national experts and the project office
- Completion and update of Enedis information system

Coordination
- Manage the realisation of each reception work study
- Coordinate all stakeholders
- Update systems in real time

Studies
- Carry out the study work
- Control/manage the study
- Complete the work

Construction
- Get the actual work done
- Monitor the execution of work
- Create and check document
- Complete the work

Reception
- Manage access and MES
- Carry out the acceptance of work
- Complete the work

Context and Challenges

Enedis is the main French DSO and as such they are in charge of developing, operating and modernising 95% of the French electricity distribution network.

Enedis was facing new challenges due to the increasing levels of renewable generation on the distribution network, the development of self consumption, and the emergence of new electricity uses such as electric vehicles.

In this context, Capgemini has provided engineering services to facilitate the grid connection of customers of Enedis. More than 40 project managers within Capgemini's teams have coordinated grid connections projects (from first studies to commissioning) since 2015 within regional branches (Paris region, Marseille and Montpellier regions, Alsace, Toulouse and Pau regions)

Key Technologies

- High voltage / Low voltage substations
- EV charging stations
- Renewables (Solar PV and Wind Power Plan)
- Electricity riser in collective buildings
- Individual connections <36KVA or >36KVA
- Authorisations H0/B0, AIPR

Results and Added Value

Capgemini is one of the two main national partners of Enedis and strongest ally regarding grid connection project management

- Activity has been growing since 2015
- Capitalisation and deployment ongoing in new regions
- Implementation of a tailormade training program for new consultants
- Expense control through performance-based payments with reduced tracking effort
- Respect of customer objectives; billing budget and schedule compliance

LCOE
LEVELIZED COST OF ENERGY

DEBARGHYA MUKHERJEE, INDIA

NUPUR SINHA, INDIA

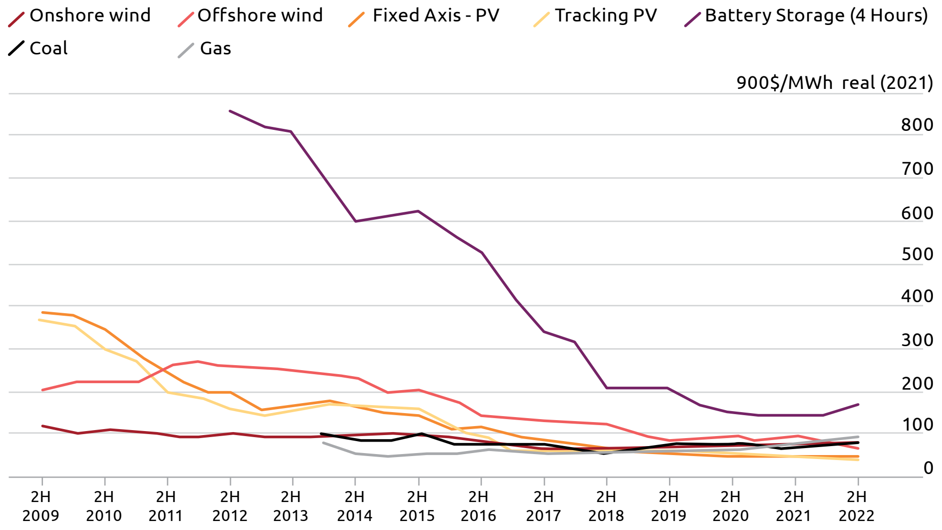
Global LCOE benchmarks, H2 2022

Global supply chain pressures have started to ease and key commodity prices are cooling off after a turbulent 18 months. **Inflationary effects are still catching up with renewables projects financed in 2H 2022** and some key commodities remain stubbornly high. In addition, new macroeconomic challenges have emerged. **Inflation is at multi-decade highs and central bank interest rate rises are hitting capital-intensive renewables and storage projects hard.**

Higher fuel and carbon prices, elevated material prices and higher debt costs have pushed up LCOEs for coal, gas and standalone battery storage projects. Central bank rate hikes in 2H 2022 have increased debt cost by 20%, compared to 1H. Rising debt costs affect renewables more than fossil fuel plants due to the higher upfront investment needs. A strong dollar has weakened the purchasing power of developers who rely on equipment imports and increased capex.

FIGURE 1

Global LCOE benchmarks (H2 2022)



Sources:BloombergNEF

Global average LCOEs for onshore wind and solar PV are expected to remain 10-15% above 2020 levels in 2024

Electricity generation costs from new utility-scale onshore wind and solar PV plants are expected to decline by 2024, but not rapidly enough to fall below pre Covid-19 values in most markets outside China. Although commodity and freight prices have dropped from last year's peaks, they remain elevated. At the same time, developers' financing costs have increased due to rising interest rates.

In addition, macroeconomic risks in the global economy – associated with rising inflation, higher interest rates and the energy crisis caused by Russia's invasion of Ukraine – lead to a higher cost of capital, including for renewable energy projects. In real terms (i.e., excluding the impact of inflation), the weighted average cost of capital (WACC) is expected to increase in most large solar PV and wind markets, excluding China. The higher cost of capital could offset most of the cost decreases resulting from lower commodity prices and further technology innovation in the next two years. Consequently, the average LCOE for utility-scale PV and wind could be 10-15% higher in 2024 than it was in 2020.

FIGURE 2

Wind onshore LCOE index based on average annual input costs, 2018-2024

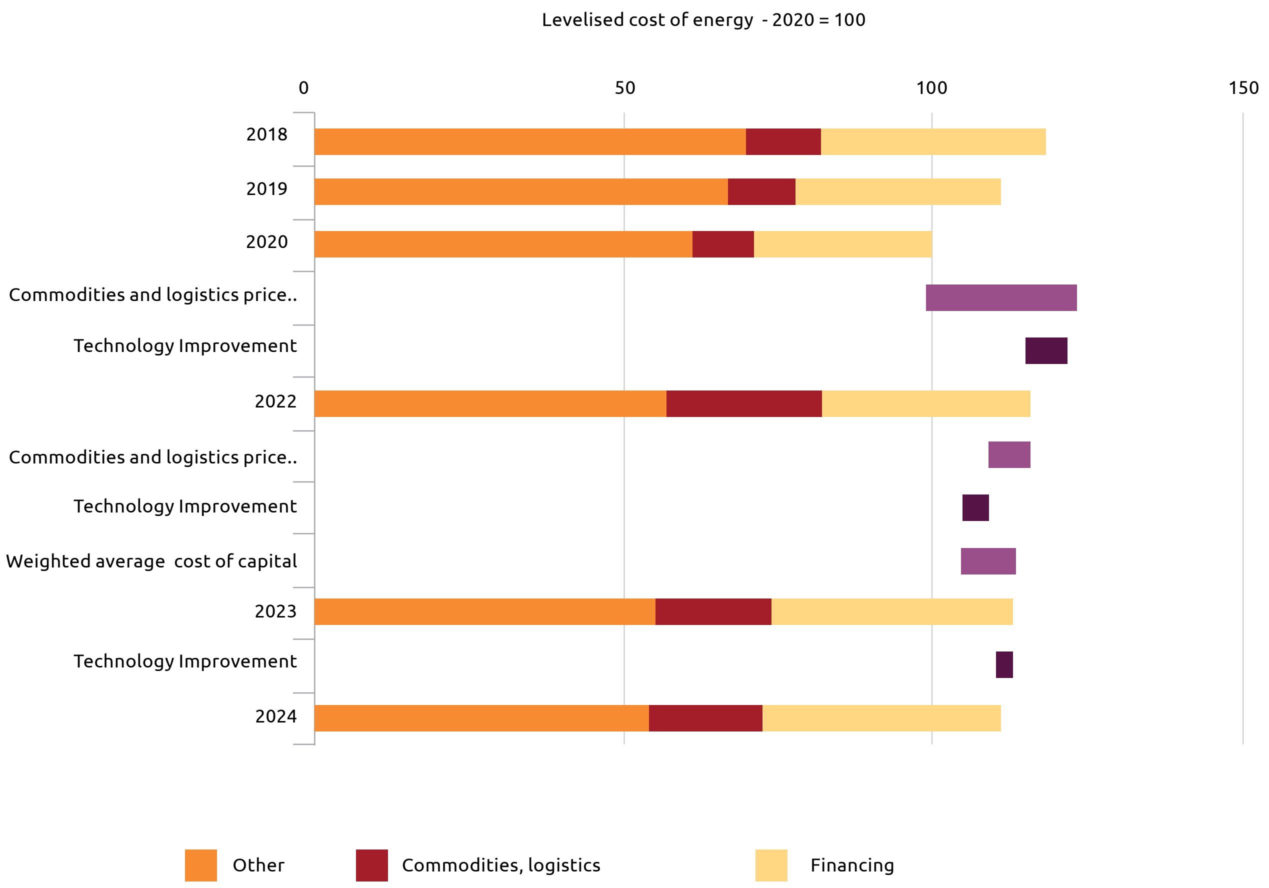
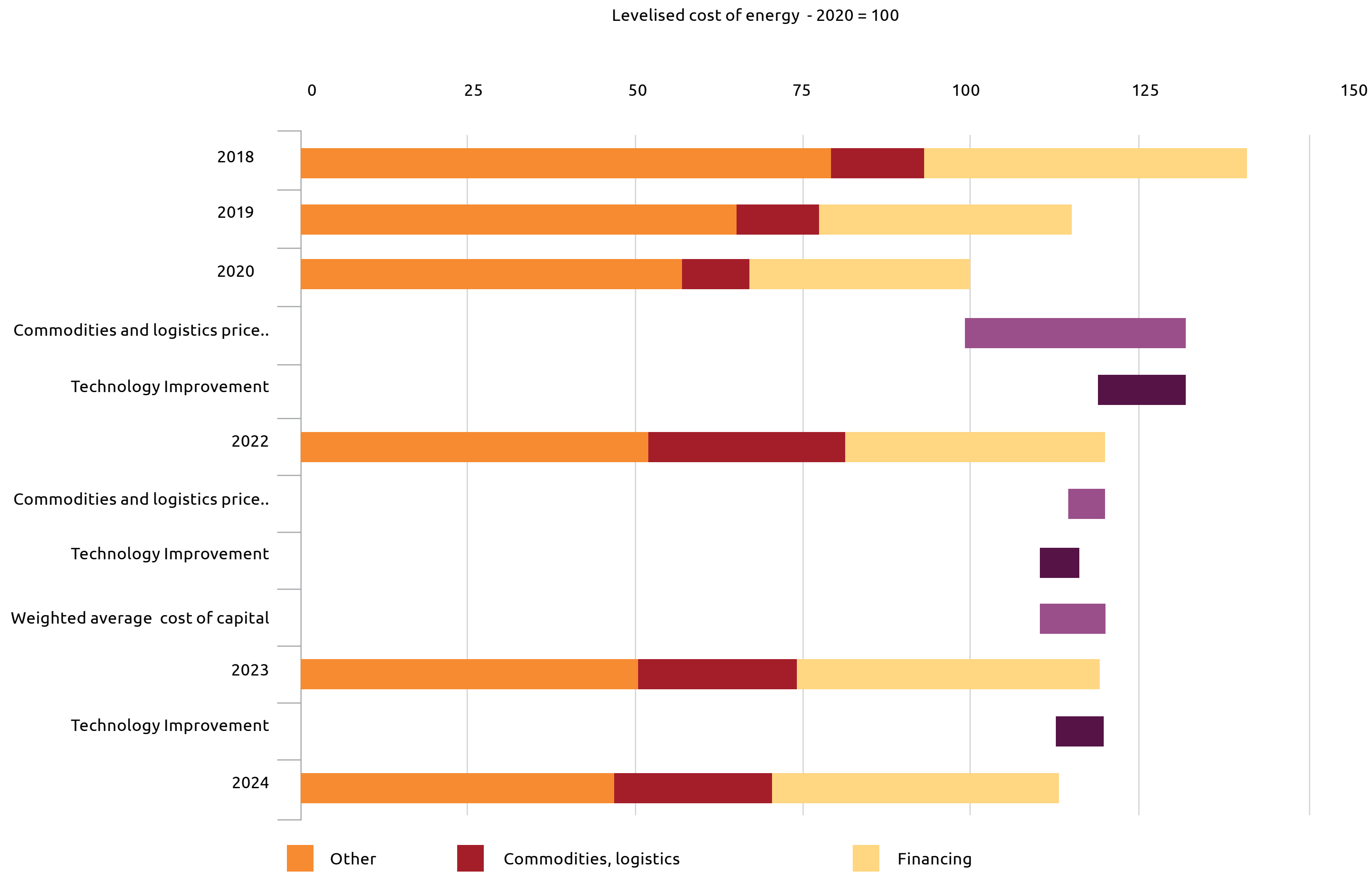


FIGURE 3

Solar PV utility scale LCOE index based on average annual input costs, 2018-2024



U.S. and European LCOE 2022

Solar and wind are still the most affordable sources of electricity, but their LCOE has increased for the first time in 2023 in U.S. In a base comparison, without considering subsidies, fuel prices, or carbon pricing, utility-scale solar and wind have the lowest LCOE of all sources.

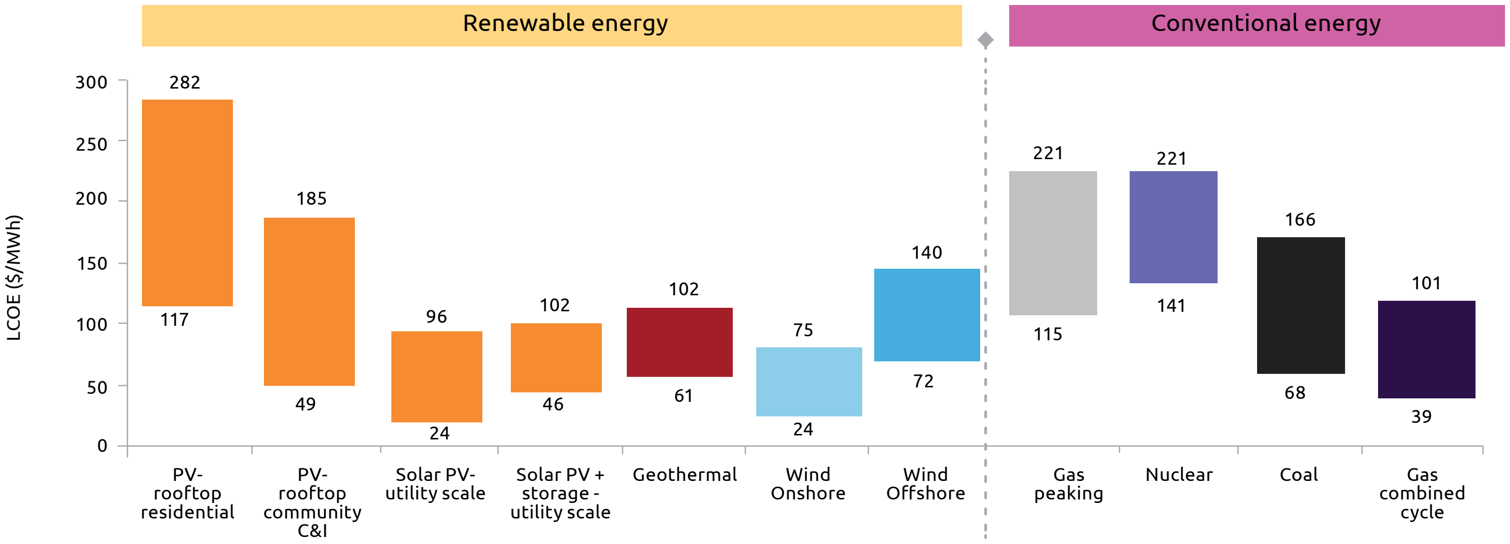
Utility-scale solar PV comes in anywhere from $24/MWh to $96/MWh, while onshore wind registers the lowest possible LCOE over the shortest range, from $24/MWh to $75/MWh. Offshore wind's LCOE ranges between $72/MWh and $140/MWh.

Wind and solar will attract the lion's share of energy investment in Europe and continue to benefit from growing scale. Europe's pivot away from its dependence on Russian supply caused the price of gas to skyrocket. However, until low-carbon technologies catch up, gas will continue to be a critical bridging fuel. LCOE figures for renewables and energy storage in 2022 rose by an average of 19% due to supply chain bottlenecks and commodity price inflation.

Onshore renewables remain the most cost-effective energy technology in Europe; the average LCOE for onshore wind across Europe expected to drop by more than half to €23/MWh by 2050 compared to 2022, making it the most cost-competitive technology. Comparatively, offshore wind remains expensive, although costs are set to decrease the most in this sector by 2050: LCOE should reduce by 68%.

FIGURE 4

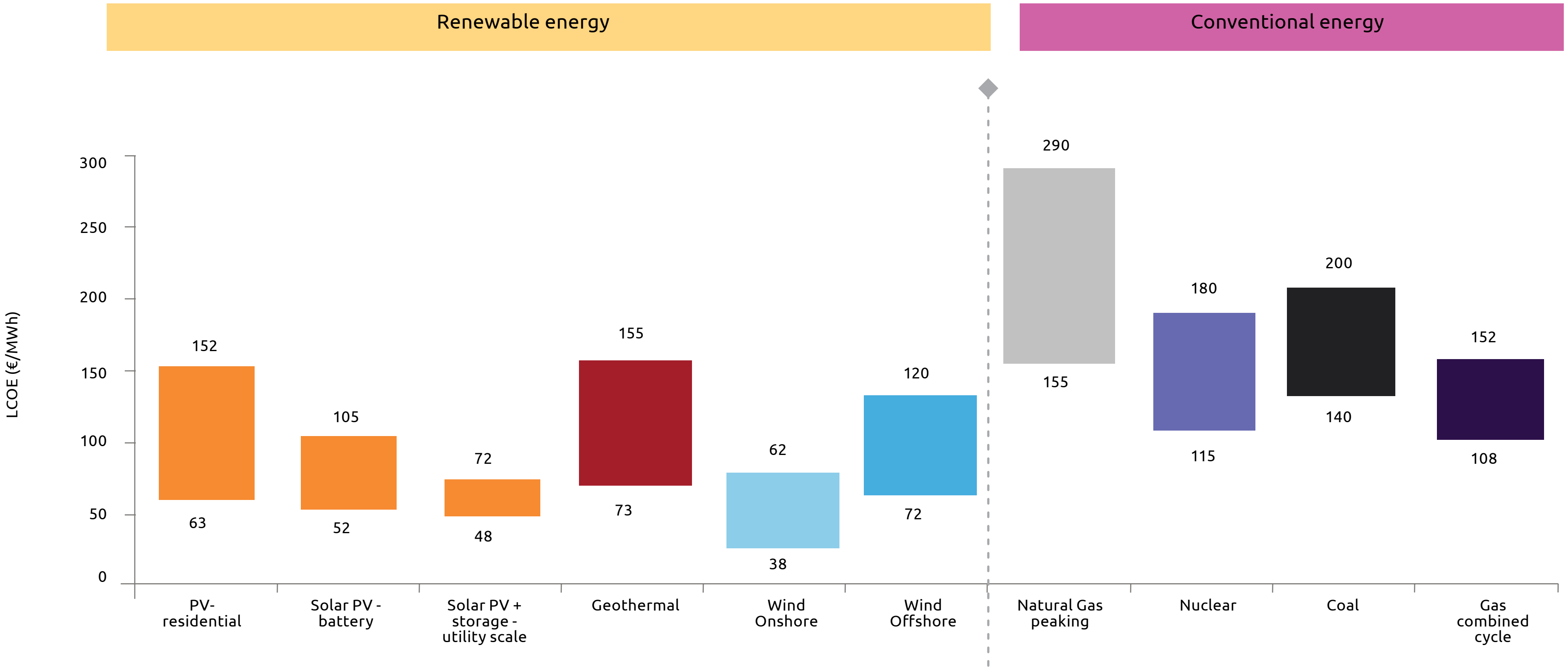
U.S. LCOE - Unsubsidized Analysis ($/MWh)



Source: 2023 Lazard's Levelized Cost of Energy Analysis, Wood Mackenzie, Fraunhofer

FIGURE 5

Average European LCOE (€/MWh)



Source: 2023 Lazard's Levelized Cost of Energy Analysis, Wood Mackenzie, Fraunhofer

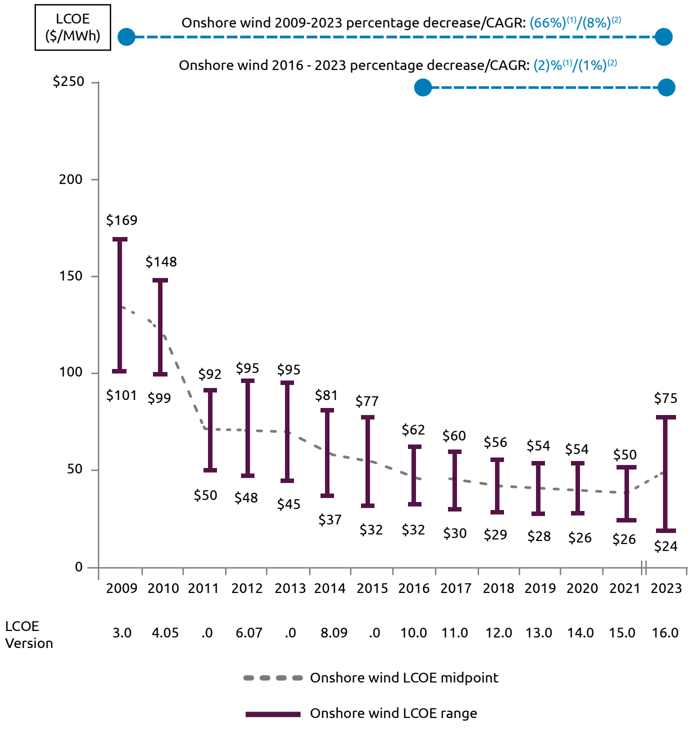
For U.S., Utility-scale solar and onshore wind LCOE increased for the first time in 2023

Even in the face of inflation and supply chain challenges, the LCOE of best-in-class onshore wind and utility-scale solar has declined at the low-end of cost range, the reasons for which could catalyze ongoing consolidation across the sector.

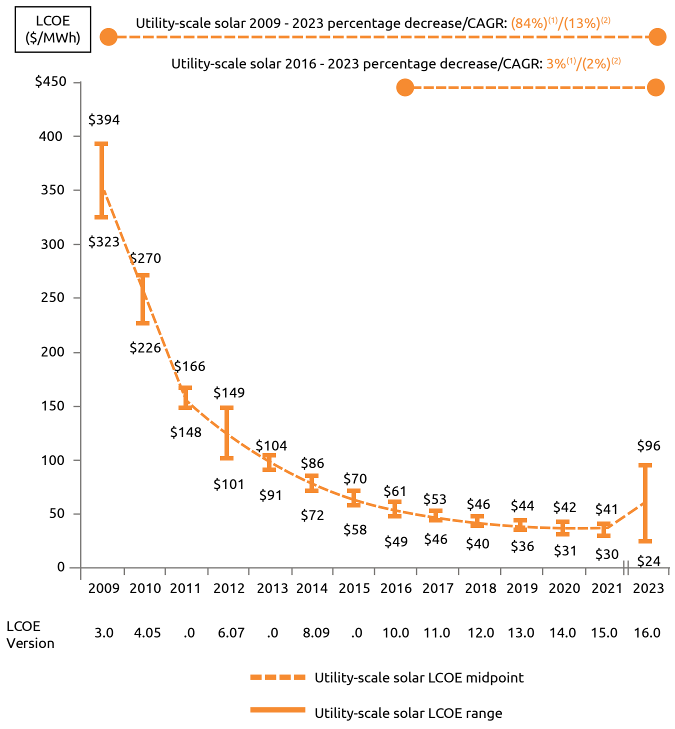
Although the average LCOE has increased for the first time in the history of studies; Inflation, supply chain challenges, and the global energy crisis all had a role to play.

FIGURE 6

Unsubsidized onshore wind LCOE



Unsubsidized solar PV LCOE



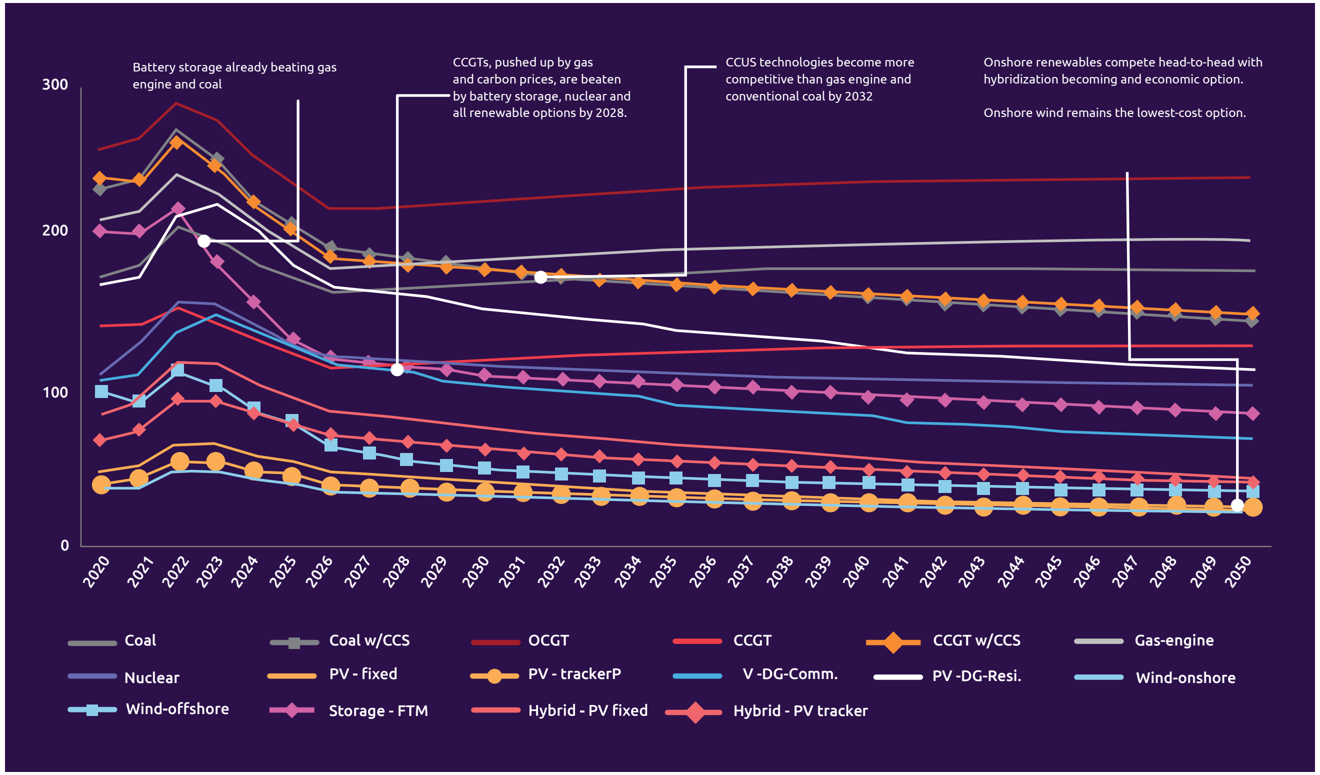
Source: 2023 Lazard's Levelized Cost of Energy Analysis

For Europe, gas is expensive but remains system critical until low carbon options can displace it

Key markets in the European power generation and storage sector will attract 1.64 EUR trillion from 2023 to 2050 with 78% of investments going towards wind and solar. Commodity price inflation and supply chain bottlenecks have pushed up the power sector investment requirements by $140 billion between 2023 and 2050

FIGURE 7

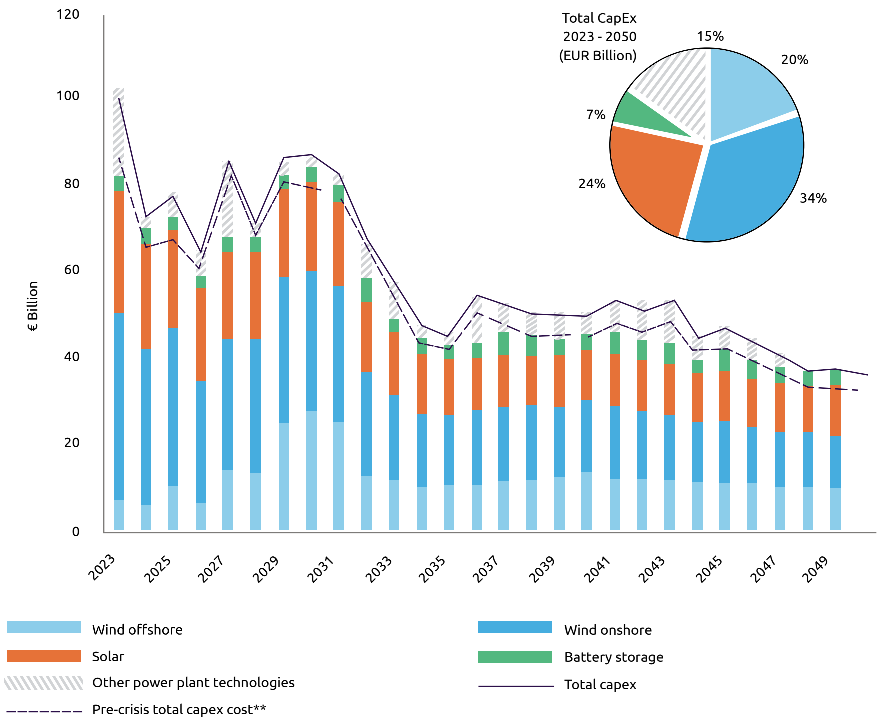
Technology average LCOEs (€ / real 2022)



Source: Wood Mackenzie

FIGURE 8

Power plants Total CapEx by Technology



NETWORKS AT THE CENTER OF THE ENERGY TRANSITION

WILL ENERGY NETWORKS ENABLE OR HINDER THE TRANSITION TO NET ZERO?


TOM CARR, UK


JOHN BRIGNELL, UK

As the world races toward a net zero future, energy networks have emerged as the pivotal engines in the pursuit of decarbonization. Historically anchored in thermal power generation, these infrastructures now find themselves at the crossroads of the global energy transition. Their role is unmistakably crucial, wielding the power to either catalyze or obstruct our collective endeavors against climate change. Yet, it's essential to underline a foundational challenge: Electricity, which currently represents approximately 20% of all energy consumed worldwide, must account for over 50% in a net zero scenario, additionality encompassing heating, cooling and mobility. An almost tripling of global grid capacity will be needed to achieve this, in less than three decades. This is not merely an investment conundrum.

The significance of energy networks as pace-setters for achieving net zero emissions cannot be overstated. These networks play a vital role in integrating renewable and distributed energy sources into our existing energy infrastructure, making them pivotal in the transition to a sustainable future.

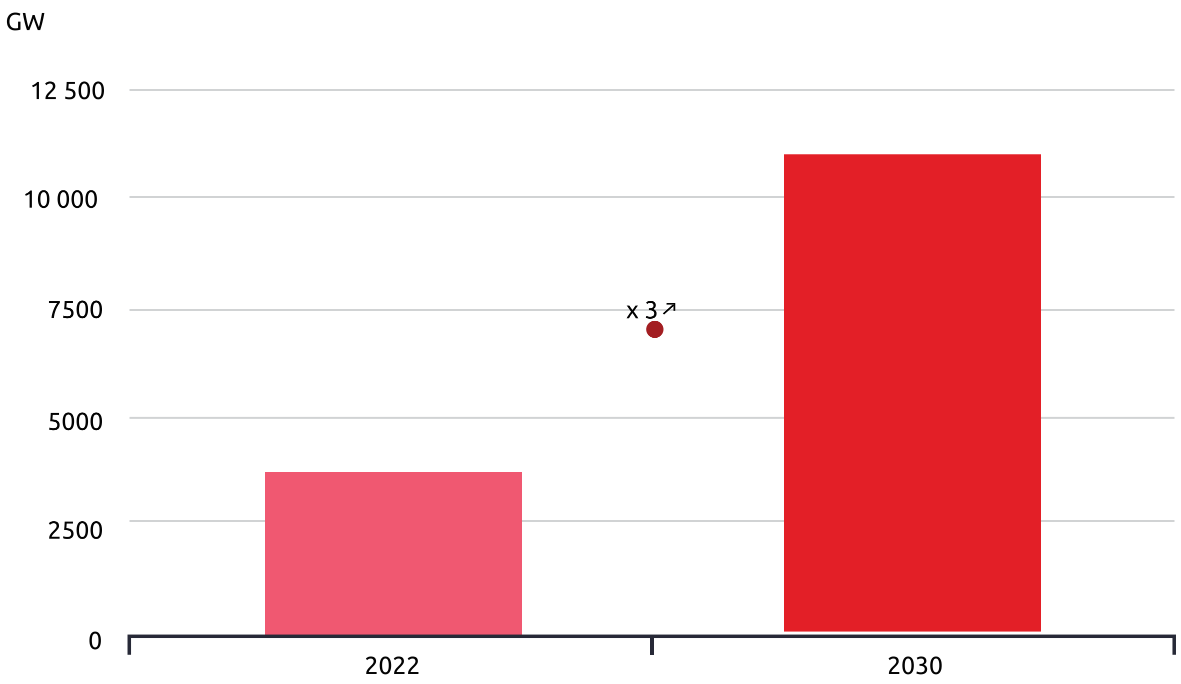
Energy networks face a myriad of challenges on the path to decarbonization. From the need to integrate distributed and decentralized renewable energy sources to the complexities of bidirectional power flows and the daunting task of expanding transmission grids, the road ahead is arduous. Furthermore, questions of cost implications, regulatory frameworks, and public engagement loom large, demanding bold solutions and decisive action.

However, energy networks also possess immense potential to lead the charge toward net zero. By embracing innovative technologies, adopting a digital-first approach, and fostering collaboration across stakeholders, they can become the driving force behind decarbonization. With the power to connect renewable energy assets, optimize grid operations, and empower consumers, energy networks have the capacity to transform our energy landscape and accelerate progress toward a sustainable future.

In this article, we will delve into the challenges faced by energy networks and explore the potential solutions that can empower them to become true catalysts for decarbonization success. From visionary regulation to anticipatory investments, from leveraging flexibility to embracing open data and digitalization, each step forward will bring us closer to achieving our net zero ambitions.

FIGURE 1

Global renewables power capacity in the Net Zero Scenario, 2022 and 2030



Note: Tripling global installed renewables capacity to 11,000 gigawatts by 2030 provides the largest emissions reductions to 2030 in the NZE Scenario.

Source: IEA
https://www.iea.org/reposts/net-zero-roadmap-a-global-pathway-to-keep-the-15-0c-goal-inreach/executive-summary

Challenge #1: Adapting to the era of renewables

Energy networks were originally designed to support thermal power generation, relying on centralized fossil fuel power plants. However, integrating distributed and decentralized renewable sources poses significant challenges. Retrofitting existing infrastructure to accommodate the intermittent nature of renewables and managing the complexities of diverse energy sources requires innovative solutions and flexibility in network design and operation. This challenge is increased by the changing nature of demand. With electrification, demand will increase significantly – in the United Kingdom, demand is predicted to double by 2050[1] but it will also change in nature. Peaks and troughs will shift as electric vehicles (EVs) and electric heating demands become significant facets of our future energy systems. Demand will also become more flexible and price sensitive, with demand shifting to take advantage of cheap electricity when the sun shines and wind blows.

A clear decarbonization roadmap

Governments can play a crucial role by providing clear decarbonization goals, as well as a roadmap. Setting ambitious targets for renewable energy deployment and carbon reduction creates a strong incentive for energy networks to adapt their infrastructure and operations to accommodate renewable sources. By establishing a clear direction, governments can encourage investments in research, development, and implementation of technologies and practices that enable the integration of renewables into the existing network, fostering a smoother transition toward a clean energy future.

Challenge #2: Keeping pace with rapid deployment

The rapid deployment of renewable energy assets presents connection constraints for energy networks. Connecting wind farms, solar installations, and other renewable sources to the grid requires careful planning, engineering, and coordination. The challenge lies in ensuring timely connections to meet the increasing demand for clean energy while maintaining grid stability and reliability.

Anticipatory investment

Energy networks can adopt an anticipatory investment approach. This involves proactive planning and investment in grid infrastructure to keep pace with the rapid deployment of renewable energy projects. According to International Energy Agency estimates, $1-3 dollars needs to be spent on grids for every $1 spent on renewables. By identifying potential areas for renewable energy development and strategically upgrading the grid infrastructure in advance, energy networks can reduce connection delays, enable faster integration of renewable assets, and ensure a smooth transition toward a more sustainable energy system.

Case study: Great Britain's Accelerated Strategic Transmission Investment (ASTI) to meet 50 GW of offshore wind goal

In April 2022, the U.K. government set an ambitious aim of connecting up to 50 gigawatts (GW) of offshore wind generation by 2030[2]. This was an unprecedented and highly-challenged ambition.

This policy was translated into practicality by the transmission system operator, National Grid Electricity System Operator (ESO), which was tasked with determining how to reinforce the existing electricity network to make it possible. Using a holistic network approach[3] they identified 26 projects needed in the next eight years, requiring £20 billion in investment. However, these came with a significant risk to delivery if the continued incremental approach to network build was not scrapped to shift to a coordinated anticipatory approach.

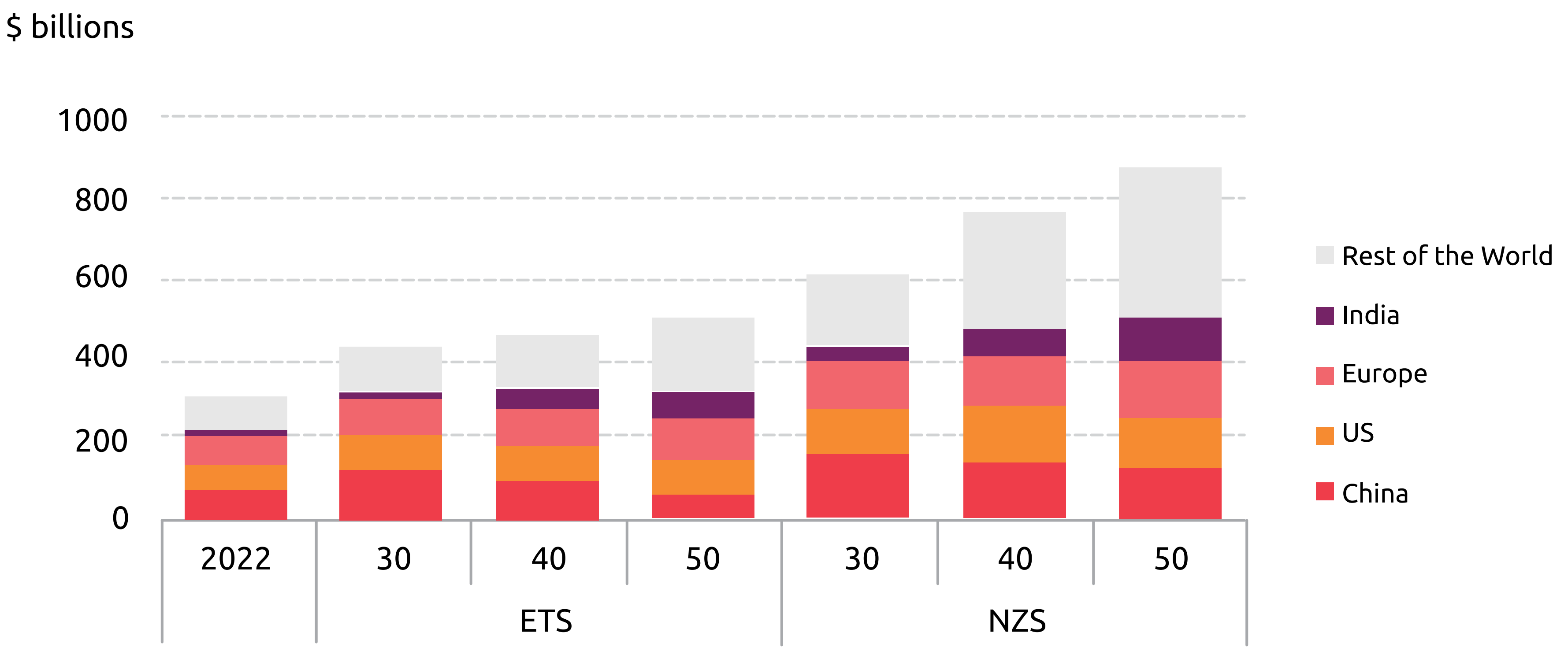
In December 2022, Ofgem, the national energy markets regulator, responded to this by overhauling the planning system for strategic investments into the transmission network[4]. They gave the green light to all 26 projects to be delivered by the regional transmission operators without competition. This could potentially shave years from their delivery dates, securing an additional £2.1 billion in consumer benefits and unlocking significant decarbonization to be delivered through meeting

1 Delivering a reliable decarbonised power system, UK Climate Change Committee

2 British energy security strategy - GOV.UK (www.gov.uk)
3 ESO Holistic Network Design
4 Ofgem ASTI Framework Decision

FIGURE 2

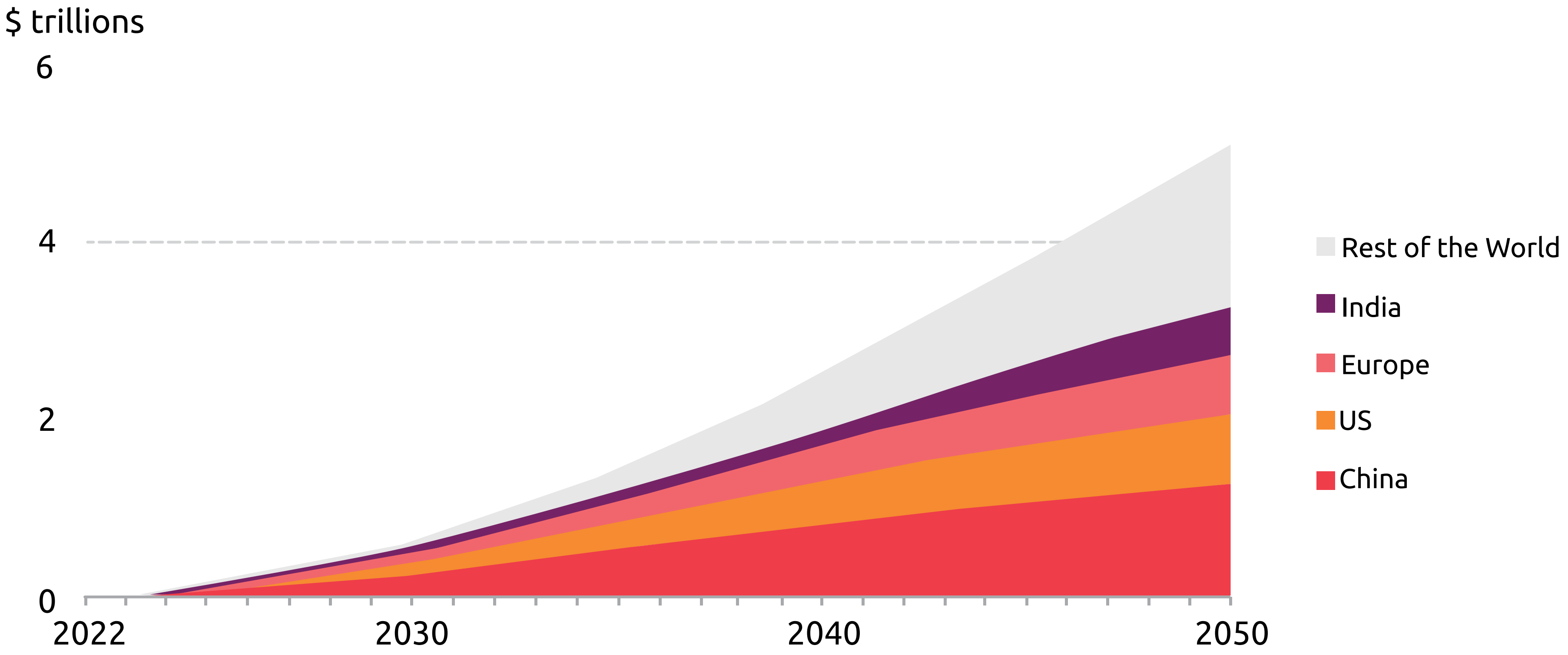
Global annual grid capex by region



Source: BloombergNEF. Note: Values for 2030, 2040 and 2050 are averages over the preceding dacade.

FIGURE 3

Cumulative capex on power grid digitalization by region



Source: BloombergNEF. Note: Excludes smart meters.

Challenge #3: **Embracing the two-way energy flow**

Energy networks have traditionally operated with unidirectional power flows, from centralized power plants to end consumers. However, with the rise of distributed generation, such as rooftop solar panels, energy networks must adapt to handle bidirectional energy flows. This transition requires technological upgrades, advanced metering systems, and enhanced grid management strategies to effectively manage the dynamic exchange of power between the grid and distributed energy resources.

Case Study: Denmark's flexibility market

Denmark's flexibility market serves as a successful example of enabling bidirectional power flows. Denmark has achieved a high level of integration of wind power into its electricity system, with wind energy accounting for approximately 50% of its electricity consumption. This accomplishment is supported by the country's flexible market rules, which allow consumers, prosumers, and aggregators to actively participate in the energy market and provide flexibility services. The Danish Energy Agency highlights that this approach has enabled efficient bidirectional power flows, better integration of renewable energy, and increased grid stability.

Market rules to enable flexibility

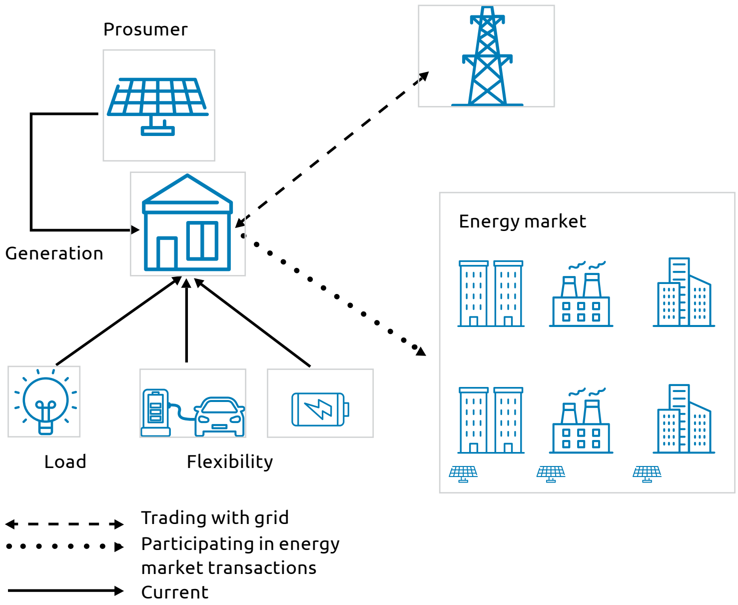
Energy networks can establish market rules that enable the expansion of flexibility providers and aggregators. These rules can facilitate the integration of distributed energy resources into the grid by allowing them to participate in energy markets, providing flexibility services to the system. These new rules should allow for flexibility providers to participate not only in wholesale markets but also in balancing and congestion markets. By incentivizing the participation of diverse actors and encouraging the development of innovative business models, energy networks can unlock the potential of bidirectional energy flows, optimize grid operations, and effectively manage the integration of distributed energy resources, thus accelerating the transition to a more flexible and sustainable energy system. Close collaboration between the transmission and distribution operators will be crucial to enabling this shift in the market and optimizing system flexibility to empower consumers and lower costs.

Challenge #4: **Scaling up for a renewable future**

To accommodate the growing share of renewable energy and ensure its efficient transmission, significant expansion of transmission grids is necessary. Offshore wind farms and remote solar installations, often rich in renewable resources, may be located far from population centers, requiring extensive transmission infrastructure development. This expansion requires substantial investment, environmental considerations, and careful planning to ensure grid reliability and optimization of renewable energy resources. Expanded grids will additionally need to be built to be resilient to climate events (floods, wildfires, hurricanes etc.), in particular grid assets connecting offshore and coastal wind sources. Our networks will need to operate safely and efficiently through decades of hostile climate events before reducing temparutes reduce their severity.

Case study: The North Sea Wind Power Hub

The North Sea Wind Power Hub[5] is an initiative that aims to enhance cross-border interconnections for offshore wind energy transmission in the North Sea region. By connecting countries such as Germany, the Netherlands, and Denmark, this project seeks to unlock the vast potential of offshore wind energy. The North Sea Wind Power Hub aims to connect 180 GW of offshore wind capacity by 2045, which will facilitate the efficient transmission of renewable energy across borders and contribute to the decarbonization goals of the participating countries.



5 https://northseawindpowerhub.eu/

Challenge #5: Managing cost implications and finance

The transition to a low-carbon energy system involves significant costs, including infrastructure upgrades, technology deployment, and system optimization. Determining who bears these costs and when they are incurred presents a challenge. Additionally, the availability of financing options and the fair distribution of costs among different stakeholders can be complex. The current regulated asset base (RAB) incentive model for grid operators needs to be adopted to stimulate investment in system innovation.

Open data to facilitate collaboration

Open data refers to the availability and accessibility of information related to the energy system, costs, and financing models. By promoting transparency and collaboration among stakeholders, open data enables a more inclusive and participatory approach to decision-making and cost allocation.

Open data facilitates collaboration among governments, energy networks, industry players, and financial institutions. It allows for better understanding and assessment of the costs associated with the energy transition and enables the identification of cost-saving opportunities; it also encourages the development of cost-effective solutions. By sharing information and lessons learned, stakeholders can collectively work toward optimizing the deployment of renewable energy technologies and reducing overall costs.

Case study: World Bank Open Energy Data Portal

World Bank is one of the largest financial institutions globally, investing billions annually in projects that will reduce poverty and increase prosperity. World Bank recognizes the importance of access to energy as critical in these pursuits, and invested more than $5 billion in energy programs in the last five years (FY18-22).

The bank has also recognized the value of the data they have access to as a result of their significant involvement in the delivery of global energy projects and have set up the EnergyData.info[6] website as a dedicated open data platform for the energy sector. The platform is freely accessible to support stakeholders globally in designing and delivering projects with open data analytics applications ranging from sizing an optima solar/storage system, to designing electrification pathways, and estimating off-grid energy services markets.

Challenge #6: Meeting the demands of decarbonization

The evolving energy landscape requires a workforce and adequate capacity to deliver, operate, and maintain the growing renewable energy infrastructure. However, there is often a shortage of skilled personnel with the necessary expertise in clean energy technologies and practices. Adopting digitally enabled approaches and system operation methods can be highly beneficial to meeting these demands.

Digitally-enabled construction approaches and system operation modernization

Across the globe, network operators, are not only extending and reinforcing their grids, many have embarked on their digital journey. More and more, regulators are changing the regulatory regimes to allow grid investment in digitalization next to hardware investments.

The digitization journey covers many parts of the grid operators activities. Digitally-enabled construction approaches should be deployed to leverage technologies such as Building Information Modelling (BIM), drones, and remote monitoring systems. These tools streamline construction processes, improve efficiency, and enhance safety measures. They also enable accurate project planning, optimize resource allocation, and reduce costs.

Modernizing system operation methods through digitalization and automation can enhance grid management and maintenance practices. Advanced monitoring systems, smart meters, smart substations, and data analytics enable real-time, automated monitoring and control of energy networks. This improves system reliability, enables predictive maintenance, and facilitates rapid response to disruptions. By leveraging digital technologies to deliver an integrated "Smart Grid", energy networks can optimize their operation, minimize downtime, and improve overall performance.

6 https://energydata.info/

Case study: Amazon's 2025 upskilling pledge

In response to the rapidly evolving landscape of work due to automation and artificial intelligence (AI), Amazon launched the ambitious initiative "Upskilling 2025" in 2019[7]. Committing $700 million, the tech giant aims to retrain 100,000 of its U.S. employees by 2025, assisting them in transitioning to more technically advanced roles or even new professions outside of the company.

To achieve this, Amazon has introduced diverse training programs, such as the Amazon Technical Academy, which transforms non-technical staff into software engineers, and the Machine Learning University, designed for those already in technical roles. Beyond preparing its workforce for future internal roles, Amazon's effort emphasizes equipping employees with skills valuable beyond its ecosystem.

This proactive approach is seen as a strategic move to not only prepare for the future of automation but also to offset potential negative optics arising from job displacements due to technology. Similar ambitious approaches are needed in the energy sector to embrace the digital revolution and support people in building new skills and transitioning to new careers.

7 https://www.aboutamazon.com/news/workplace/upskilling-2025

Conclusion

Energy networks at the center of the transition to net zero

Energy networks play a pivotal role in the success of the transition to net zero. They serve as the backbone for integrating renewable and distributed energy sources into our existing infrastructure. However, achieving net zero is a collaborative effort that involves various external forces. Regulatory frameworks, technological advancements, and supportive policies are equally crucial in enabling the transformation of energy networks. By aligning these external forces with the capabilities of energy networks and implementing solutions like clear decarbonization goals, anticipatory investments, and collaborative partnerships, we can empower energy networks to drive the transition to a sustainable future. It requires a collective commitment from governments, regulators, industry stakeholders, and society as a whole to unlock the full potential of energy networks and pave the way toward a cleaner, greener, and more sustainable world.

Call to action

Governments:

- Set clear decarbonization goals and provide a roadmap for the transition to net zero
- Establish supportive regulatory frameworks to incentivize clean energy investments and ensure equitable cost distribution

Energy networks:

- Adapt infrastructure for renewable and distributed energy integration
- Invest in anticipatory measures and grid upgrades to address connection constraints
- Promote flexibility and bidirectional power flows through market rules
- Embrace digital technologies for optimized system operation
- Collaborate with educational institutions to develop skilled workforces

Industry and technology providers:

- Innovate and develop cost-effective clean energy technologies and solutions
- Collaborate with energy networks to deploy compatible technologies
- Ensure seamless integration with existing infrastructure

To achieve net zero, we must empower energy networks through clear goals, strategic investments, and collaborative partnerships, driving the integration of renewable sources and fostering a sustainable energy future.

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