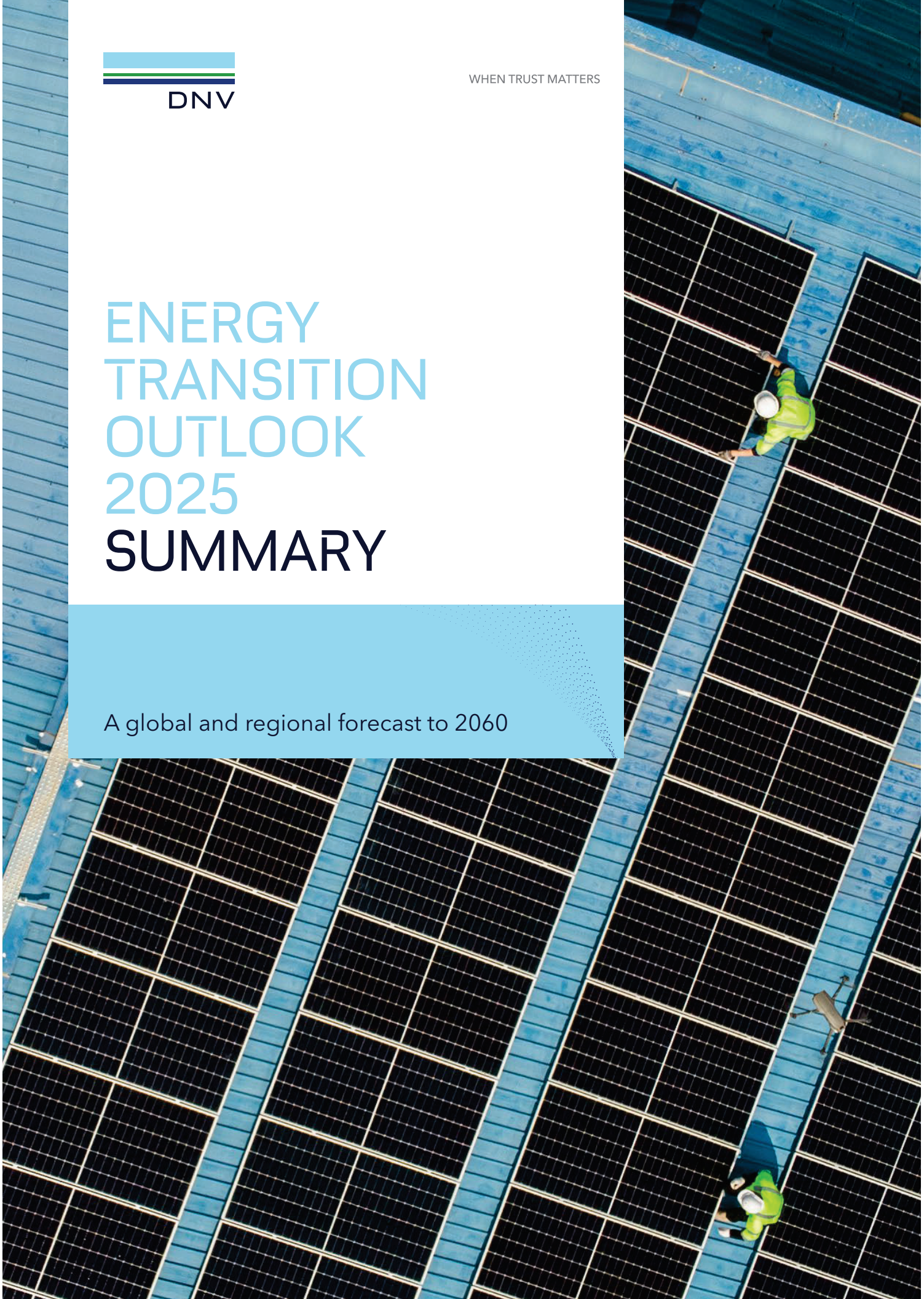
DNV

WHEN TRUST MATTERS

ENERGY TRANSITION OUTLOOK 2025 SUMMARY

A global and regional forecast to 2060



FOREWORD

Ten years have passed since representatives from 196 nations signed the *Paris Agreement*. Since then, only six countries have reduced their emissions in line with their pledges, while the US has exited the Agreement, again. It is now widely acknowledged that the world will not achieve net-zero emissions by 2050. This means warming will exceed 1.5°C and then increase relentlessly until we reduce greenhouse gas emissions to zero.

Faced with these developments, a casual observer might conclude that the energy transition is stalled or in reverse. That is most definitely not the case. The energy transition is rolling on. DNV's annual *Energy Transition Outlook* has, consistently, forecast a shift from today's 80/20 fossil/non-fossil primary energy mix to a 50/50 mix by 2050. That is still our prediction this year, although some aspects of the transition are supercharged and progressing rapidly, while other aspects of the transition have hit turbulence and are delayed. This leads to a marginally slower transition than our forecast last year.

Hydrogen and its derivatives, floating offshore wind, and novel nuclear solutions comprise the expensive side of decarbonization, with uptake driven by policy rather than market forces. These technologies all play a more muted role in this year's forecast, only really scaling in the 2040s.

In contrast, cheap renewable electrons, stored when necessary in ever-cheaper batteries, are already an unstoppable force. We forecast that solar (both with and without storage) and wind will be 32% of the global power mix by 2030. We expect a resurgence in offshore wind by 2030, such that variable renewables will provide more than 50% of all electricity by 2040. By then, electricity will have grown 55% from today's levels. What is stopping runaway developments in electrification is a lagging grid buildout. We estimate that in Europe, absent the present 'gridlock', solar capacity could be 16% higher by 2035, and wind capacity 8% higher.

Soaring power demand from AI data centres is placing additional strain on already congested grids, particularly in North America. Our analysis finds that AI's energy demand growth is likely to become more linear over time (outpaced, for instance, by EV charging demand) even as the cognitive services of AI expand exponentially. That is due to many efficiency effects working together, a theme we explore in some depth in this year's forecast.

In our view, the heightened focus on energy security by policymakers worldwide slightly favours non-fossil over fossil sources in the long run. That includes a resurgence of investment in nuclear power, which we predict will grow 150% from today's levels by 2060. On the fossil side of the mix, policy reversals in the US will see its emission reductions set back around 5 years. The US accounts for one seventh of global primary energy use and thus exerts some influence on the overall picture. However, massive scale decarbonization of the Chinese economy continues, coupled with low-cost electro-technology exports from China to other regions.

This year, our forecast runs to 2060, not 2050. That is mainly because the transition is by no means complete in 2050 and there is a very important dynamic unfolding in the decade thereafter as the world trends further towards a decarbonized energy mix. That trend is unstoppable but too slow, setting up grave risks for future generations.

Net-zero emissions in our forecast is only achieved towards the end of this century, and the accumulation of emissions until then takes us beyond 2°C of warming by 2100. Science has shown beyond any doubt that humanity will then be experiencing, to its great cost, how critical each tenth of a degree of global warming is to our planet and society.

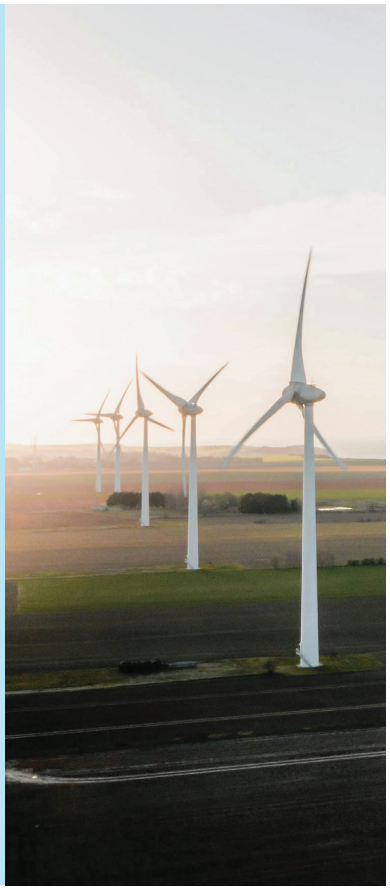
Remi Eriksen

Group President and CEO

DNV

HIGHLIGHTS

1. **Policy reversals in the US will have only a marginal impact on the global energy transition**
2. **Energy security actions globally produce a net result of lower emissions over time**
3. **EV and solar set new milestones as electricity production grows and greens with a progressively higher non-fossil share**
4. **AI's energy use may seem alarming, but at only 3% of global electricity by 2040, it is projected to stay below booming sectors like EV charging and space cooling**
5. **Emissions are not even halving by 2050, and urgent action is required to reach the 'well below 2°C' target**



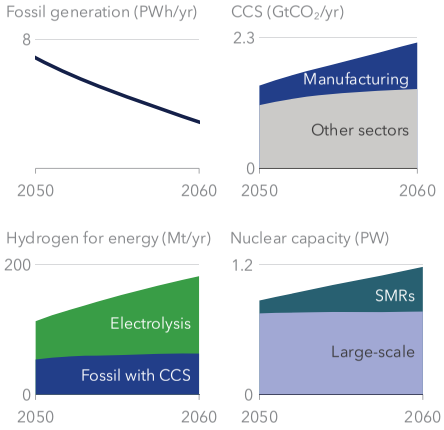
FORECAST TO 2060

This year, for the first time, our full forecast runs to 2060 instead of 2050. Our projection shows that while the energy system will have changed significantly by 2050, in many areas the transition will then still be in mid-stride.

Many national climate pledges look beyond 2050. Moreover, we find that net-zero emissions by 2050 is beyond reach for all practical purposes. Hence, looking in detail at developments after 2050 is becoming more relevant.

2060 is the limit to which we are willing to take our forecast before uncertainties (like economic growth, technology breakthroughs, policy shifts, and behavioural changes) detract from the quality and usefulness of close modelling. Our detailed commentary thus stops at 2060, but we extrapolate developments through to 2100 for the emissions and climate part of our forecast.

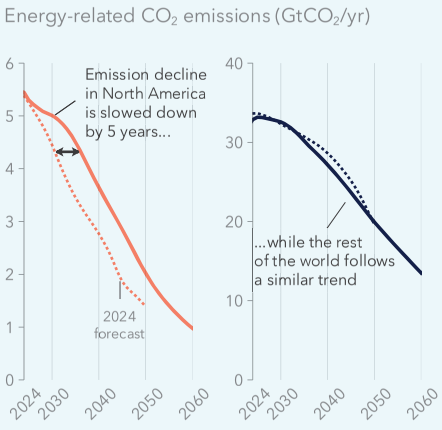
By 2060, fossil fuels will have almost exited the global power mix and internal combustion engine vehicle sales will be a rarity. However, rapid developments will still be happening in areas like changing aviation fuel mix, phasing out natural gas boilers, and building out SMRs for nuclear.



HIGHLIGHTS

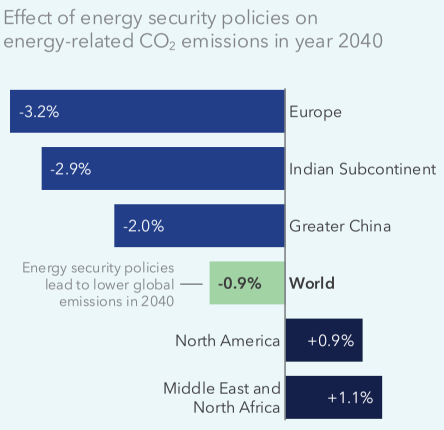
1. Policy reversals in the US will have only a marginal impact on the global energy transition

- This year, we project an energy transition that is marginally slower than the transition we forecast last year, both in terms of emissions and fossil's share of primary energy.
- In the US, fossil fuel promotion and the reversal of clean energy support policies markedly slow that nation's transition. Emission reductions are delayed by about five years and through to 2050 annual CO_2
- emissions are reset 500 to 1000 Mt higher than we predicted one year ago.
- China continues to set renewables buildout records with 390 GW of solar PV (56% share of new global capacity) and 86 GW of wind (60% share) expected to be installed this year. Chinese clean tech exports continue to propel the transition in the rest of the world.
- Europe is seeking to balance climate action with competitiveness. Harder-to-decarbonize sectors are progressing slowly. While Europe's renewable energy buildout remains relatively strong, it falls short of the EU's 2030 renewable energy targets.
- In the rest of the world, most countries are embracing competitive Chinese green technologies, with year-on-year growth in installations at around 25%. Fossil energy use is also rising, but not as quickly. The primary energy fossil fuel share only shrinks from 79% to 75% over the next 10 years.



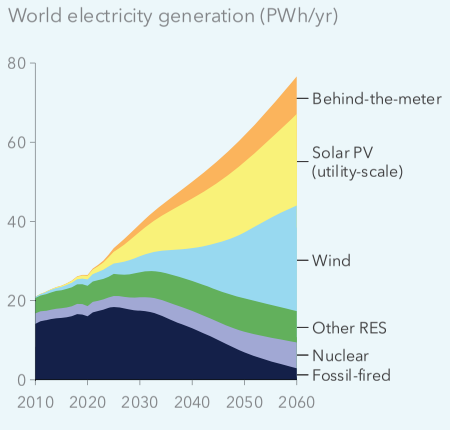
2. Energy security actions globally produce a net result of lower emissions over time

- Energy security priorities result in a decrease in emissions among energy-importing countries, while energy-exporting countries tend to see an increase in emissions. This trend endures even with the increased emphasis on domestic coal production in China and India.
- When we remove the energy security dimension in our global energy model, leaving only the affordability vs sustainability dilemma, sustainability suffers more. The effects are moderate, but we find energy security actions taken together lower global emissions by a percent or two depending on year. For Europe, the effect is marked: emissions 9% lower in 2050.
- Security-focused governments are pushing nuclear power, and it will account for 9% of electricity supply in 2060. Without the energy security boost, nuclear power would have been a third lower.
- Energy and national security concerns produce several dilemmas, including varying degrees of willingness to import cheap Chinese technologies.
- Building up effective domestic production, alternative supply chains, and sourcing materials from new sites are all lengthy and expensive exercises, but fully possible. Increasing global tension is weaponizing both energy and energy technologies, with the US and China at the forefront of that race.



3. EV and solar set new milestones as electricity production grows and greens with a progressively higher non-fossil share

- This year, the world reached the milestone of 50 million EVs on the road. Most of them (60%) are in China, with Europe at 21%, and North America at 13%. By 2030, we expect 200 million EVs on the road. EVs will be 50% of global new passenger vehicle sales by 2032.
- By the end of 2025, global solar PV capacity will exceed 3,000 GW, with 47% installed in China and 20% in Europe as the two leading regions.
- The plunging costs of solar panels and batteries have made behind-the-meter (BTM) solutions attractive for a range of households and business. BTM will represent 30% of all solar and 13% of all power generated by 2060.
- Globally, electricity is growing and greening rapidly and at scale. A 120% expansion from today to 2060 will see electricity shift from a 21% share of global energy demand to 43%. This encompasses growth in transport, buildings, and manufacturing in all regions. The fossil share of electricity supply over the same period falls from 59% to just 4%.
- For hard-to-decarbonize sectors, like heavy transport and high heat, we see that global rivalry and the economic slowdown are having an impact. Over the last three years, our forecast for the hydrogen share of the 2050 energy mix has shrunk from 4.8% to 3.5%.



HIGHLIGHTS

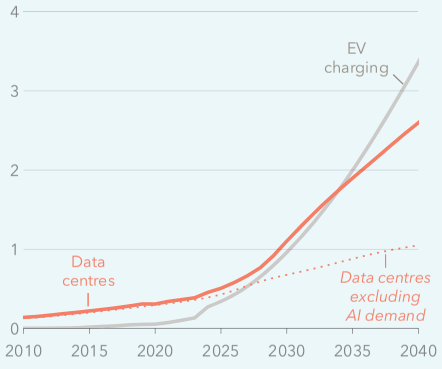
4. AI's energy use may seem alarming, but at only 3% of global electricity by 2040, we project it will stay below booming sectors like EV charging and space cooling

- With power-hungry data centres multiplying to service the rapid growth of AI applications, we find that the initial exponential growth in power demands will give way to a more linear pattern over time.
- Data centre energy use will quintuple to 2040, equalling 5% of all global electricity. 3% of this is for AI and 2% for general-purpose data centres. There are large regional variations; in North America the 2040 share is 16% of all electricity, with 12% being AI.
- Looking at short-term electricity growth, AI is the biggest driver of electricity consumption the next five years in North America. In Europe, EV charging growth far exceeds AI's demand growth, as do both EV charging and the cooling of buildings in China and India.
- The direct involvement of big tech in data centre energy supply is a new driver for new nuclear R&D, in part because big tech is less cost-sensitive than traditional power consumers. However, new nuclear energy will not be ready any time soon, and for the near to medium term, additional supply needed by data centres will come from renewables and fossil fuels, with regional variations.

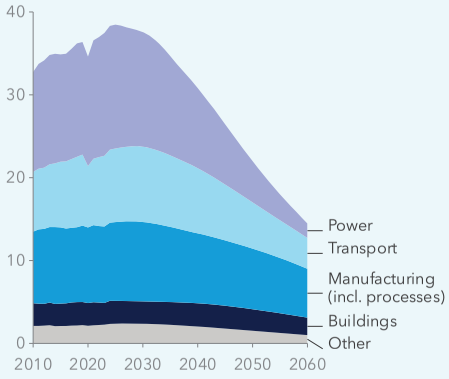
5. Emissions are not even halving by 2050, and urgent action is required to reach the 'well below 2°C' target

- Global CO_2 emissions reduce 43% from today to 2050 and 63% to 2060 – reaching net zero only after 2090. Emissions reduction is strongest in the power sector with an 88% (13 Gt) decrease, followed by the transport sector with a 58% (5 Gt) reduction.
- CCS and net-negative emission technologies remove 35 Gt of emissions from today to 2060, equalling 4% of cumulative emissions in the period. Although moderate, CCS is an important part of emissions reduction. Beyond our forecast period, an enormous amount of carbon dioxide removal (CDR) alongside nature-based solutions will be required to ensure net-negative emissions, which we estimate will only occur after 2090.
- The carbon budget for 1.5°C is exhausted in 2029 and 2°C in 2052; limiting global warming to 1.5°C without a temporary overshoot is no longer possible.
- Emissions in our forecast are associated with a temperature rise of 2.2°C above pre-industrial levels by 2100. There is an additional risk of higher warming based on new research on climate sensitivity not yet included in IPCC carbon budgets.
- Limiting global warming to 'well below 2°C' is still possible and urgent actions in all sectors and in all countries and regions are crucial to ensure this.

World electricity demand (PWh/yr)



World CO_2 emissions by sector ($GtCO_2$/yr)



THE INVESTMENT TRANSITION

Energy expenditures are set to plateau

Energy expenditures are the costs related to producing energy and transporting it to the user, including operational expenditure (OPEX) and capital expenditure (CAPEX). While global energy expenditures have grown 50% since 2010 in line with global GDP, that correlation is now starting to unravel. While progressively less is expended each year in the fossil fuel energy system and more is spent on building and running non-fossil power and grids, overall energy expenditure does not rise dramatically. Indeed, the average annual expenditures on energy around 2050 will be USD 6.5trn, no larger than today's levels, while GDP will have almost doubled.

That energy expenditures become an ever-smaller proportion of global GDP during our forecast period is testament to the very low OPEX of the dominant technologies in the mid-century energy mix and the vast efficiencies enabled by electrification. This pattern will likely be mirrored at a micro level in most households. As prosperity increases and efficient electrification of end uses deepens, we expect energy costs to comprise an ever-smaller proportion of household expenditures.

The rise and fall of fossil investments

Fossil fuel demand has grown steadily since the 19th century. The prospect of falling demand setting in before 2030 – a high likelihood given the ongoing electrification of transport and heating and rising carbon costs – is new territory for investors. The implication for the fossil fuel industry is reduced investments in new fields, geographic concentration of production, and falling operational expenditures from the early 2030s.

The timing of the transition will differ across regions. This is exemplified by coal-fired power generation. There is a market-driven movement away from installations of new capacity in many regions. However, in the medium term, some are still prioritizing coal for firm capacity or energy security. Coal production will increase by 46% across the Indian Subcontinent by 2039 to meet its growing energy demand.

Variable and firm power generation

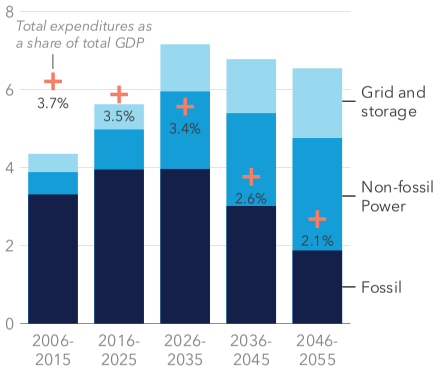
Investments in solar (including storage) rose from USD 110bn in 2014 to USD 570bn in 2024, and will grow to USD 900bn by 2044. Wind power saw a tripling in investment over the last decade to USD 180bn, and is set to triple again by 2044. As these two sources begin to dominate electrical power supply, substantial investments in energy storage and flexibility will be made, not least in firming capacity that can generate power on demand. This includes other renewables, nuclear, and fossil power. These sources will deliver power for the relatively rare time periods when variable+storage proves insufficient, supporting the grid when necessary at higher capture prices. Firm power generation will continue to attract USD 350bn on average in investments annually through to 2050.

Grid and storage

Investments in energy storage, such as batteries and pumped hydro storage, have grown 7-fold over the last decade to USD 50bn/yr. Going forward, ever more solar farms will be built with battery storage included, attracting as much investment as standalone solar PV in 2029. The combined storage investments will reach USD 150bn/yr in the 2030s and USD 300bn/yr in the 2050s.

Even though the grid buildout lags the renewables buildout, investments in the grid will double by mid-century (see Chapter 3.6 of the ETO 2025).

World energy expenditures (Trillion USD/yr)

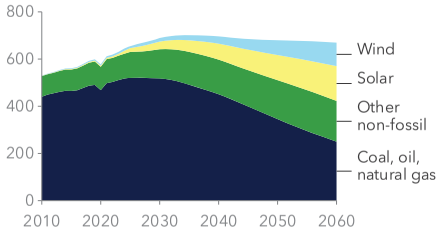


ENERGY SUPPLY AND DEMAND

Renewables replace fossil energy

- Renewable uptake will be driven by **solar and wind**. From 3% today, they will provide more than a third of primary energy supply by 2060.
- The growth in solar and wind, combined with other sources like nuclear or hydropower, will lead to **non-fossil energy** dominating from the 2050s.
- **Fossil energy** has provided a constant 80% share of primary energy for the past few decades. That pattern is now breaking. Primary energy supply will start to level off from the 2030s, while non-fossil steadily displaces fossil energy in the primary energy mix.

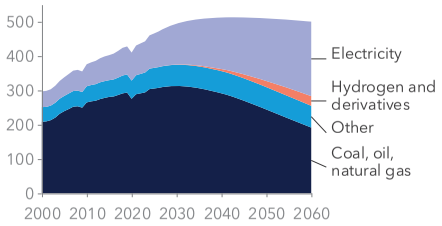
World primary energy supply (EJ/yr)



Rapid electrification

- Decarbonization goals, spurred by cheap renewable electricity, will see **electricity demand more than double** by 2060.
- As final energy demand plateaus, electricity will push **fossil fuels** out of the mix.
- Electricity will also be used to produce **hydrogen and its derivatives** for the indirect electrification of hard-to-decarbonize sectors like high-heat applications and heavy transport. Hydrogen and its derivatives will cover 1% of demand by 2040 and 6% by 2060.

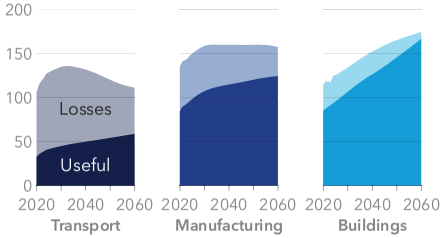
Final energy demand by carrier (EJ/yr)



More efficient energy systems

- The actual need for energy, or **useful energy, increases** in the three main demand sectors: transport, manufacturing, and buildings.
- However, electrification leads to massive **efficiency gains**, with ever lower losses. This is a key reason for energy demand plateauing in spite of GDP growth.

Final energy demand by sector (EJ/yr)

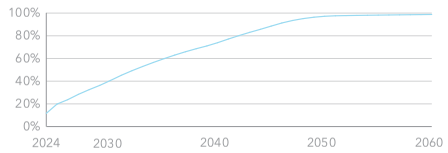


Different trajectories for the three main demand sectors

Transport

Demand for transportation services will grow. However, EV uptake in road transport, the most energy-demanding sector, means that **energy demand levels off and then falls** from the mid 2030s. Hard-to-electrify aviation and maritime sectors will also move away from oil dominance to a more diversified and decarbonized fuel mix.

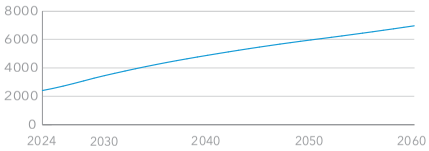
Global share of EVs in new passenger vehicle sales



Buildings

Energy demand will **continue to grow**, driven by a more affluent population using more appliances and an increased demand for space cooling. The only end-use category that will decline is space heating, as efficient electrical heat pumps progressively replace traditional gas boilers.

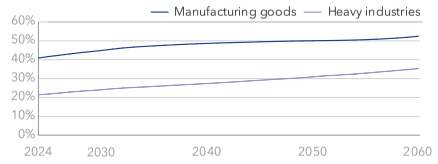
Global space cooling demand (TWh/yr)



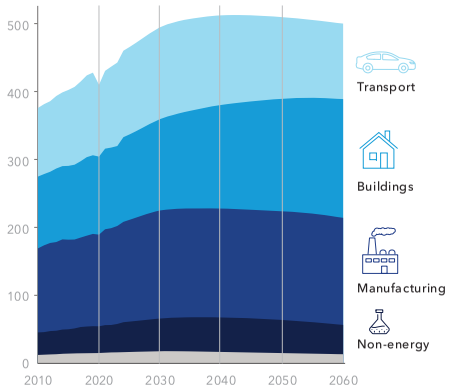
Manufacturing

Energy demand will see **slow transformation** compared with other sectors. Due to electrification challenges and cost-driven global competition, heavy industries will rely on fossil fuels for high-temperature processes for the next few decades. Meanwhile, the faster pace of cost-competitive electrification of goods manufacturing will create global competition for the future location of high-tech industries.

Share of electricity in energy demand



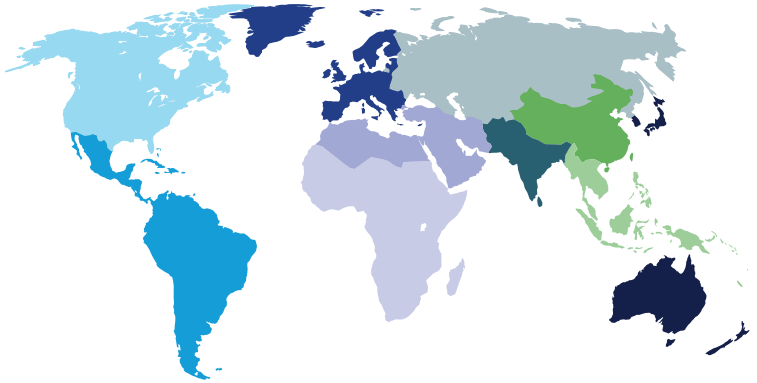
Final energy demand by sector (EJ/yr)



Historical data source: IEA WEB (2025). Bottom category: Other sectors.

NON-ENERGY, the use of energy carriers (mostly fossil fuels) as chemical feedstock for plastics, chemicals, asphalt, etc., will continue to grow in the next decade before higher plastics recycling rates curb the demand of virgin material made from oil and gas.

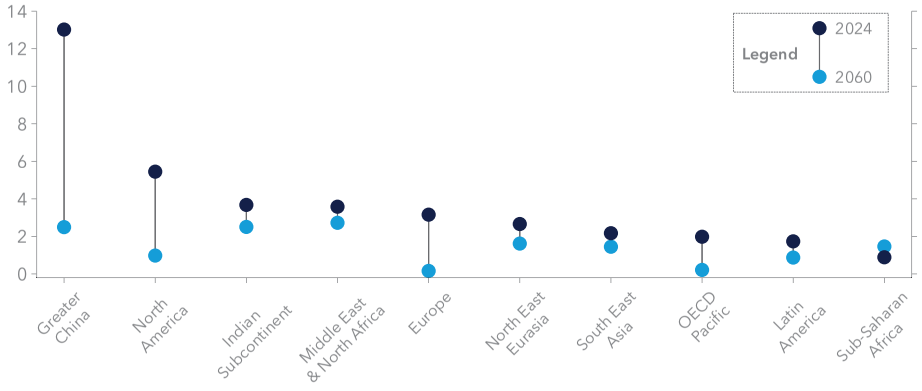
A GLOBAL DIRECTION, BUT DIFFERENT REGIONAL PATHWAYS



A regional perspective is essential to understanding the global energy transition. Different parts of the world have vastly different starting points, from mature, industrialized economies to rapidly-growing developing nations. Tracking CO_2 emissions provides a critical indicator of how each region's energy system is evolving.

In 2024, global CO_2 emissions are highest in Greater China and North America. Looking to 2060, while most developed regions show a consistent and steep decline, the story is more complex for developing economies. The Indian Subcontinent, South East Asia, and the Middle East and North Africa are projected to see emissions rise and peak between 2030 and 2040 before beginning their decline. Sub-Saharan Africa is the only region where emissions continue to grow through 2060, reflecting a different stage in its economic and energy transition.

Regional energy- and process-related CO_2 emissions ($GtCO_2/yr$)



OTHER ENERGY TRANSITION OUTLOOK REPORTS

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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 our 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 2025.

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