

ENERGY TRANSITION OUTLOOK 2024 EXECUTIVE SUMMARY

A global and regional forecast to 2050



FOREWORD

Last year, in the foreword to our 2023 *Energy Transition Outlook*, I wrote that the *global* energy transition had not truly started. Clean energy had not started replacing fossil energy in absolute terms. Now, one year later, we have reached that point. 2024 is the year that the global energy transition has begun; it is also the year that emissions are likely to peak.

Emissions peaking is, of course, good news, but we must now focus on how quickly emissions decline. Worryingly, our forecast decline is very far from the trajectory required to meet the *Paris Agreement* targets. Our ‘most likely’ energy transition described in the pages that follow is one that leads to warming of 2.2°C by the close of this century.

If we want a faster transition, we must understand what is working and what is not.

Firstly, solar PV and batteries are booming. In 2023, new solar installations globally surged by 80% to reach 400 GW. One of the reasons solar is gaining ground so fast is because battery prices are plunging, making 24-hour solar+storage power more accessible. Battery prices fell 14% last year, and they will keep on falling. That means that EVs are poised to become cheaper too, and the world is on track towards our long-standing prediction that 50% of new passenger vehicle sales worldwide will be electric by 2031.

Developments in solar and batteries are key reasons for emissions peaking. Record EV sales in China have seen petroleum demand there beginning to ebb, while solar is finally edging out coal in China’s power sector. China’s achievements in the production and export of clean technology are positive for the global transition, but are also facing a tariff backlash. Policymakers must strike a difficult balance between national security, economic goals, and *Paris Agreement* ambitions. Meanwhile, investing in clean tech recycling systems and digitalization/AI for efficient energy production, transmission, and use are no-regret choices.

Secondly, the transition is in difficulty with technologies for decarbonizing hard-to-electrify sectors. Hydrogen and carbon capture and storage (CCS) are indispensable to a *Paris Agreement* aligned transition. Many of the first commercial hydrogen energy projects have experienced

cost overruns or have been stopped amidst market uptake uncertainty.

We have revised our long-term forecast for hydrogen and its derivatives down by 20% (from 5% to 4% of final energy demand in 2050) since last year. Without a meaningful carbon price and/or direct market-stimulating support, hydrogen will struggle to scale and move down a cost-learning curve. The same holds true for CCS where our current forecast is that investment in CCS during our entire forecast period will be less than the amount invested in solar and wind in 2023 alone.

The *Paris Agreement* involves a mission-oriented energy transition, and not one simply reliant on market forces. While the transition is now finally starting, its downwards trajectory is too slow because enabling policy is too weak.

In this Outlook, we quantify the many efficiencies gained from a doubling of electrification globally in the next 25 years. These efficiencies result in very large cumulative benefits that should give policymakers justification to tackle the difficult, hard-to-electrify sectors while doubling down on renewable technologies, including much-needed short-term support for offshore wind.

I hope this year’s Outlook inspires action, and as ever, we welcome your feedback.



Remi Eriksen

Remi Eriksen
Group president and CEO
DNV

HIGHLIGHTS

- 1 **2024 is likely the year of peak energy emissions, but the slow decline of post-peak emissions keeps key climate goals out of reach**
- 2 **Slow developments in hard-to-electrify sectors contrast with rapid cost reduction and growth of PV and batteries**
- 3 **Highly competitive Chinese clean technology is speeding up the transition**
- 4 **National and economic security priorities dominate the international agenda and slow the transition**
- 5 **Market forces are necessary but insufficient; energy policy needs urgent alignment with climate goals**

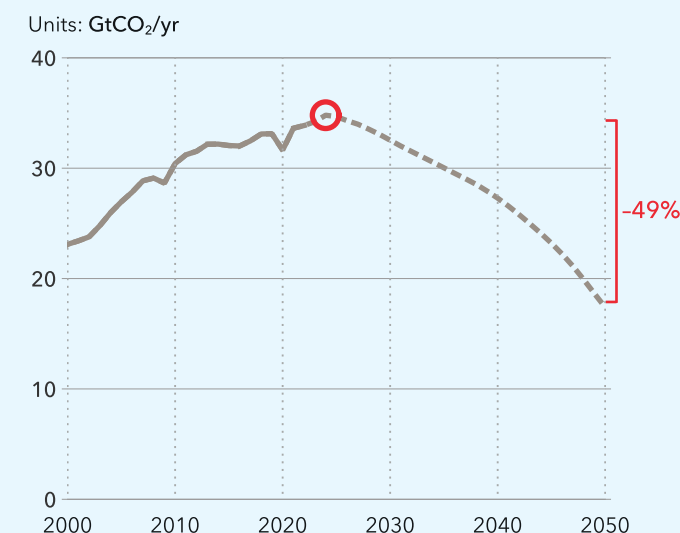
1. 2024 is likely the year of peak energy emissions, but the slow decline in post-peak emissions keeps key climate goals out of reach

- Solar PV installations are growing so rapidly that the need for coal power is reducing; global coal consumption in power stations is lower in 2024 than 2023. In the coming decade, the Indian Subcontinent is the only region with expected growth in power emissions.
- EV uptake is so high that peak gasoline in China is behind us and global peak oil is expected within a couple of years.
- The expected reduction in energy-related CO₂ emissions in 2025 (-0.4%) is marginal and not very certain. Unforeseen political or economic priorities may delay the peak by a year or two, but it is more likely than not that 2024 is the year of global peak energy-related CO₂ emissions.
- Slow scaling of decarbonization solutions in hard-to-electrify sectors like heavy industry, maritime, and aviation is an ongoing challenge. Moreover, we expect a strong increase in global aviation travel demand.
- Global energy-related CO₂ emissions reduce 5% by 2030, compared with 2023 levels. In 2050, CO₂ emissions are at 17 Gt – half the present level. This is two decades later than the 2030 halving of CO₂ emissions

outlined by the IPCC, and very far from net zero in 2050. Cumulative emissions drive a global temperature increase, and we are most likely heading towards 2.2°C of warming in 2100.

HIGHLIGHT 1

World energy-related CO₂ emissions will peak in 2024



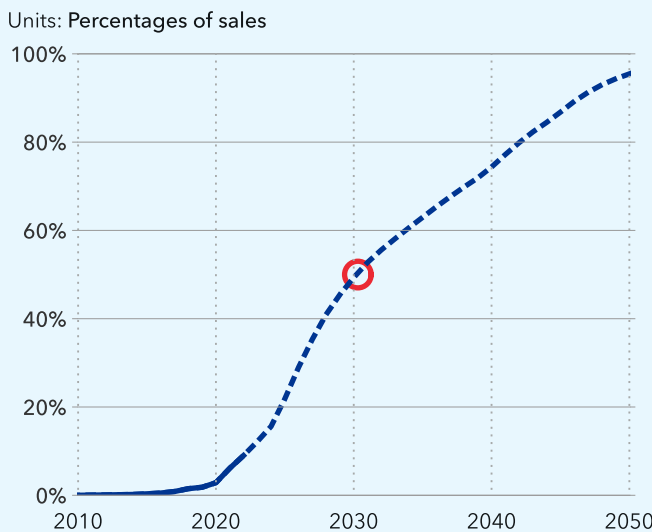
HIGHLIGHTS

2. Slow developments in hard-to-electrify sectors contrast with rapid cost reduction and growth of PV and batteries

- Annual global solar installations were up 80% to 400 GW last year; installations will increase in 2024, but at a lower growth rate.
- Solar+storage is growing fast, enabling 24-hour delivery of solar power.
- EV sales increased 50% last year and are on track towards a 50% global passenger EV sales share in 2031.
- Costs of both PV and batteries continue to decline sharply, a trend we expect to continue.
- There are slower developments in core technologies needed for hard-to-electrify sectors: we have revised down both our short- and long-term forecasts for hydrogen. CCS is gaining some momentum, but only 2% of global emissions will be captured by CCS in 2040 and 6% in 2050.
- Within electricity, offshore wind (down 18% in 2050 versus last year’s forecast) and small modular nuclear reactors (SMR) are running behind earlier promises.
- Overall, renewables grow 2.2x from now to 2030, well behind the COP28 goal of tripling to 2030.
- Near-term energy efficiency improvements are also relatively slow. Global energy intensity improves 2%/yr to 2030, only half of the 4%/yr target from COP28.

HIGHLIGHT 2

Half of passenger vehicle sales are electric by 2031

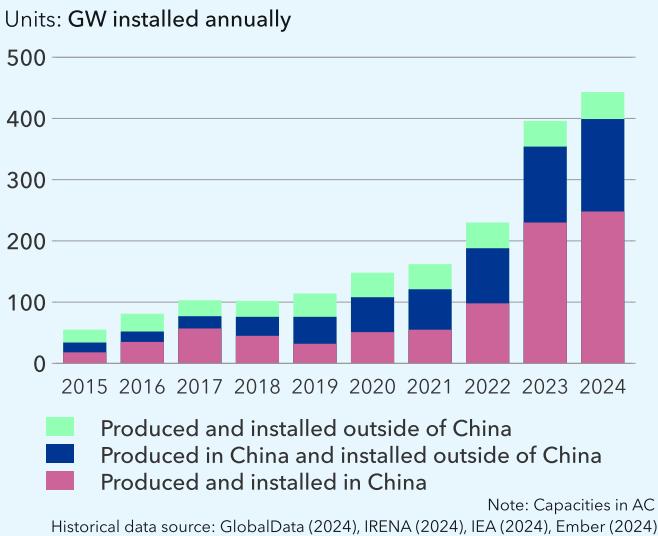


3. Highly competitive Chinese clean technology is speeding up the transition

- China has pursued strategic industrial policies on 'new energy' technologies for decades and now dominates the manufacture of almost all of those technologies. The Chinese domestic market provides a scale advantage: in 2023 China accounted for 58% of global solar installations and 63% of new EV purchases.
- China’s exports of low-cost clean technologies and overseas direct investments enables the transition abroad: with solar PV and batteries dominating export and wind turbines and electrolyzers growing.
- National, economic, and energy security considerations are leading to tariffs and other protectionist policies for home-grown supply chains and manufacturing in North America and Europe in particular.
- Diversifying from China too rapidly risks a sharp increase in supply chain and production costs, a duplication of innovation effort, and a slower transition.
- Alternative supply chains will take root, with sectors like battery storage which are of strategic security importance being prioritized, following substantial government investment in research and innovation, sourcing, and production support. In our model we reduce the temporary cost disadvantage of alternative supply chains over time.

HIGHLIGHT 3

China dominates global solar PV installations

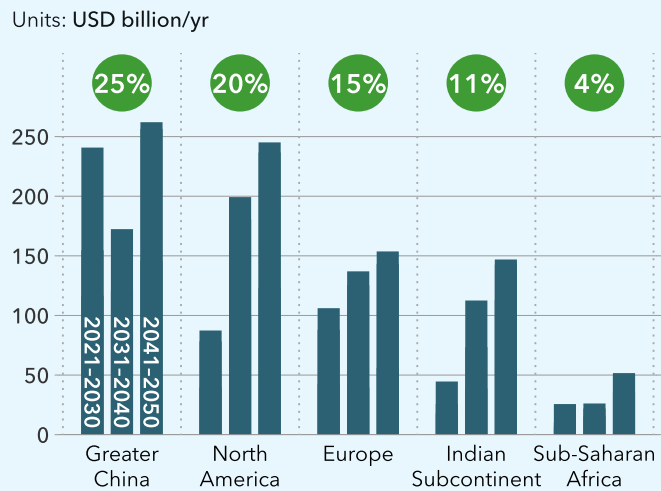


4. National economic and security priorities are headwinds for the transition

- There is a heightened security focus and diversion of national budgets towards military spending and away from government support for the transition and development aid financing the transition in the Global South. Only 4% of renewables investments are expected to go to Sub-Saharan Africa from now until 2050.
- High borrowing costs, albeit slightly easing, continue to squeeze public budgets and prolong a cost-of-living crisis in many individual households.
- Extreme weather events are draining budgets and yet not cementing climate action.
- A lack of effective action across all tiers of government addressing permitting delays/NIMBYism and other regulatory delays making renewable projects less profitable in several regions.
- Rising biodiversity concerns challenge renewable/grid developments. Aligning with the *Global Biodiversity Framework* is important; however, regulation does not (yet) reflect that climate change will surpass land use changes as the number one cause of biodiversity loss before 2050.
- In some instances, energy security priorities are speeding up the transition, like the accelerated renewable buildout in Europe, while elsewhere energy security favours continued expansion in fossil fuels.

HIGHLIGHT 4

Investment in renewable power will be concentrated in a handful of regions



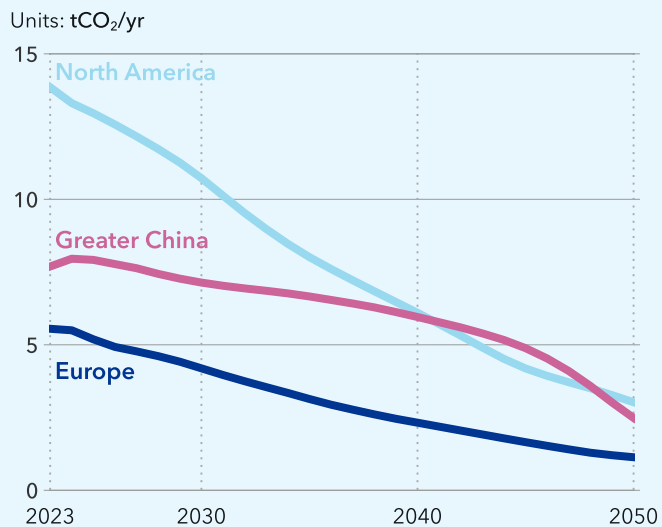
Bubbles show regional share of global investment over the 2021-2050 period

5. Market forces are necessary but insufficient; energy policy needs urgent alignment with climate goals

- Market forces alone cannot achieve the *Paris Agreement*'s goal of keeping the temperature rise well below 2°C. While markets are often effective in promoting renewable electricity and EV uptake, they fall short in addressing costly and complex technological measures in other sectors.
- Market forces are distorted because externalities are not priced correctly. This inhibits fossil fuel substitution, carbon capture and removal, and energy efficiency investments. Fossil subsidies in the forms of ‘contracts’ to citizens and producer support are widespread and block decarbonization.
- A cost on carbon is needed to achieve sufficiently rapid emissions reductions. While the US follows an incentive-based approach to promote renewables and clean energy uptake, the lack of disincentives results in persistently high emissions. China’s carbon pricing is evolving in scope but start late and remains at a low level compared with Europe.
- The virtual disappearance of emissions in Europe by 2050 (as shown below) is due to the comprehensiveness of its decarbonization policies – combining incentives for renewables uptake with disincentives, including a high carbon price, for continued fossil use.

HIGHLIGHT 5

CO₂ energy-related emissions per capita will decrease, but at different paces



ENERGY DEMAND

Why isn't energy demand growing?

Final energy demand *is* growing, but only by 10%, from 455 EJ to 502 EJ between now and 2050. That might seem like an odd result for a world where the population increases by 20% between now and 2050 and global GDP almost doubles to USD 320trn at the same time. Indeed, the total energy services needed globally – measured in goods produced, kilometres transported, and square metres heated – will grow about 80% across the globe. However, the transition we forecast involves massive efficiency gains, mainly linked to electrification, that will almost entirely offset demand for energy services associated with the population and economic growth. Thus, final energy demand, in other words the energy delivered to the door of a house or factory, grows more slowly than demand for energy services, and in some regions will shrink in absolute terms.

Transport

Why does demand for transport reduce?
We see much more transportation, but less energy used to deliver it. Enormous efficiency gains from the electrification of road transport through to 2050 will more than offset

energy demand growth in aviation, and slight upticks in energy demand in the maritime and rail subsectors. Overall transport energy use peaks before 2030 and will reduce to a level 12% lower than today by mid-century – despite a near-doubling in the size of the global vehicle fleet, a doubling in passenger flights, a 40% expansion of tonne-miles at sea, and a doubling of rail passenger trips.

When will EVs 'take over'?
By 2031, EVs will be half of all new vehicle sales, and will make up 62% of the passenger vehicles and 35% of the commercial vehicles on the road in 2050. The road transport sector will see the strongest shift to electricity and therefore also the strongest efficiency gains. We expect road energy demand to reduce from 94 EJ in 2023 to 70 EJ by mid-century.

Will aviation switch to hydrogen?
Only minimally. While pure hydrogen offers near emission-free transport, its low energy density requires new aircraft designs and infrastructure. This will limit its adoption to 4% of the energy mix by 2050. We project e-fuels to dominate over pure hydrogen due to their versatility, reaching a 12% share by 2050. Energy demand for aviation will grow by 60%, but oil's share will fall from nearly 100% now to 60% by 2050, with electrification having a minimal impact and bio-based sustainable aviation fuels (SAFs) taking most of the share relinquished by oil.

But what about ships?
Here, we expect hydrogen to play a much bigger role than in aviation. A significantly decarbonized maritime 2050 fuel mix is dominated by hydrogen-based fuels with 24% ammonia and 12% e-fuel (likely methanol) with an addition of 11% biofuel. Electrification will be low (4%).

Buildings

Will buildings fully electrify?
No. We see electricity growing from 35% of the buildings energy mix in 2023 to 53% in 2050. Electricity's growth eats most into the share of biomass (principally, the traditional use of biomass for cooking and heating), which declines from 23% of the mix in 2023 to 12% in 2050. Electricity takes a much smaller bite out of natural gas, which only declines from 28% to 25% over the same period. Hydrogen takes a very small share, with less than 1% of buildings energy demand.

What about all that air-conditioning in a warming world?
Energy demand for cooling will soar from 8.2 EJ/yr in 2023 to 28 EJ/yr in 2050. It will be the most important source of growth in energy demand from buildings driven by both rising average temperatures and increasing – but far from uniform – capacity to invest in cooling due to GDP per capita growth. Efficiency gains in insulation and air conditioning technology will temper what could otherwise be runaway energy demand for cooling.

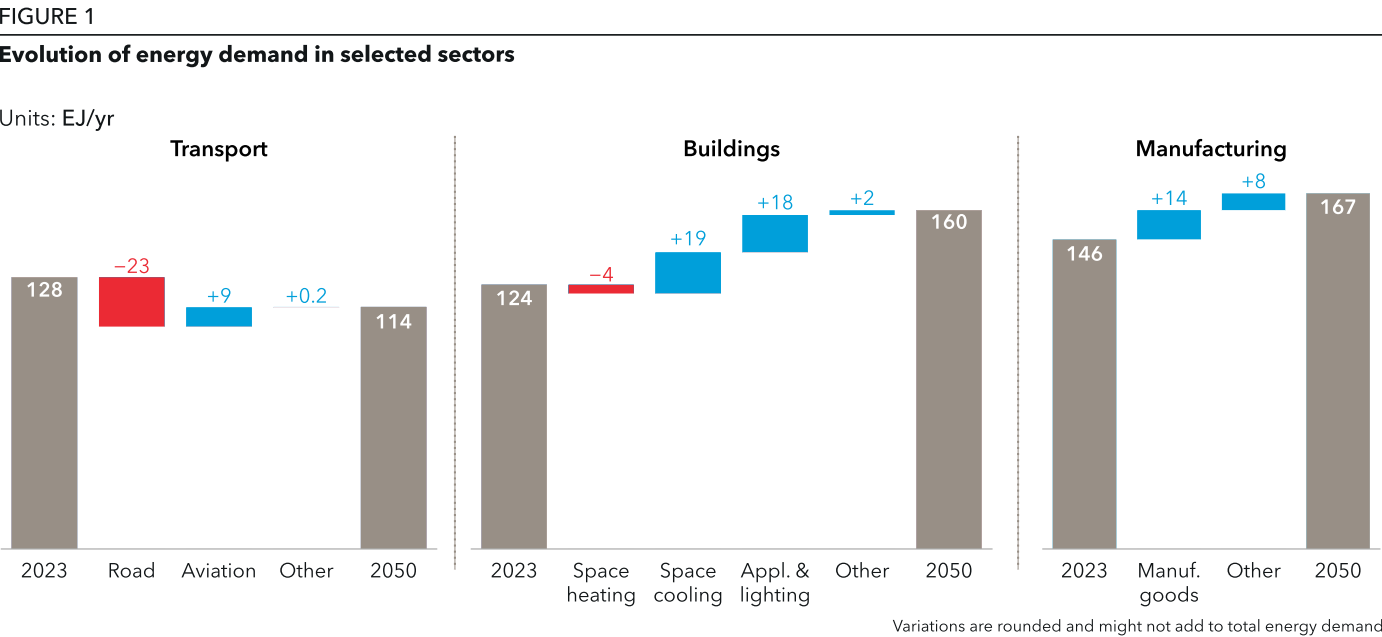
Will urbanization affect energy demand?
Yes – it is part of the reason why we see a roughly 50% expansion in commercial and residential floor area combined, coupled with rising GDP per capita. However, new buildings and electrifications generally go hand in hand and will benefit from considerable efficiencies – e.g. heat pumps can operate with an efficiency above 300%. Nonetheless, global energy demand for buildings is set to grow nearly 30% over the next three decades, to reach 160 EJ/yr in 2050.

Manufacturing

Why is manufacturing so hard to electrify?
Almost all high temperature processes are currently supplied by fossil fuels. Low-temperature heat pumps are promising in regions with favourable electricity-to-gas price ratios. High-temperature solutions like advanced heat pumps and thermal storage systems are still in early stages. SMRs could provide heat and power, but their adoption is likely limited due to costs.

How can we fully decarbonize manufacturing?
Where electrification is unfeasible, hydrogen and carbon capture are key decarbonization options, though they require significant investment and supportive regulatory conditions like carbon pricing and/or long-run incentives. We forecast that by 2050 manufacturing has only 5% of hydrogen in the energy mix, and total CCS of 800 Mt, of which more than half (of the CCS) is for hydrogen and e-fuel production.

What does more people buying more things do to energy demand?
There will be a ramp-up in manufacturing output due to a larger, more prosperous population and total manufacturing energy demand is projected to increase by 15% to 2050. Manufacturing electricity demand will increase around 50% over the same period, and will add to efficiency gains. For example, steel production from scrap in electric arc furnaces uses 10 times less energy than the coal-intensive blast furnace route.



ENERGY SUPPLY

How much more energy will the world be using in 2050?

Only 3% more primary energy than today. Primary energy supply is expected to peak in 2038 at 673 EJ/yr, just 6% above current levels, and drop by around 3% to 654 EJ by 2050. This minimal growth is due to reduced conversion losses, such as heat lost in coal-fired power plants, as non-fossil energy use rises.

Fossil fuels



When will coal peak?

Coal peaked in 2014, and after a relatively flat development, it will have a new peak now in 2024 marginally lower than 2014. From 2025 onwards, we expect a downward trend due to structural changes, e.g. the permanent replacement of coal by renewables in electricity generation in China. Coal use is set to fall by almost 70% to 2.7 Gt by mid-century – a big drop, but not fast enough in terms of meeting international climate goals.

When will oil peak?

We expect oil to start to decline around 2027. Peak oil will be hard to spot because it will be more like a small bump on a plateau. From its level of 189 EJ in 2023, we forecast annual oil use to end 7 EJ lower in 2030. More important is how fast and how far oil use falls during our forecast period.

How far and fast does oil fall?

From peak annual oil use, we expect annual oil use to fall almost 40% ending at 121 EJ in 2050. Overall oil use in transport will halve during our forecast period. As the electrification of road transport accelerates, the decline of oil between 2035 and 2050 is almost twice that seen between 2025 and 2035.

When does gas peak?

We expect a slight uptick in gas use between now and 2027 and then a plateau for three to four years before a very gentle decline to a level 3% lower than present use in 2050. Rather than peak gas, the focus should be on its staying power. It is roughly one quarter of the mix now and will still be around 22% of the mix in 2050. Gas use generally

increases in low- and middle-income regions, and there will be demand for gas in new sectors, like maritime transport and as a feedstock for blue hydrogen and ammonia.

Solar and wind



Does solar or wind win the green race?

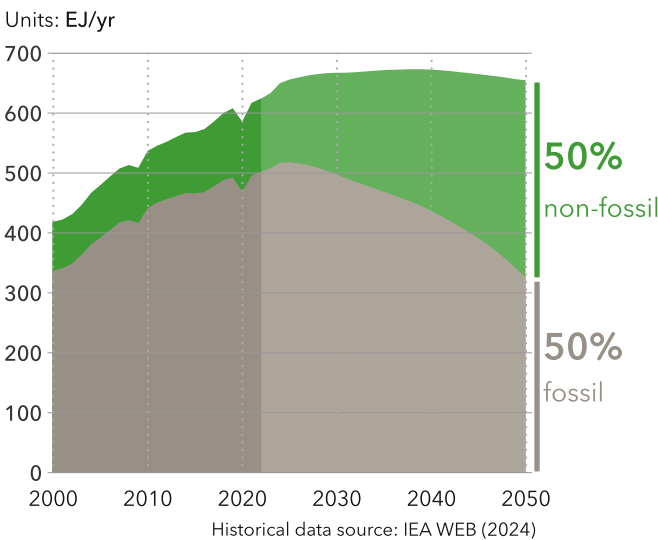
We expect a 12-fold increase in global solar installed capacity (including off-grid) from now through to 2050 when solar will be at 117 EJ, or 18% of primary energy. We expect a six-fold increase in global wind capacity to 65 EJ 2050 when wind will be 10% of primary energy. Solar's share of global electricity production in 2050 is 44%, while wind supplies 28% – a higher share than the relative size of its installed capacity would imply, owing to the higher capacity factor of wind vs solar.

Is wind in trouble?

We have lowered our forecast for offshore wind installed capacity in 2050 by 20%, owing to cumulative difficulties – costs, reliability, lack of government support – that offshore wind supply chains and projects have encountered across the OECD in the last few years. Offshore wind is emerging from these doldrums now, and we predict a 12% average annual growth through to 2050.

FIGURE 2

World primary energy supply



Other non-fossil energies



Is a nuclear renaissance in the offing?

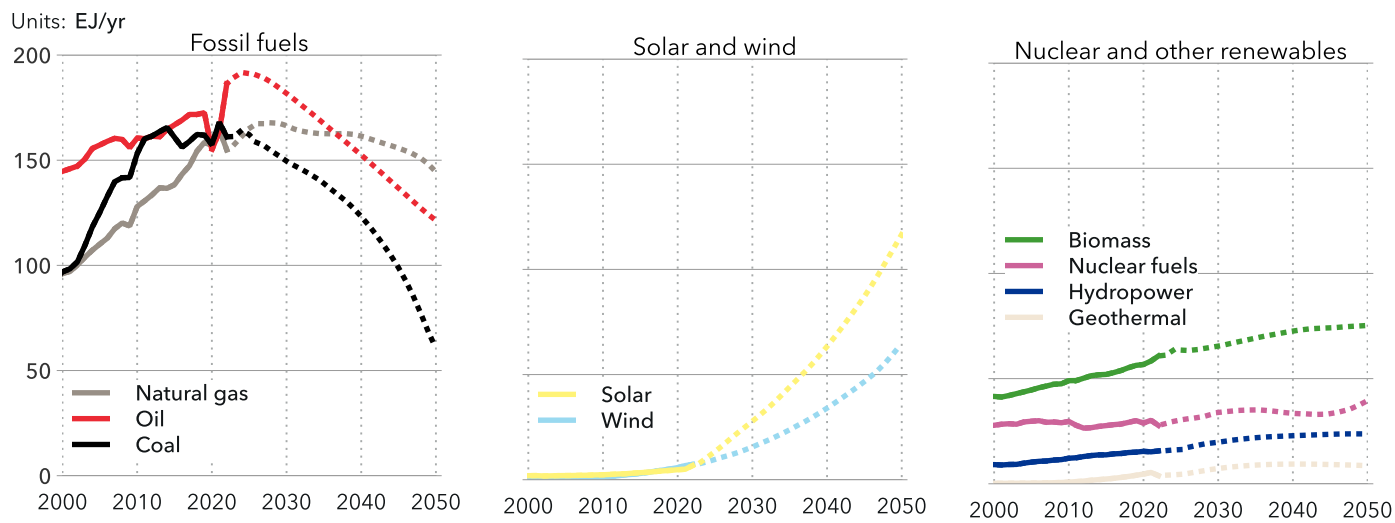
Not in our forecast period. However, we do see nuclear growing: by 2050 output will be 30% higher than today. Our forecast factors in additional 'energy security' support by governments of 5% to 20% of the levelized cost of nuclear energy from 2024 to 2050, demonstrating willingness to pay extra for domestically controlled energy. We also see SMR technology commercializing in the 2030s and contributing to capacity additions in the 2040s. The primary obstacle for both large-scale and small-scale nuclear technology remains cost.

Will climate change favour hydropower?

A warmer, wetter world might seem like good news for hydropower, but greater weather extremes, including recurrent droughts, will impact its reliability. That said, hydropower will expand by almost 50% by 2050, and there will be a tripling in pump hydro storage capacity by then. While important, this growth is dwarfed by the massive expansion of solar PV and wind – such that the share of hydropower in global grid electricity generation reduces from 14% now to below 11% in 2050.

FIGURE 3

World primary energy supply by source



Will bioenergy clash with food production?

In general, the answer is: not more than it does today. We forecast a modest increase, 23%, in biomass demand for energy. Nevertheless, bioenergy remains an important energy source at 12% of primary energy in 2050 and is only surpassed as the leading renewables source by solar in the 2040s. Expanded biofuel production will be based on biomass sources such as agricultural by-products, residues of forestry and wood industries, municipal waste, and industrial residues. First generations biofuels based on energy crops will fall away because on a full lifecycle basis they make a very minimal contribution to emissions reduction making the land and water opportunity costs involved difficult to justify.

The primary energy supply mix will change significantly through to 2050 with fossil fuel's share falling from 80% today to 50% in mid-century. This change accelerates throughout our forecast period, suggesting that the trend will continue well beyond 2050.

ELECTRICITY

Why is electricity demand doubling?

Electricity more than doubles, from 30 petawatt-hours (PWh) in 2023 to 62 PWh by 2050. This can partly be attributed to a rising and more affluent global population. Additionally, in the next 25 years, significant new categories of demand will surface, such as 1.3 billion passenger EVs, billions of heat pumps for residential and industrial heating, thousands of electrolyzers generating green hydrogen, cooling demand escalating by 2.5 times, and new data centres augmenting overall consumption levels equivalent to those of Germany and France combined.

1.3 billion EVs! Will that reshape electricity consumption?

There will naturally be a rise in demand for EV charging from a negligible quantity in total electricity demand now to 6 PWh in 2050. There will be an increased need for upgrades to distribution networks where they have limited capacity – in part because of other new categories of demand (see above). However, EV charging is unlikely to result in much ‘peakier’ demand as some expect. Most charging will be done smartly – i.e. during hours of low demand/prices. Moreover, we estimate that around 7% of the EV fleet will be available at any given time to participate in vehicle-to-grid flexibility trades.

Will the grid handle all this?

We project the global transmission and distribution grid length to double from 104 million circuit kilometres (c-km) in 2023 to 215 million c-km by 2050. From a throughput perspective, we expect grid capacity to expand 2.5 times within the same period to connect growing supply and demand. To support and accelerate the renewable energy transition we forecast, the grid must undergo significant transformation that integrates advanced grid enhancing technologies, digitalization, and AI.

How cheap is electricity from renewables and will it get cheaper?

IRENA (2024) recently estimated that the levelized cost of electricity (LCOE) of solar PV was 56% lower than the weighted average fossil fuel-fired alternatives in 2023, having been 414% more expensive in 2010. We project that average solar PV LCOE will fall 39% between now and 2050, onshore wind will decline by 46%, and offshore wind by 53%. The general conclusion is that if renewables have a cost advantage in the power mix already, this will intensify over the coming decades.

So, renewables will completely dominate the global power mix?

This statement is broadly correct in the sense that, by 2050, we project solar will supply 44% and wind 28% of global electricity, meaning that these two sources will together account for over 70% of the world's power generation. However, renewables will encounter challenges along the way. In the short term, there are grid capacity limitations, public perception issues, temporary material shortages, and market design obstacles. As renewables become more economically attractive, most new demand for electricity and a growing share of existing demand is likely to be met by solar and wind until the system starts to encounter limits such as profitability challenges due to price cannibalization, reliability concerns stemming from the variability of renewable sources, and local land availability constraints.

You mention reliability. Will solar and wind lead to blackouts and grid collapse?

We can ensure grid reliability and prevent blackouts even with a high penetration of variable renewable energy sources like solar and wind. Energy storage systems, such as batteries, are crucial for retaining surplus power generated during peak renewable output for later use when generation is low. Fast-

ramping gas peaker plants and hydropower stations provide quick responses to fluctuations in supply and demand, enhancing grid stability. Enhancing grids with smart technologies allows for real-time monitoring and control, improving efficiency and resilience. This includes the automatic activation of demand response programmes that help balance the grid by allowing consumers to adjust their energy usage based on supply conditions. We will also see continuous advances in forecasting tools for weather patterns and the use of AI to predict demand more accurately. By leveraging these technologies, grid operators can better manage the variability inherent in renewable energy sources.

Will my energy bills reduce?

That depends on where you live and your individual circumstances. While it is true that with more renewables, the wholesale price of electricity will reduce, the end-use price may not reduce as much due to grid charges, taxes, and levies on energy bills. However, households worldwide are likely, on average, to be spending less on energy as a proportion of their income as the energy transition progresses. The main reason for this is the efficiencies that electricity will bring to households through, for example, the electrification of transport and heating.

Will electricity uptake differ by region?

Yes. Developing regions like Sub-Saharan Africa and the Indian Subcontinent will see the most rapid increases in power demand due to electrification, industrialization, and urbanization. For instance, Sub-Saharan Africa is projected to experience a 290% rise in electricity demand by 2050. Similarly, the Indian Subcontinent will see a 270% increase, driven by a young, growing population, rapid urbanization, and the mechanization of agriculture. In contrast, developed regions like North America and Europe will see more moderate demand growth, influenced primarily by the electrification of transport and heating. In North America, where electricity demand is set to grow by 64%, the adoption of EVs and the expansion of data centres will be key drivers, while Europe’s 81% increase is largely due to the uptake of electric heat pumps and the growing demand for low-carbon hydrogen production.

Electricity will double by 2050 and will be almost 90% decarbonized by then.

FIGURE 4

World grid-connected electricity generation by power station type

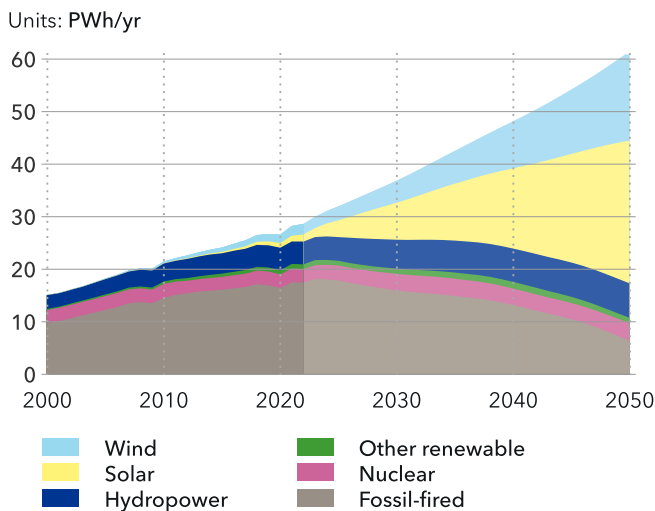


FIGURE 5

World annual electricity demand by segment

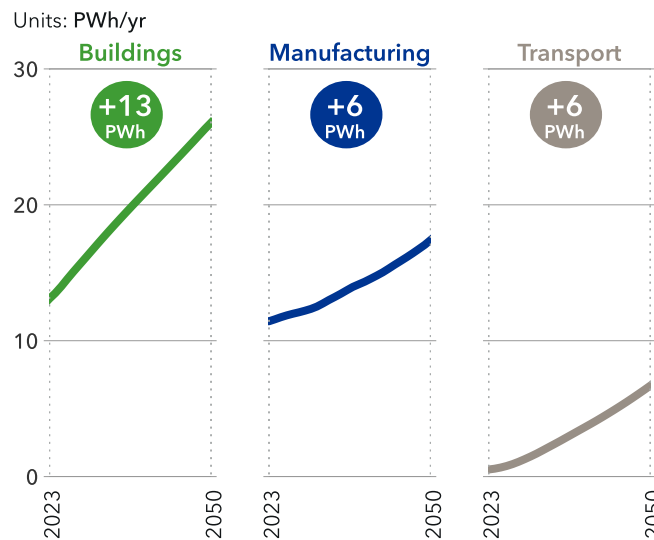
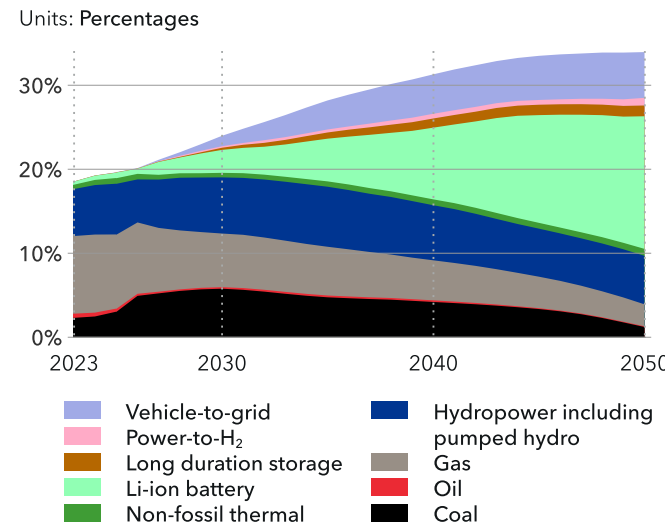


FIGURE 6

Global flexibility provided by technology as a fraction of annual average demand



HYDROGEN

Revising down our forecast

This year, we have revised our mid-century hydrogen-for-energy uptake forecast downward. From last year's forecast of 240 MtH₂, we now expect only 190 MtH₂ of hydrogen to be used for energy purposes in 2050. This is a 20% reduction and means that we now expect hydrogen to satisfy just 4% of global energy demand in 2050, and not 5% as we stated last year. Our forecast is now even further from the 15% share of the energy mix that hydrogen should take if the world is to reach agreed climate goals. We have also revised our short-term forecast downward, decreasing our expectation of hydrogen's share within the energy mix from 0.4% to 0.2% in 2030 and from 2.6% to 1.5% in 2040.

Struggling to scale

Despite the national strategies aimed at supporting hydrogen uptake, implementation delays and insufficient demand-creation policies are hindering progress. Projects are struggling to reach final investment decision, and some prominent projects have been abandoned. Hydrogen remains an expensive option, with costs for dedicated renewables-based electrolysis currently averaging USD 5/kgH₂. At present, that makes hydrogen up to 5 times more expensive per megawatt than natural gas in Europe. Even when the technology is ready for use, potential buyers are often hesitant to pay the higher costs associated with hydrogen as a fuel. Additionally, the technology itself faces delays; as an example, we see

far more electric options available for trucks than hydrogen alternatives. Finally, authorities are not mandating hydrogen use, which could serve as a viable alternative when the market is not fully prepared.

Fast-moving regions

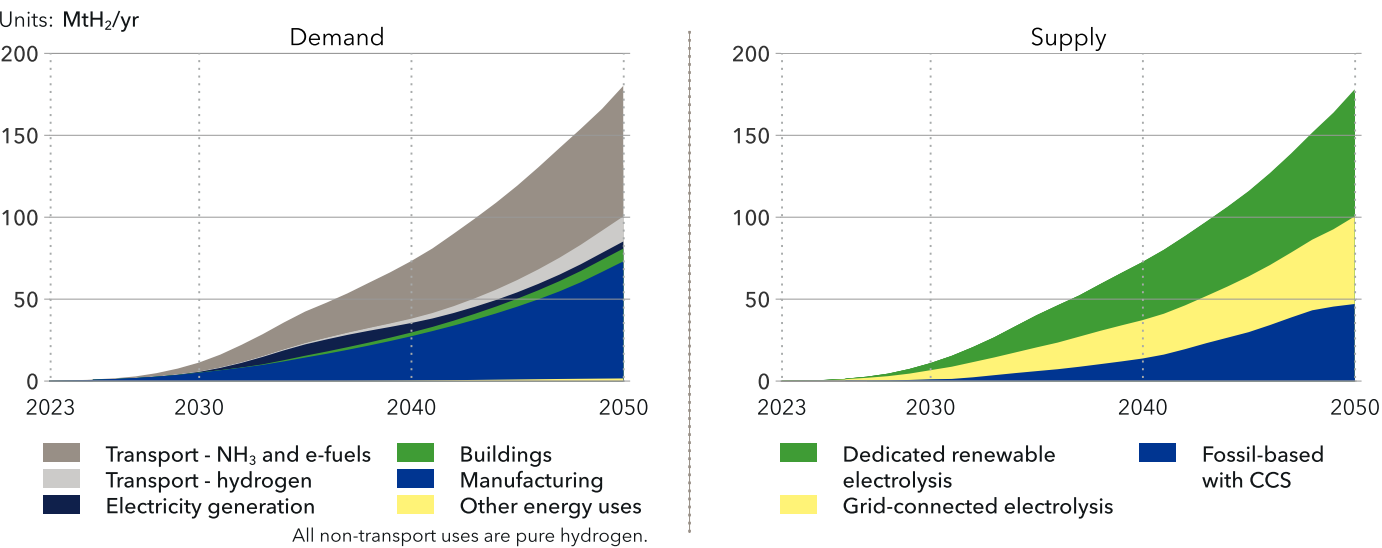
However, despite the headwinds, policy developments in Europe, North America, and the OECD Pacific are leading to a growing number of projects in these regions and a relatively rapid increase in hydrogen adoption towards and beyond 2030. As a result, we expect these regions to achieve significantly higher shares of hydrogen and its derivatives in their final energy mixes – around 7% each by 2050 – positioning them as frontrunners in hydrogen use.

A seat at the table

The continued expansion of wind and solar power will result in substantially lower electricity costs. That, along with decreasing costs for electrolysis equipment and stronger carbon pricing in hard-to-abate sectors, are likely to position hydrogen as an important component of the future energy mix, with production costs around USD 2/kgH₂ on average by 2050 and some projects at under one dollar per kgH₂. An impressive 81% of the world's hydrogen will come from renewable and low-carbon methods. Acceptance of 'blue' hydrogen from natural gas is increasing, and we foresee that it will comprise 23% of the hydrogen mix in 2050.

FIGURE 7

World demand and supply for hydrogen and its derivatives as energy carrier



EXPENDITURES

In our forecast, global annual energy expenditures remain almost stable, barely increasing 5% from now to 2050. At the same time world GDP is expected to grow from USD 169trn/yr in 2023 to USD 320trn/yr in 2050 – a near doubling. This highlights that the huge gains in energy efficiency will translate into a decreasing share of the economy spent on energy.

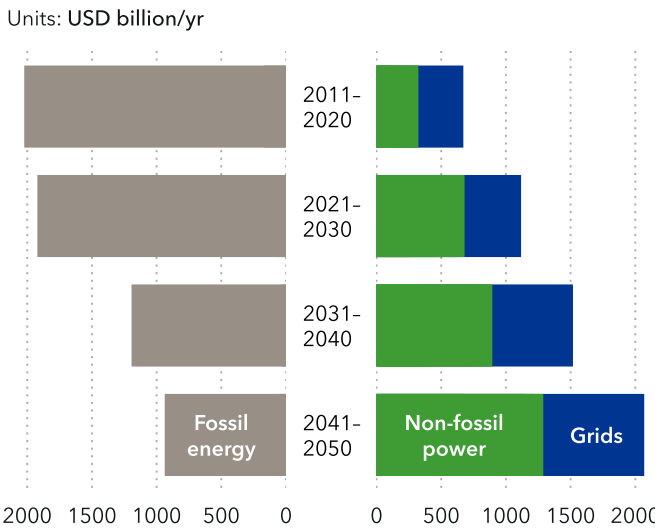
The investment transition

In the coming decades, we will see a steady shift from fossil to non-fossil energy investments and expenditures. Non-fossil energy investment will increase in all regions, from USD 570bn in 2023 to USD 1,700bn annually in 2050. Investment in fossil will progressively decrease; though even in the 2040s, upstream production of oil and gas will still be a large share of energy investment, with around USD 800bn spent annually.

The investment transition is characterized by changes in capital flows, risk models, and in the financial landscape. Solar PV exemplifies this transition; its unequalled scalability potential means that the upfront investment cost can be sized 1:1 with the available capital. It attracts all kinds of investors, from households to governments and corporates. It is reasonably low-tech and modular, and hence easier to finance in regions like Sub-Saharan Africa where access to capital is more difficult and expensive.

FIGURE 8

Average yearly investments in the energy system



Costs of capital

We anticipate that inflation's effect on borrowing costs will diminish by 2030. In the long run, the cost of capital will be influenced by risk perception. Renewables and nuclear energy will receive more favourable financing, whereas fossil fuel projects will incur higher costs. Figure 9 shows expected trends in North America.

Regional imbalances

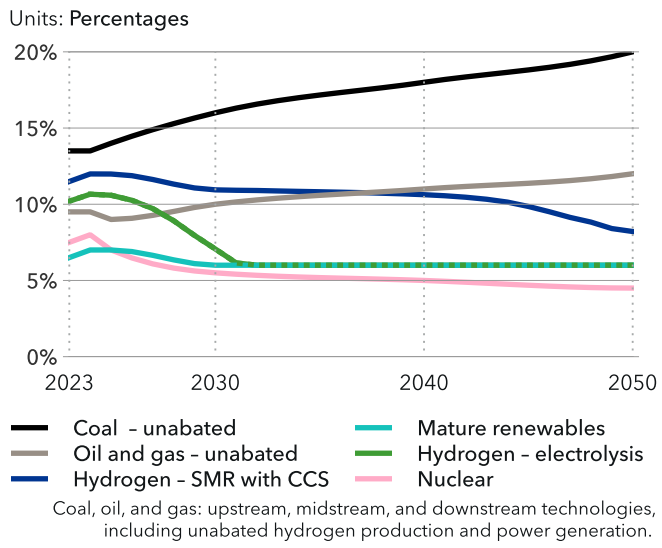
There will be large differences between regions, with Europe and North America seeing most of the funding coming from commercial sources, much less so in Greater China and North East Eurasia. Grid investments lean heavily on public funding in most regions. Overall access to capital from both development finance and commercial finance in low-income regions is the bottleneck for accelerating new energy investments, with only 20% of total energy investment financed through development finance institutions.

Investment in a just transition?

From a purely financial perspective, a just transition may be broadly achievable. As the share of renewable resources increases, the world will spend a progressively smaller portion of economic output on energy. Energy expenditure is projected to decrease from 3.3% of global GDP in 2023 to 2% in 2050. The prospect of savings of this magnitude in a reasonably short time frame could be used to motivate a faster and more just transition.

FIGURE 9

Development of cost of capital in North America



ARTIFICIAL INTELLIGENCE

Some argue that the ‘AI Age’ will accelerate the energy transition through exponential improvements in the production, transmission, and use of energy. Others argue that AI will slow the transition because of its large energy requirements. We address both perspectives in this year’s ETO.

Energy use

We project that AI will see a tripling of the energy consumption from data centres between now and 2050 to more than 1,100 TWh per year. That equates to 2% of global electricity demand by then.

There is uncertainty in our forecast owing to the lack of published data on AI’s energy use, and because AI itself is evolving so rapidly. The widespread use of generative AI is very recent and the rise in global data centre energy demand in 2023 is not a reliable indicator of the future impact of AI on consumption, but it provides a clue. Other clues include research emerging about the overall split between the energy needs of AI training and inference (i.e. the use of AI), at roughly one third and two thirds respectively.

The AI market is likely to exceed USD 1 trillion in value by 2030 – five to six time higher than today. However, the energy footprint of AI will not grow as quickly because there are many ongoing efforts to reduce energy use. These include rapid developments in GPU speed and

energy efficiency, more efficient AI model architectures, better algorithms, cloud computing and edge computing, as well as many innovations within data centres themselves, not least on cooling or harvesting waste heat for district heating.

Our overall assessment, therefore, is that AI’s energy use is meaningful, but relatively small at a global level – essentially adding the equivalent of France and Germany’s current electricity use to electricity demand over the next 26 years. However, it is important to look at the regional impact of data centres (North America houses a third of the roughly 8,000 data centres worldwide) and the local impact of data centres, for example on water systems and on distribution grids.

Impact on the energy system

The use of AI technology is enabling significant advancements in various areas such as power grid management, materials science, energy storage, short-term weather forecasting, renewable energy siting, and environmental impact assessments. These topics are covered in detail in this year’s ETO, along with important considerations about cyber security and the assurance of AI-enabled systems.

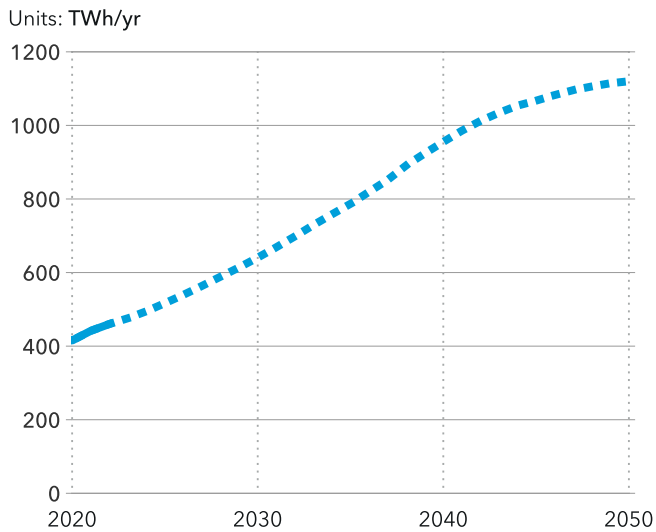
Policy, not AI, will remain the main driver of the energy transition. However, the role of AI in optimizing energy end uses could be considerable and is an area that we continue to monitor closely.



More detail on the current and expected impact of AI on power systems is available in our recent report on ‘New Power Systems’ (see last page of this report). The report also details prerequisites for AI deployment, including the main building blocks of advanced digital systems, as well as new approaches to AI assurance to advance safety in AI applied to critical systems and ensure compliance with, inter alia, the provisions of the ‘EU AI Act’. See also DNV’s [Recommended Practice on the Assurance of AI-enabled Systems](#).

FIGURE 10

World AI and data centre energy demand



POLICY

Since last year’s Outlook, policy interventions in energy systems have continued to expand, seeking alignment on climate, industrial, and energy goals. There is also shift towards seeing clean energy value chains as national assets, with transition spending aiming to accrue primarily domestic benefits.

Is transition policy being sustained in an era of uncertainty?

All regions are advancing renewable electricity policies for economic and energy security reasons. Beyond the power sector, the picture is more mixed:

- **High-income regions** have comprehensive technology-push policies and funding packages for hard-to-electrify sectors. However, there is a lack of demand-pull policies – guaranteeing deployment and offtake, expanding carbon pricing, dissolving fossil-fuel subsidies. ‘All carrot and no stick’ approaches raise serious questions about emissions reduction realistically achieved.
- **Among middle-income regions**, China is the front-runner with long-term planning, comprehensive supply- and demand-side policy, and supportive measures. Other regions have technology-push policies that depend on ‘capacity to fund’ diversification of economies and energy mixes, but less demand-side policy clarity compounded by immature carbon pricing and persistent fossil-fuel subsidies.

- **Low-income regions** have plans signalling investment and funding needs, but face a lack of resolve on financial commitments from high-income regions. Widespread fossil-fuel subsidies strain public budgets. India is an outlier with significant investment programmes to deliver on technology goals and with evolving demand-side policies.

The slowdown in global cooperation risks technical standards being developed separately which may jeopardize an effective, harmonized, and global response to address climate change and SDGs.

Policy factors included in the forecast

Policy influences all aspects of the energy system, and Figure 11 gives a snapshot of the policy factors incorporated into our analysis. For details, see Chapter 6 in the Outlook report.

Geopolitics

The present geopolitical environment – marked by conflicts – growing tension between power blocs, and persistent North-South inequalities, is generating uncertainty in energy markets. Nations now increasingly value energy security over both affordability and sustainability. Our forecast considers critical factors such as the added costs for energy security and the expense of bringing manufacturing back home. Analysing the impact of geopolitics involves navigating complex and evolving dynamics, but we assess the current situation as somewhat unfavourable for the energy transition.

In our model we include the following quantitative adjustments:

- An additional willingness to pay for energy that is domestically sourced and controlled. This includes renewables and nuclear, but in many regions also coal. In the model, the regional policy support level reflects the actual and likely future support to the various power sources.
- Additional short- and medium-term cost increases associated with the reshoring of energy technology manufacturing infrastructure.
- Shifts in manufacturing coming from production moving from one region to another as companies move to diversify their supply chains.

FIGURE 11

Policy factors included in our Outlook



COMPARISON OF REGIONS: ENERGY-RELATED CO₂ EMISSIONS

The Outlook covers the energy transitions in **10 world regions**. We compare regions on key transition indicators, like energy-related CO₂ emissions, shown opposite as:

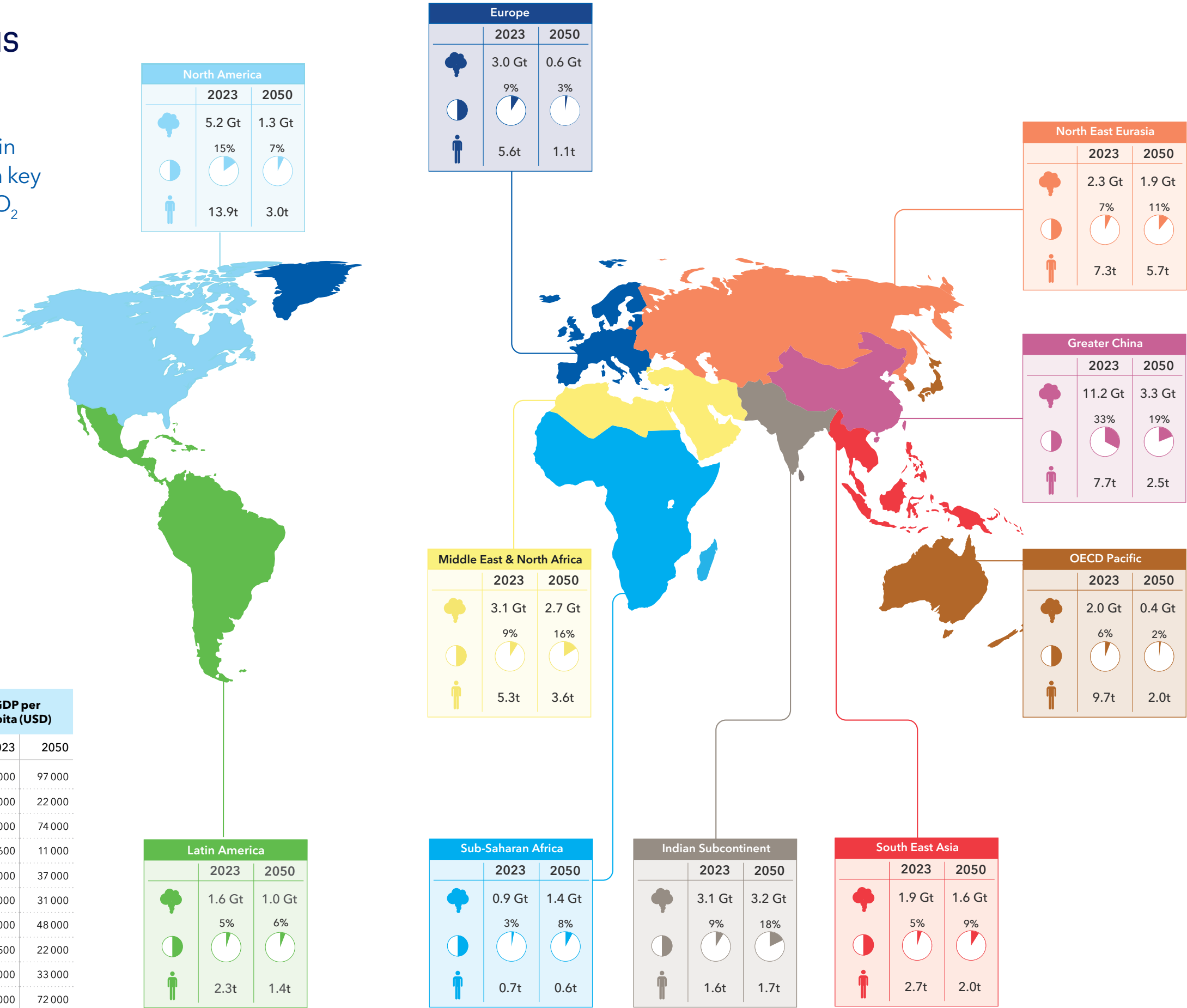
Key

Total energy-related CO₂ emissions

Share of world emissions

Energy-related per capita emissions

Region	Population (million)		Energy use per capita (GJ)		GDP per capita (USD)	
	2023	2050	2023	2050	2023	2050
North America	376	419	285	195	74 000	97 000
Latin America	669	744	54	55	19 000	22 000
Europe	544	542	125	104	53 000	74 000
Sub-Saharan Africa	1 220	2 140	24	22	4 600	11 000
Middle East & North Africa	575	770	100	98	23 000	37 000
North East Eurasia	320	334	140	122	22 000	31 000
Greater China	1 450	1 340	115	106	24 000	48 000
Indian Subcontinent	1 920	2 230	28	42	8 500	22 000
South East Asia	696	797	48	60	16 000	33 000
OECD Pacific	206	189	173	138	53 000	72 000



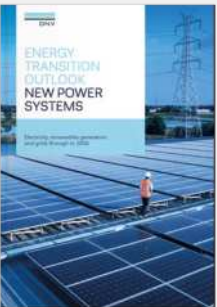
OTHER ENERGY TRANSITION OUTLOOK REPORTS



The 8th edition of our **Maritime Forecast to 2050** report pragmatically assesses the road ahead for shipping, analysing regulations, technologies, and fuel availability, and helping stakeholders to make the correct decarbonization decisions today. Our report considers how a complex regulatory framework is taking shape, the technological state of play in the maritime industry today, how a range of operational and technical energy efficiency measures can deliver significant short-term emissions reductions, and the role of other technologies, like onboard carbon capture, shore power and nuclear.



The **Energy Transition Outlook China 2024** focuses on the energy system transformation critical both to its future and to the success of the global energy transition. Our report explores what China is likely to achieve in the next 25 years as it pursues its overarching goal of energy security, which is largely congruent with its stated aim of carbon neutrality by 2060. China is currently the largest consumer of coal, and by far the largest installer of renewable capacity. Over the next three decades, renewables will largely replace coal in the power mix, and oil use will halve by 2050 from its 2027 peak. A faster transition to net-zero by 2050 where more oil and gas is replaced by domestically produced renewables and nuclear, would significantly boost independence.



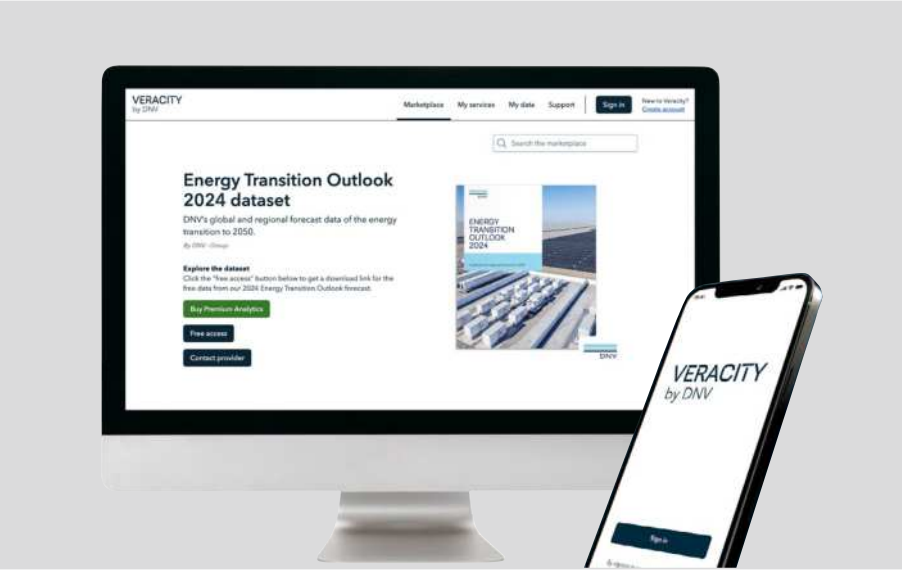
In our **New Power Systems** report, DNV takes a detailed look at the growing and greening of electricity. Not only is electricity use doubling in the next 25 years, but by 2040 solar and wind will together be responsible for 50% of all power generated. By 2050, that proportion will be 70%. Our report explores the growing need for flexibility and storage, how demand will increasingly follow supply, the need for grid expansion and the role of grid enhancing technologies, the impact of digitalization and AI to manage growing complexity, and new market designs. Throughout the report we emphasize the need for systems thinking, where all parties need to see the bigger picture when connecting and pursuing various technologies.



Country reports

Over the last year we have made adjustments to our model to enable the production of reports on the energy transition at country level. This year, we have released a UK Energy Transition Outlook, and ETOs on Norway and Spain to be released before the end of the year. Early in the new year, we will release a report on Germany's energy transition.

PROJECT TEAM



Download our forecast data

All the forecast data in DNV's suite of Energy Transition Outlook reports, and further detail from our model, is accessible on Veracity – DNV's secure industry data platform.

dnv.com/eto-data

DNV's Energy Transition Outlook is prepared as a cross-disciplinary exercise between the DNV Group and our business areas of Energy Systems and Maritime across 20 countries. The core model development and research has been conducted by a dedicated team in our Energy Transition Outlook research unit, part of the Group Research & Development division. In addition, we have been assisted by internal and external experts.

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For full list of all internal and external resources involved in the work, please visit the last page of the main Energy Transition Outlook 2024.

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DNV is an independent assurance and risk management provider, operating in more than 100 countries, with the purpose of safeguarding life, property, and the environment. Whether assessing a new ship design, qualifying technology for a floating wind farm, analysing sensor data from a gas pipeline or certifying a food company's supply chain, DNV enables its customers and their stakeholders to manage technological and regulatory complexity with confidence. As a trusted voice for many of the world's most successful organizations, we use our broad experience and deep expertise to advance safety and sustainable performance, set industry standards, and inspire and invent solutions.



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2024 marks our 160-year anniversary of safeguarding life, property, and the environment. Watch our short history film on dnv.com/history