ONS ENERGY AGENDA VOL. 2

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FROM ONS AND THE CHIEF EDITOR

The choice of the word "Imagine" as the theme of ONS 2024 was not accidental. From one perspective the choice reflects the need for new thinking beyond the conventional wisdom to find answers to the unresolved challenges the world faces – climate change, conflicts, and continuing energy poverty. From another perspective the word reflects the absence of certainty and the inability to predict what will happen next. We can only imagine.

Progress is not linear. Of the themes identified in the ONS Energy Agenda two years ago the only example of prediction becoming reality has been the steady growth of China as a power in the world energy market. The world as a whole is not an easier or more settled place than it was in 2022. We survived Covid, but at a cost which continues to affect the global economy. The war in Ukraine continues, as does the latest conflict in Palestine. There is no obvious easy solution to either. Meanwhile greenhouse gas emissions continue to rise. The word "optimism" is now at best qualified by the word "cautious". Resilience is prized above risk. We do not know what will happen next.

The articles in this second edition of the ONS Energy Agenda demonstrate the breadth of possibilities in front of us. On balance optimism is the predominant message of this year's essays, but several of the pieces warn that the face of change in the energy sector has not been rapid enough and that the support of public opinion, which is essential given the upfront costs of the energy sector, is weakening.

The energy industry is as ever inherently forward looking and positive. The companies and individuals involved see their role as part of society being to find answers to needs and challenges as they emerge. The main source for those answers according to most of the authors of this volume is likely to be science and technology – through breakthroughs and through the more gradual process of finding ways to reduce costs. But science and technology depend in turn on individuals and groups of people to make those advances. As one very personal contribution to this set of essays makes clear, individuals do make a difference and there is a huge value in encouraging and making use of the widest possible diversity of views and experience.

All the essays look forward and seek to offer view of what the energy world might look like in 15 or 25 years time. No one pretends to have an easy answer but equally there is no sense of despair – there is a world to win, and to save, and the solutions are more likely to come from within the energy industry than from anywhere else. The future is not preordained, and it is up to all of us to imagine and then to shape what comes next.

We would like to thank all those who have contributed to this publication – as authors, designers, editors and as staff of ONS. Without them there would be no ONS Energy Agenda. This is the 50th anniversary of the creation of ONS. We can and should celebrate the history and achievements of the organisation over five decades, but that is not our priority. As all these essays show there is much to do and the spirit of ONS 2024 is that life begins at 50. Imagine that!


Leif Johan Sevland, President & CEO, ONS Foundation
Nick Butler, Chief Editor and visiting professor, King's College London


ERP

Beyond complacency

IMAGINE THE POSSIBILITIES

The theme of ONS 2024 is "imagine" – an invitation to think about the possibilities which lie ahead – positive and negative. How will our successors in 2040 judge what we did, or did not, when we had the opportunity, asks Nick Butler, Chief Editor of the ONS Energy Agenda and visiting professor at King's College.

By Nick Butler, Chief Editor of the ONS Energy Agenda and visiting professor at King's College.

The essays which make up this Agenda cover a wide range of topics – the structure of the industry, the technology we use to produce and consume energy in all its forms and the political climate in which we operate.

In different ways they all offer ideas about what could be – what the energy market could look like in 2030 or 2040 and what it will take to get to the positive outcomes and avoid the all too obvious risks. Taken together they provoke the question of how our successors in 2040 will judge what we did, or did not, when we had the opportunity.

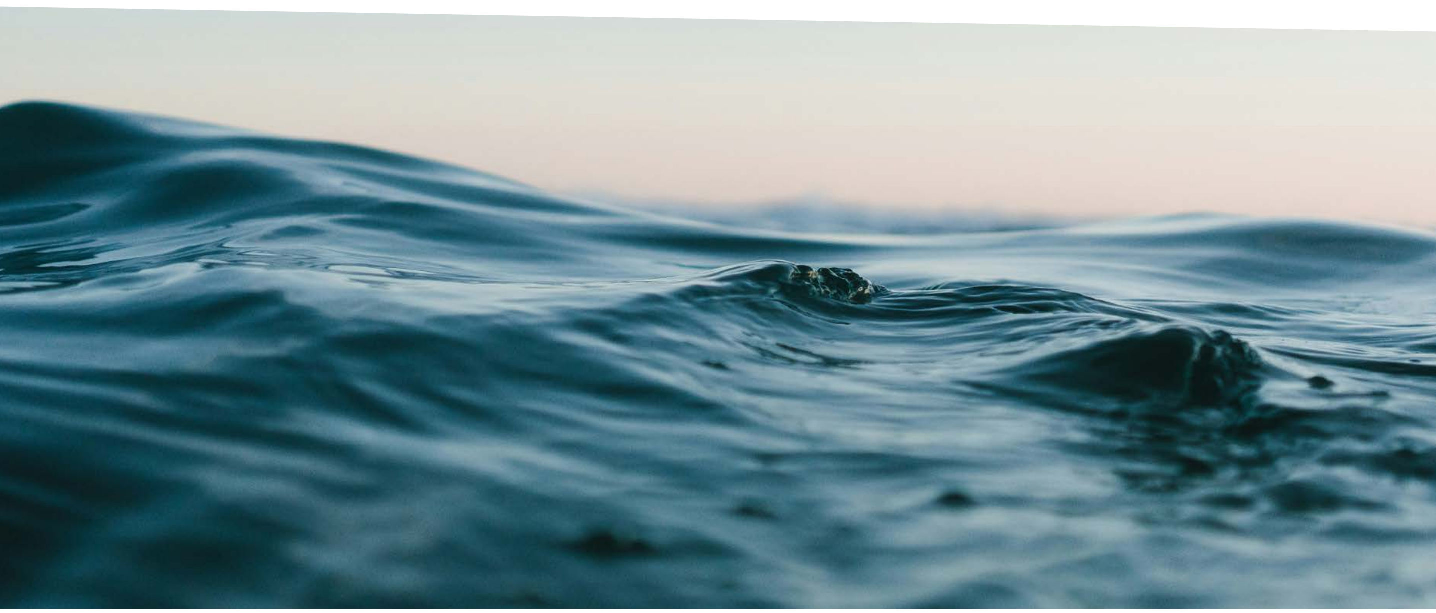
To begin we should take a hard look at where we start. What is the shape of the energy market today? What progress have we made in averting the risks of climate change? What has happened since ONS was held in Stavanger in the summer of 2022? What should surprise, encourage or disappoint us?

Let's start with a set of facts:

- The world's population has risen to some 8.1 billion – an increase of well over 200 million each year. Over the last half century, the world's population has doubled, and on current projections the total number of global citizens will rise to nine billion before 2040 and to 10 billion by 2050.

- Despite the set-back of Covid an increasing proportion of the eight billion can now afford commercial energy supplies. There are an estimated 250 to 300 million new consumers for energy every year, but still anything up to 1.5 billion people whose energy use is minimal and who need to be given the opportunity to enjoy full access to the heat, light and mobility which we take for granted.

- The gradual, if incomplete, spread of higher standards of living combined with population growth is the fundamental driver of energy demand. Energy



consumption rose by an estimated 1.3% in 2023 with another 1.8% growth forecast for 2024. Global energy demand is 240% greater today than when the first ONS meeting was held in 1974.

- Current demand growth comes predominantly from the emerging economies of Asia. China now accounts for over a quarter of daily global energy consumption. Chinese oil demand is now running at around 16 million barrels per day making the country the world's largest single oil importer. India, the world's most populous country, is also seeing a dramatic increase in energy use – up by more than 15% the last two years and now 40% higher than a decade ago with much more to come given that energy use per capita in India is still only one fifth of that in the European Union.

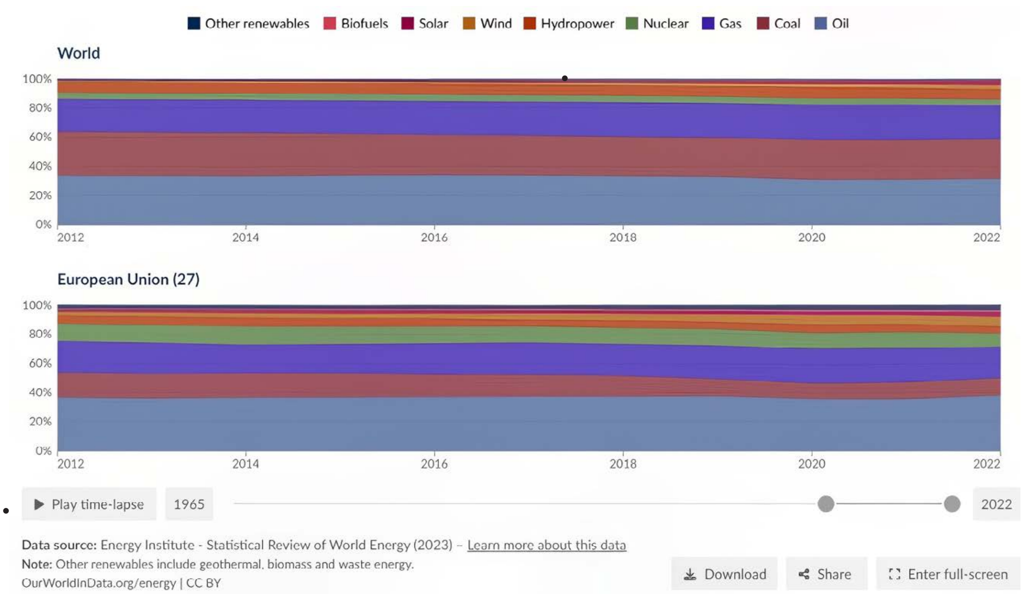
- By contrast European demand continues to fall, as it has done since 2021, as a result of improvements in the efficiency of energy use and slow economic growth.

- Most of the world's energy demand is still met by hydrocarbons. Oil, natural gas and coal account for over 80% of the total - a figure which has remained almost constant for the last 25 years (figure 1).

- Coal is still the predominant source of power in Asia where most of growth in demand is occurring. Oil remains the major source of fuel for transportation in all forms from private passenger cars to aircraft. Natural gas is a major source of electricity but also of power for industry and home heating.

- Despite spikes after the Russian invasion of Ukraine, energy prices, though never completely stable, have ended up lower than many observers expected. Russian oil continues to flow around the world regardless of sanctions. Gas prices have fallen because of Europe's ability to find alternatives – mainly in the form of Liquified Natural Gas (LNG) – after the loss of a large proportion of Russian supplies. The war in Gaza continues but has had no material impact on energy supplies or

FIGURE 1: World's energy demand



prices. The oil price remains dependent on the decisions of OPEC and its Russian allies. Gas supplies, particularly from US shale production have, for the moment at least, kept prices below the levels prevailing before the invasion of Ukraine.

- Renewable power supplies – from wind and solar - provide a growing proportion of the world's electricity needs and the largest source for newly built power plants. Fully 86% (a remarkable 473 GW) of power capacity additions in 2023 were from renewables. That growth has continued over the last two years, but because electricity from all sources accounts for no more than a fifth of total consumption, the contribution of wind and solar power amounts to only 6 to 7% of the world's daily energy needs.

- Hydro and nuclear also provide power, but nuclear's share of total supply remains constrained by the retirement of ageing stations built in 1970s and 80s and by costs of new build. The long decline of German nuclear came to its conclusion with the closure of the last three plants in April 2023. One of the sharpest examples of the move way from nuclear came in the UK where nuclear's share of electricity supply has fallen from over 25% at the turn of the century to less than 15% today - a decline likely to continue for the rest of this decade as the closure of older plants comes ahead of any new build.

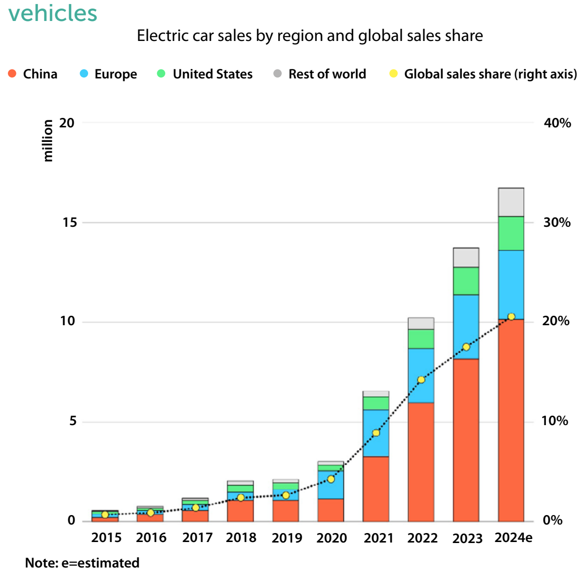
- Nuclear power is expanding in scale in China but elsewhere high upfront capital costs and the poor track record of failing to deliver nuclear projects on time and on budget are discouraging private investment. Nuclear projects are dauntingly expensive for Governments to fund either through general taxation or through enforced increases in consumer bills.

- The growth in the number of electric vehicles (EVs) on the world's roads continues with 14 million sold worldwide in 2023 according to the latest research from the International Energy Agency (figure 2). That figure is expected to rise by another 17 million this year. But the growth of EVs should be seen in context. There are some 1.4 billion internal combustion engine cars on the roads and sales of SUVs still outstripped the sales of EVs in 2023 by a factor of 3. Most electric vehicles are made and used in China with many running on batteries powered by electricity generated through the burning of coal.

Crisis versus climate

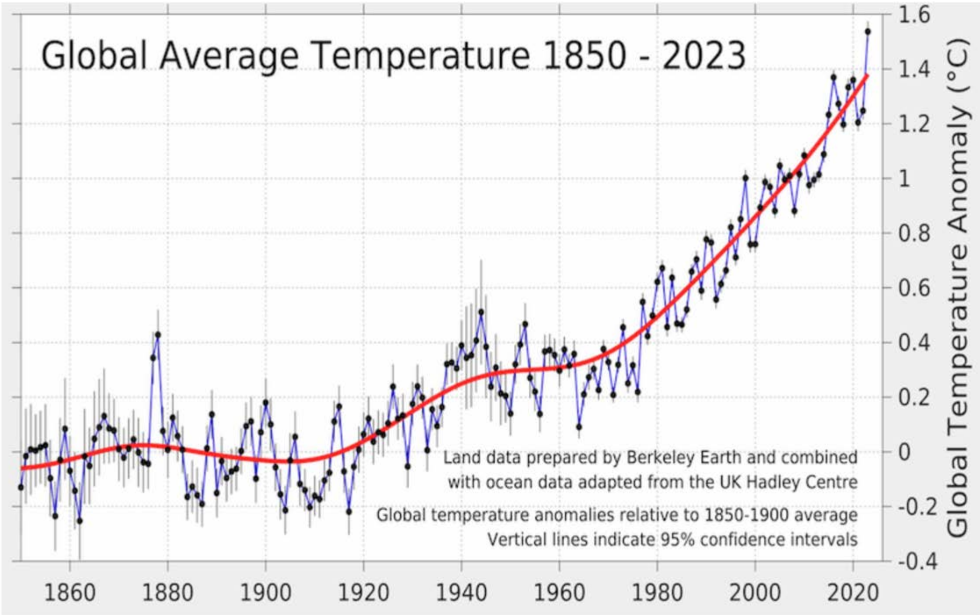
Overall the pattern of energy production and consumption is changing, but the main change has been in the geography of demand rather than its make up.

FIGURE 2: The growth in the number of electric vehicles



Source: IEA

FIGURE 3:

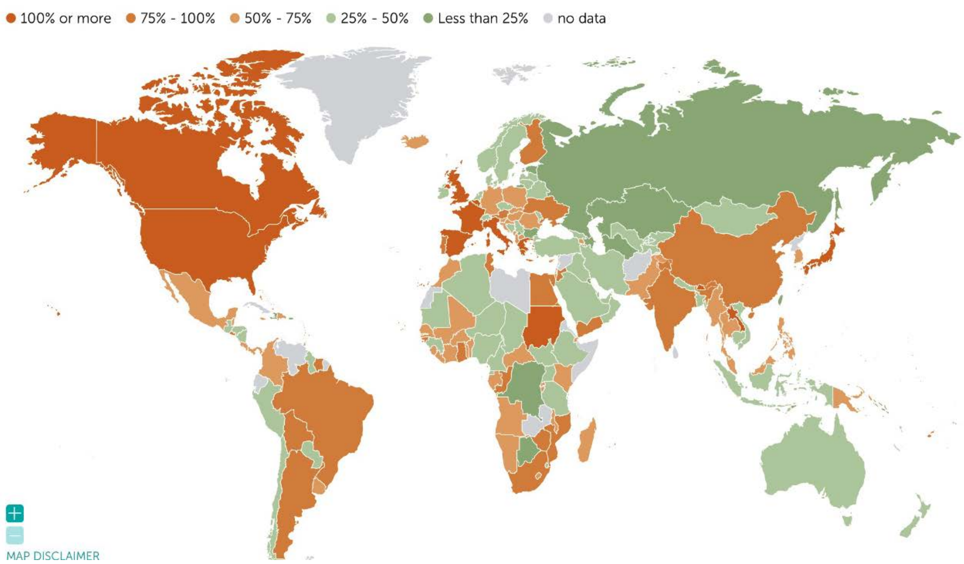


Regardless of the declarations of successive climate conferences, the global energy mix has barely altered. Fossil fuels continue to dominate the picture with the unsurprising result that emissions continue to rise (figure 3).

Perhaps the sharpest and most vivid graph of the last two years is the record of temperature increases produced by the Berkeley Earth research centre which shows the extent and pace of the change which is already taking place.

Despite the increasingly obvious reality of climate change – not just as measured by the changing temperature but also by the incidence of extreme and volatile weather - the eyes of policy makers have moved elsewhere. After a period of intensive

FIGURE 4: Gross public debt as a proportion of GDP



Source: World Bank

focus on climate issues their attention has shifted to more immediate challenges – to the two unresolved conflicts in Ukraine and Gaza, to the renewed challenge of inflation and to the overstretched state of the public finances in both developed and emerging economies (figure 4).

The cost of the transition

Energy and climate change has slipped off the front pages and down the agenda of public policy. Because of public concerns about the cost of living much of the public commentary on climate policy now focuses on the costs of the transition.

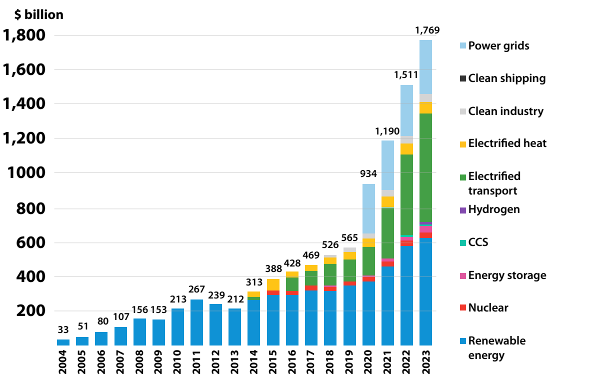
One of consequences of this combination of circumstances is that too little attention is being paid to the limited amount of investment in future energy supplies by both the public and the private sectors. Investment in both oil and gas and low carbon sources of supply begins to look inadequate to meet the inexorable growth in demand.

Investment in all the main elements of the energy transition is growing but not by enough (figure 5).

The pattern of existing investment reflects the attractiveness of wind and solar after the steep falls in costs over the last decade. The growth in investment, however, remains below the levels necessary to reduce emissions and to ensure that the atmospheric concentration of carbon stays below the levels at which fundamental changes in the climate are likely to occur (figure 6). Current spending is also, as the graph shows, heavily concentrated in China. Europe and the US have also seen increases in investment but across most of the rest of the world and in particular in emerging markets where continued growth in emissions is strongest, investment levels are low.

FIGURE 5:

Global investment in energy transition, by sector



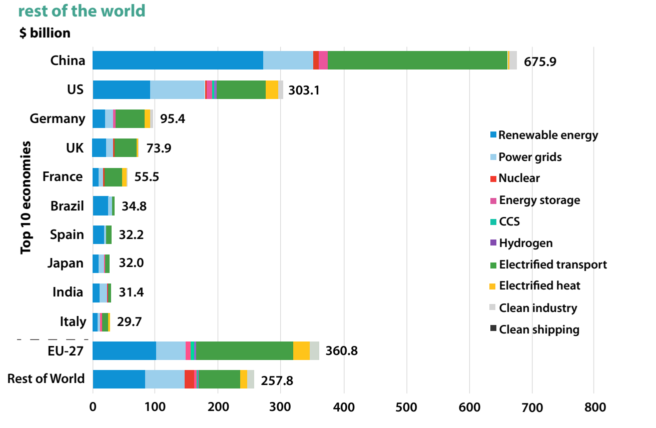
Source: BloombergNEF. Note: Start years differ by sector but all sectors are present from 2020 onwards; see Methodology for more detail. Most notably, nuclear figures start in 2015 and power grids in 2020. CCS referes to carbon capture and storage.

China invests in low carbon – emissions rise

The growth in low carbon investment in China signifies the recognition in Beijing there is an opportunity for the country to become the industrial leader in the delivery of the energy transition. China is already the dominant supplier of wind turbines, solar panels and the rare earth minerals essential for production and use of equipment essential for the

FIGURE 6:

Top 10 economics for 2023 energy transition investment, plus the EU-27 and rest of the world



Source: BloombergNEF. Note: EU-27 bar also includes the EU member states shown. Rest of World is global investment excluding the EU and individual economies in the chart. CCS refers to carbon capture and storage.

energy transition - from batteries and electric vehicles to wind turbines and electrolysers. The country provides 80% of the global production of lithium-ion batteries and produces more than half of the world's electric vehicles. In addition, China is building a leading position in long distance grid technology and in the nuclear sector both for domestic use and for export. 55 nuclear plants are operating in China producing 57 GW of power and 26 more are under construction. Chinese nuclear companies have a stated goal of winning a 20 to 30 % market share in 40 countries which are part of the Belt and Road initiative.

The investment in low carbon technology is beginning to make a material contribution to China's own energy needs but has not yet displaced coal – still the provider of 60% of total energy supplies – with consumption still increasing as new coal powered plants are commissioned. As a consequence, China's emissions continue to rise.

The result is that for the moment reductions in emissions are coming mainly from Europe and the US but in aggregate are outweighed by the continued growth in fossil fuel use elsewhere.

It is hard to avoid the conclusion that barring dramatic success in the application of carbon capture technology emissions will remain at or close to current levels for the next decade, with each year adding to an accumulating concentration of carbon in the atmosphere.

The investment gap is wide and extends to every part of the energy supply chain – from production to processing to distribution – for instance in grids – to the demand side and the need to replace or transform the capital stock through which energy is consumed- from vehicles and factories to transport systems and home heating. The amount of investment required for a full transformation over the next two or three decades is estimated by different commentators at between USD 3.5 and five trillion a year.

Immature technologies

These facts demonstrate that despite much effort and millions of words, the move to a materially lower carbon economy has barely begun. The COP28 meeting in Dubai in November 2023 concluded with a statement committing the signatories to the phasing out of hydrocarbons, but there is no plan in place to achieve that ambitious goal.

A recent paper from McKinsey sets out the challenge (figure 7).

"Collectively 12 categories of climate technologies could potentially reduce as much as 90% of total man-made greenhouse gas emissions if deployed at scale...The maturity levels of the 12 are uneven: only 10% are commercially competitive, while a further 45% are commercially available but will require further cost reductions through innovation and scale-up to become competitive. The remainder hold great promise but are in earlier stages."

The conclusion is that while the proportion of the energy mix provided by wind and solar still represent only 12% by 2040. With hydro and nuclear providing another 9%, unabated fossil fuels will still retain a share of around 70% in 15 years' time.

The estimates produced by IEA based on current stated policies show demand for both oil and gas in fifteen years' time will be much the same as it is today. At best, even with some additional policy steps put in place, that would result in demand for oil plateauing at around 90 to 100 million barrels per day. Gas demand could increase before plateauing reflecting a move away from coal as a source of power generation in some countries, the requirement for back up supplies to cover for the intermittency of wind and solar, and the attractiveness of gas as a source of industrial power and heating.

Demand for coal will decline if US and European policy continues to reduce coal use through ever tighter regulation, and would decline more quickly if China were to enforce a move away from coal.

The continued need for oil and gas poses the second challenge of underinvestment.

Over time decarbonisation will eat into the markets for oil and gas, but the time scale of that shift is much more gradual than many hoped, not least because the policies necessary to deliver net zero are simply not in place. In the absence of rapid short-term decarbonisation, investment in continuing supplies of

FIGURE 7: High-potential climate technologies

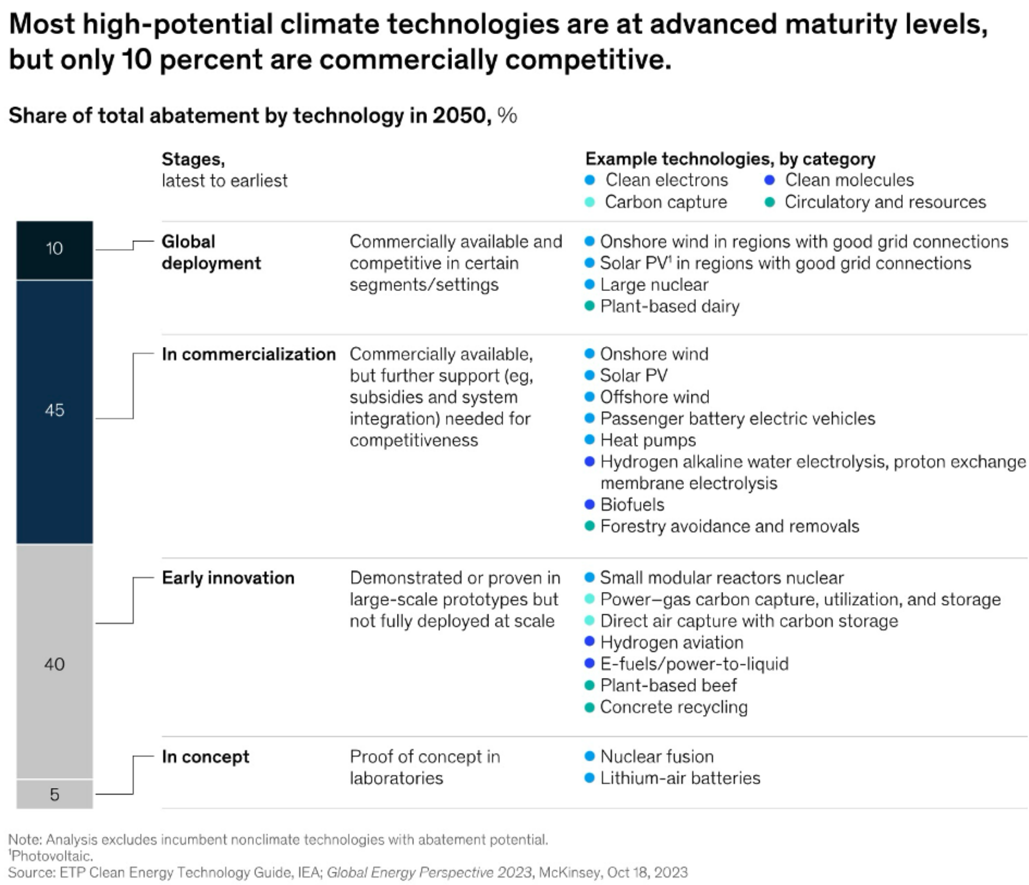
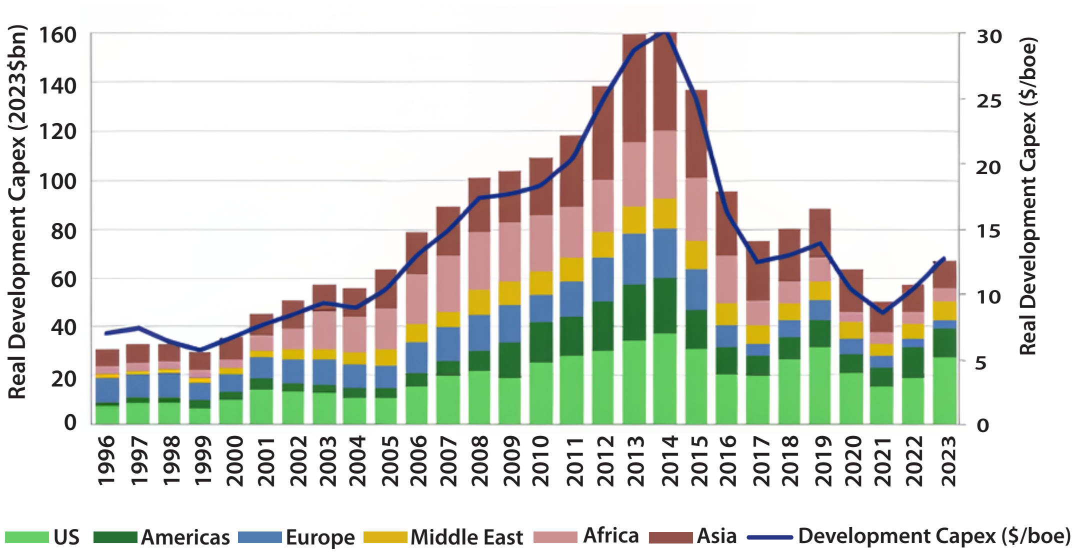


FIGURE 8: Real development capex



Development Capex is still 20 per cent below the level reached in 2016-19 and 60 per cent below the 2013-14 peak

oil and gas is essential and needs to be spread across diverse sources in order to maintain energy security and to avoid undue levels of dependence.

The decline of oil and gas investment (figure 8 and 9) is evident in the track record of the majors (Exxon Mobil, Chevron, BP, Shell and Total) as set out in a recent paper from Thunder Said Energy:

The clear conclusion is that the majors will be unable to sustain their current level of production which amounts to around 10% of global oil supply and 12% of global gas.

Shortfall in investments

The private sector faces a number of pressures which are working to reduce investment – demand from shareholders for returns in cash or share buybacks, increased taxation to relieve public finances, increased costs resulting from stretched supply chains and the limited access available to the resources required to replace existing production capacity. Some areas which could offer access additional supplies could be partially or totally closed because of the view that we already have sufficient identified volumes of fossil fuels to meet the net zero carbon budget to 2050 and should not be looking for more.

The only large-scale exception to this trend of underinvestment by the private sector companies is the United States where shale developments of both oil and gas continue. Those developments will sustain US self-sufficiency and provide some limited export volumes, but that alone will not be sufficient to meet growing global needs.

For different reasons there is also a constraint on investment by the state-controlled enterprises.

Although there are some signs of a new focus on investment in some of the Gulf States the shortfall is also evident in many of the state-owned companies who control the majority of remaining reserves. In many cases activity is constrained for political reasons including the application of international sanctions which limit involvement by international companies.

Russia, Iran, Libya and Venezuela hold between them some 35% of remaining oil reserves and 45% of global gas reserves. All four have the potential to be major sources of supply – in contrast to a number of the existing producing states whose reserves are running down. All four, however, have for obvious reasons, cut back on the development of the new fields in recent years.

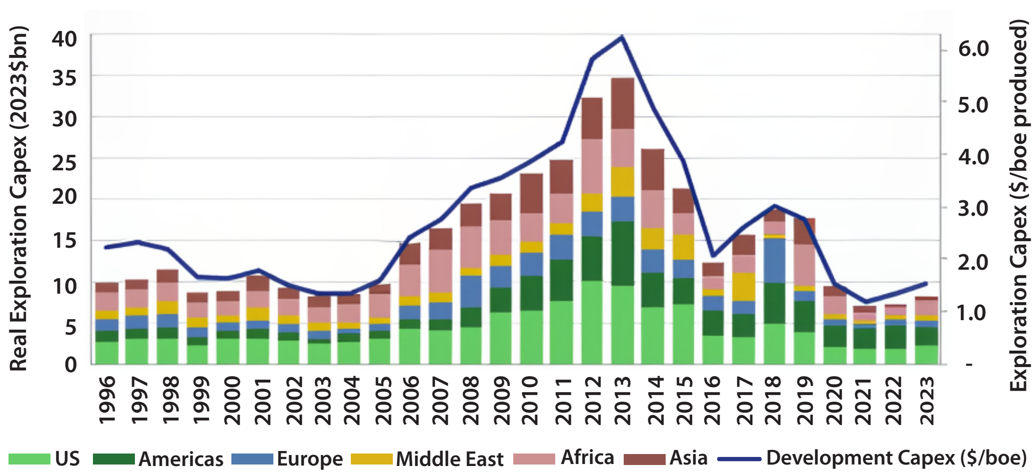
Given the timescales involved in developing new projects, the loss of skills in each country and the inexorable decline of existing production as output plateaus and then declines there is a serious risk that a gap between demand and available supplies will emerge. That is liable to push up prices and to increase the world's dependence on a small number of oil exporting countries.

Wasting our chance to change?

Because of underinvestment there is a serious risk of energy shortages within the next decade, and simultaneously a continuing increase in the reality of climate change as the world moves past 1.5-degree level of increases in temperatures towards 2 degrees and even more. The current sense that supplies are plentiful and resilient to the impact of events in Ukraine and the Middle East could soon turn out to be a temporary mirage.

The danger, all too imaginable, is that seen from the vantage point of 2040 the current period will be seen as wasted years in which the focus was on the easy work

FIGURE 9: Real exploration capex



Exploration Capex rose in 2023 to $ 8bn but remains 75 per cent below its 2013 peak.

of setting ambitious targets for the future rather than the harder work of delivering changes today. Some campaigners will say another spike in energy prices will trigger a dramatic period of rapid decarbonisation. That might be partly true but change in a world where energy consumption is largely dictated by the availability of infrastructure substitution cannot be instant. In those circumstances the risk is that for many consumers, especially the poorest, the only available short-term substitute will be low-cost coal.

From the vantage point of 2040 the current period could be seen as one of complacency. A time when we knew what could and should be done but failed to act. Those who did too little could be seen as modern equivalents of the lotus eaters - the subject of a story in Homer's Odyssey - a group of sailors seduced by the short-term pleasures of eating the fruit of lotus plant into losing all sense of urgency and forgetting the real challenges of the time.

The unanswered question is whether it will take a dramatic shock – a sudden rise in sea levels as the Arctic melts or a deep shortage of the sense of urgency which is so badly needed.

How much can change?

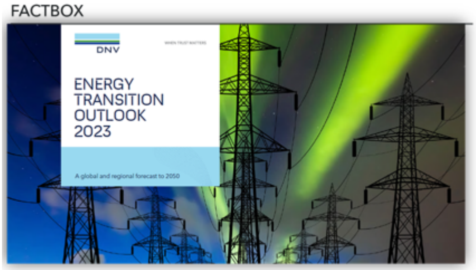
THE SHAPE OF THE ENERGY INDUSTRY IN 2040

How much can the world energy system change in 16 years? If we go back 16 years to 2008, we have events like the birth of the iPhone, the financial crisis, and Barack Obama elected as US president. All events, which, while not quite feeling like 'yesterday', still seem recent enough. How much can change in a decade-and-a-half? 2040 is just 16 years away, and from an energy perspective, we will see fundamental change, states Remi Eriksen, Group President and CEO at DNV.

By Remi Eriksen, Group President and CEO, DNV

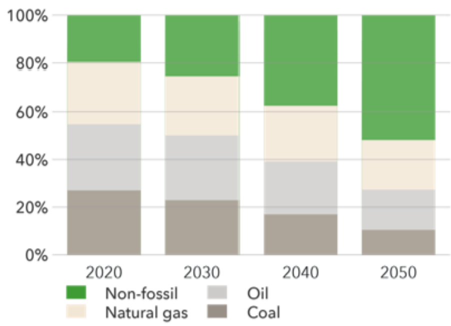
That is a bold assertion, given that transition so far in 2024, appears to be partly in stall mode. Record emissions from fossil energy last year are on track to move even higher this year. High oil and gas prices are fuelling an exploration surge, while many renewable projects are experiencing an increase in cost due to inflationary and supply-chain pressures. Geopolitical developments over the past two years have brought energy security into sharp focus with the disruption of energy supplies and price shocks for energy importers. Local sourcing of both energy and energy infrastructure is emerging as a prominent national objective.

FACTBOX



Fossil vs. non-fossil in primary energy supply

Units: **Percentages**



The analysis in this chapter is based on DNV's Energy Transition Outlook - a regional and global forecast to 2050. The figure illustrates that 2040 marks a pivotal year in the energy transition, signaling an accelerated transition to non-fossil energy sources. By 2050, these sources are expected to comprise slightly more than half of the global energy mix.

©DNV 2024 Historical data source: IEA WEB (2023)

However, amidst these short-term perturbations, the long lines of development are clear: the energy landscape will look very different by 2040. There are three major themes to keep an eye on: solar PV; electrification; and fossil fuels. These are themes executives and boards should address now in order to position and diversify their operations to thrive in the energy transition. Should countries and regions choose to reinforce their energy and climate policies beyond our anticipated measures, the associated trends and consequences would intensify at an accelerated pace.

A world becoming more efficient - delivering more useful energy with less waste!

According to our latest Energy Transition Outlook (2023), electricity demand is set to grow by 60% between now and 2040. The shift to the use of electricity as an energy carrier, brings enormous system efficiencies that will fundamentally alter how humanity uses energy. As the world's population increases and the global economy expands, it's clear that humanity will need more energy services (heating, cooling, transport etc.). Yet, energy demand will grow at a rate much slower than economic growth and even level off in the 2040s. The key to understanding this paradox lies in distinguishing between 'useful energy' and 'final energy.'

Useful energy is the energy output that serves a specific purpose, such as heating a stove, propelling a vehicle, lighting a room, or running a machine. In our forecast, useful energy grows by 50% between now and 2040. What will not be growing nearly so fast is so-called final energy – i.e. the total amount of energy required to meet various needs, which, crucially, includes both useful as well as wasted energy. Final energy demand refers to the energy delivered to end-use sectors (e.g. transportation, buildings, or manufacturing) and includes losses, mostly in the form of heat. In our forecast, global final energy demand grows by just 10% before flattening after 2040 (figure 1).

The difference between useful energy and final energy demand is clearly illustrated in the case of an internal combustion engine vehicle (ICEV), which is typically only 25% to 35% efficient – meaning that much of the chemical energy in the form of diesel or gasoline (the final energy demand) is wasted as heat, incomplete combustion, and friction before it provides the useful work of propelling the vehicle (useful energy). As ICEVs are replaced by electric vehicles (EVs) that have much higher efficiencies (>90%), enormous energy losses will be eliminated. As a consequence, as energy end use becomes increasingly electrified, there will be a lot less demand for oil.

Solar PV

2023 saw an almost 50% increase in the amount of new renewable projects coming online. Global annual renewable capacity additions amounted to 510 gigawatts (GW) in 2023, with solar PV alone accounting for three-quarters of the total additions. This is the fastest rate of growth of renewable capacity additions in the past two decades, and the growth will continue. A few regions stand out, like Europe, the United States and Brazil which hit all-time highs, whereas China's acceleration was extraordinary - which we have detailed in a recent report, DNV Energy Transition Outlook China 2050 (released April 2024).

By 2040, we expect solar PV to have an installed capacity of 9.7 TW and produce almost 14 TWh which is 30% of all electricity generation. Solar PV will be the cheapest new electricity source globally, with exceptions only in areas with less conducive irradiation conditions like the higher northern latitudes. By 2040 the reduction in cost per kWh will be another

FIGURE 1: The diminishing share of losses in the global energy system

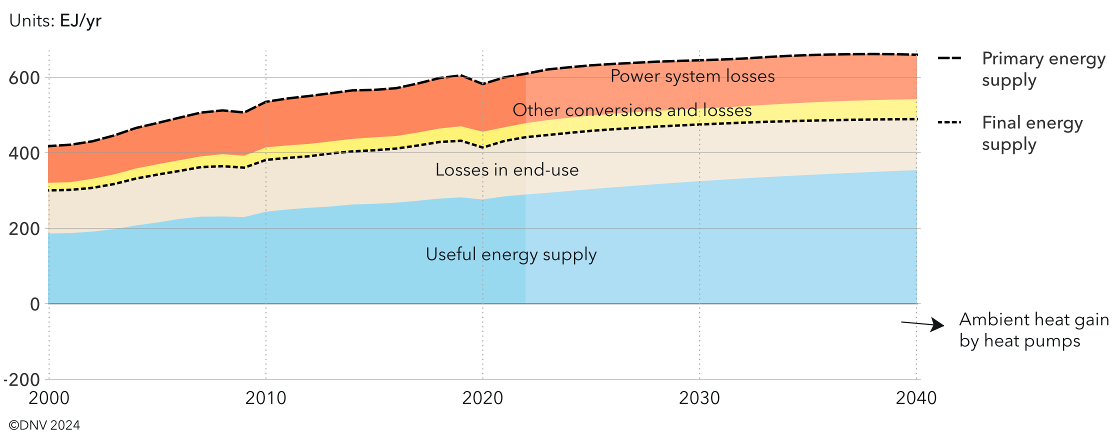
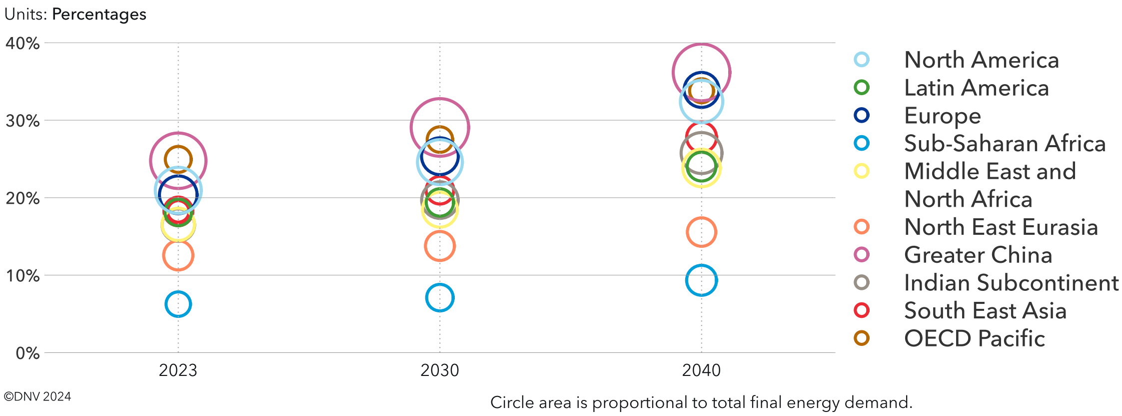


FIGURE 2: Share of electricity in final energy demand



40% compared with today. Speed of deployment at utility scale as well as ample industrial capacity for producing panels paves the way for solar PV dominance as the major source of electricity generation.

With variable renewable energy, there will be a need for flexibility and storage in a growing electricity grid. This is where Li-ion batteries play the primary role. These batteries will either be integrated with renewables or operate as standalone systems. The ability to store excess energy during peak sunlight hours and then sell it when after-dark prices rise, gives solar + storage an edge over standalone solar PV and provides a solution to the variability problem. This means that existing thermal power plants will increasingly operate with (rather than instead of) renewables, with the viability of those thermal sources increasingly tied to their flexibility to follow demand. We expect 6.2 terawatt-hours (TWh) of lithium-ion battery storage by 2040, with a substantial part integrated with renewable energy sources and a matching amount of storage available from EVs enabled to dispatch stored electricity to the grid.

Electrification

Technology, cost, and policy factors are all driving increased electricity use, which naturally holds efficiency advantages over other energy carriers. From a decarbonization perspective, everything that can be electrified should be electrified. Because electricity is fairly easy to decarbonize compared with other energy carriers, ever-more ambitious decarbonization policies will inevitably favour electricity. Additionally, the costs of solar and wind power are expected to continue decreasing (global average by 45% mid-century), making electricity increasingly more cost-effective compared with other fuels, especially hydrocarbons which will increasingly be subject to carbon tax in most jurisdictions.

The delivered cost of electricity is of course highly dependent on market designs and on the manner in which grid buildout is supported and funded. New applications requiring modern energy are also emerging — for example, AI, communication appliances, and air conditioning — for which there are few or no alternatives to electricity.

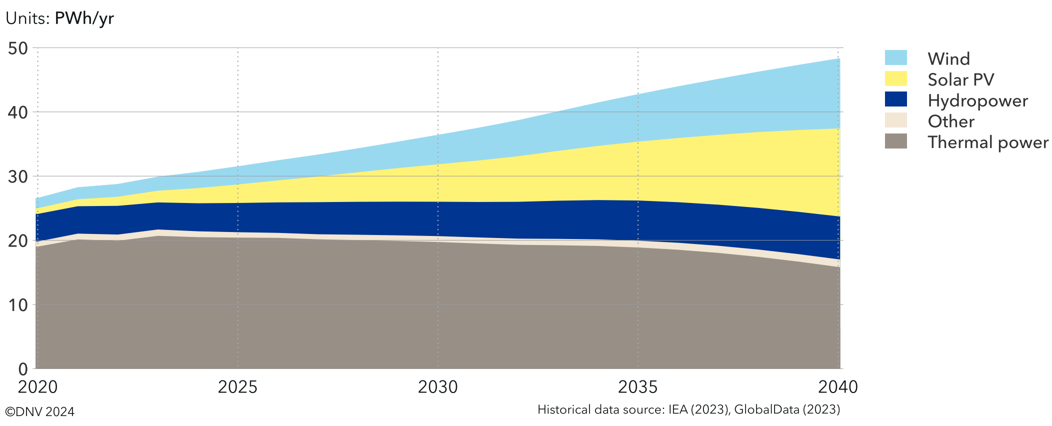
Electricity stands centrally in the ongoing global energy transition, shaping innovation and strategies in both supply and demand sectors, with China leading the way owing to its focus on achieving energy independence (figure 2). By 2040, electricity will account for 28.4% of the world's total energy demand, a significant increase from 20% in 2023, but more importantly a guidance for how the future beyond 2040 will unfold. Renewable electricity generation will power much of this growth, increasing from 9.2 petawatt-hours per year in 2023 to 32.5 petawatt-hours by 2040. This increase means that the share of renewables in electricity generation will rise from 31% 2023 to 67% by 2040 (figure 3).

The emergence of so-called 'new' power systems (i.e. those characterised by a high penetration of renewable sources) is a reality that deserves a great deal more attention than it is currently given. Nations stand to benefit greatly in competitiveness and security of their national energy systems if issues such as adequacy, flexibility, grid capacity, and power market design are tackled early. See, for example, DNV's report on New Power Systems (May 2024).

At present, there is a shortage of grid capacity to accommodate the coming expansion of both generation and load (i.e. demand). While enhanced transmission planning and build-out is the long-term solution to addressing a capacity-constrained electric grid, there are near-term tools at our disposal to ensure we are getting the most out of the grid we have. Their deployment does not require new gridlines and are becoming increasingly standardized and adopted in regulatory frameworks. These 'non-wire' grid enhancing technologies offer a promising pathway to rapid and cost-effectively increase grid capacity and efficiency, facilitating the integration of renewable energy and enhancing grid reliability over a bridging period to the 2030s.

From a financial perspective, an implementation of this grid enhancement approach not only reduces the capital expenditure associated but also lowers operational costs by enabling an earlier penetration of renewable energy sources, which are typically cheaper to operate than fossil-fuel-based sources.

FIGURE 3: World grid-connected electricity geneation by power station type



Oil and gas

Historically, oil demand has increased roughly 1% annually due to population and economic growth, maintaining a significant presence in the transportation sector where it has comprised about 70% of the energy use since 2017. However, this trend is set to shift significantly as EV adoption reaches double digit percentages of new vehicles sales in several major markets.

Our forecasts show that by the late 2020s, EVs will make up 50% of new passenger vehicle sales in Greater China and Europe. This shift will extend to the OECD Pacific and North America by the early 2030s, and it is expected to reach a market share of 50% by 2031 globally, which means that by 2040 almost 40% of the passenger vehicle fleet will be electric.

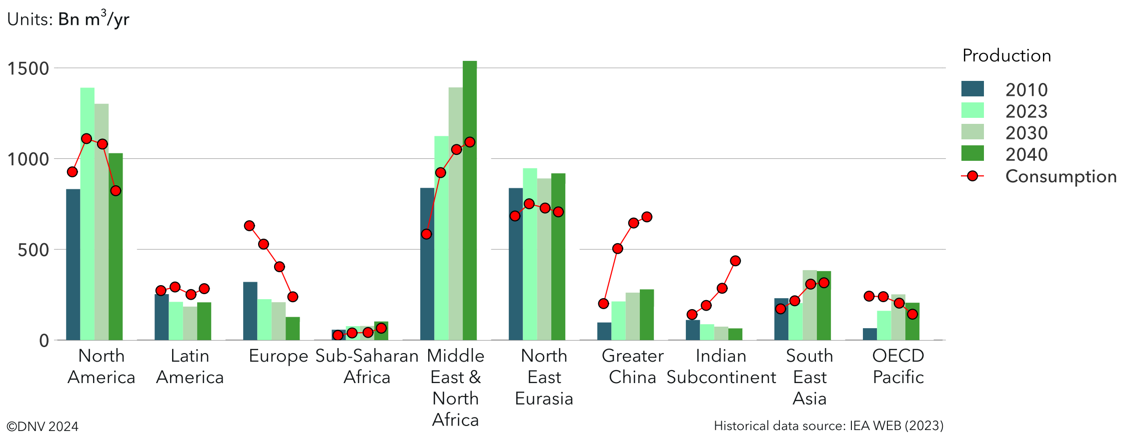
The impact of EVs is particularly pronounced in China, the world's largest passenger vehicle market. In 2023, EVs made up about 20% of new passenger vehicle sales, rising to about 25% in recent months of 2024. Mid-2023, the Chinese oil giant Sinopec unexpectedly announced that it expects gasoline demand in China to peak in 2023, two years earlier than was set out in previous forecasts. Globally, we expect oil demand to peak before the end of this decade, with its subsequent decline primarily driven by rapid EV uptake, steepening in the 2030s as other key transport sectors like shipping and aviation start their decarbonization journeys deploying alternative fuels such as ammonia, methanol and other synthetic fuels.

> By 2040 the global demand for oil will have dropped 22% from today's levels and will be in perpetual decline.

Looking ahead, we forecast that by 2040, oil demand in China's road sector will decrease by 75%, which will have major repercussions for both domestic oil production and the global oil market. By 2040 the global demand for oil will have dropped 22% from today's levels and will be in perpetual decline.

Natural gas demand will vary by region, typically growing in low- and medium-income regions and declining in OECD regions (figure 4). Furthermore, there will be demand for natural gas in new sectors, particularly with increasing use in maritime transport, and as a feedstock for making blue hydrogen and ammonia. Over the past 10 years, power generation

FIGURE 4: Natural gas production and consumptions by region



accounted for 35% of gas use. This share will rise to 37% in 2026 before receding to 30% by 2040, a shift driven by the expansion of renewable energy sources. However, global demand for natural gas increases to 5,035 billion m^3 around 2027 and plateaus for about a decade before gradually declining to 4,800 billion m^3 in 2040.

Gas consumption in Europe and the OECD Pacific is projected to decrease to approximately 55% and 40% of 2023 levels by 2040, respectively. This significant reduction is largely due to the natural gas supply constraints following Russia's invasion of Ukraine. In Greater China, gas demand is expected to increase by 28% by 2030, but it will level off as it approaches 2040. Both Greater China and the Indian Subcontinent are characterized by high demand and limited domestic natural gas resources and will import larger amounts via LNG. In contrast, gas production in North America and Europe is projected to decrease by half, which corresponds to a 10% reduction in their market shares.

The Middle East and North Africa, along with Russia, have long been net exporters of gas and are anticipated to continue in this role. Notably, export volumes from the Middle East and North Africa are expected to double by 2040, with its market share also rising from todays 10% to reach 35% in 2040.

Conclusion

According to our Energy Transition Outlook, by 2040, the world's energy system will be distinctly more non-fossil – roughly a 40/60 non-fossil/fossil ratio compared with today's 20/80 ratio. Solar PV will have led the charge for renewables penetration, followed by wind. By then, there will also be a large share of dedicated renewables (almost 7 PWh) for green hydrogen. Fossil sources will still be dominant in the energy mix, with gas exhibiting staying power due to its dispatchability and relatively low emissions, but starting to diminish; oil, one the other hand, will be in sharp decline.

This sets up two very important considerations:

1. Start planning for less oil. The world has never seen a permanent reduction in oil demand; shrinking demand is likely to gravitate production to lowest cost sources, and a reduction in prices.

> **The potential application of AI is so deep and wide that the world has yet to place any precision on the dimension of its impact.**

2. Start planning for New Power Systems. This requires action on grids – in the short-term exploring non-wire transmission enhancement, with longer-term plans for massive grid expansion, and for the introduction of new power market designs to optimize conditions for a high penetration of renewables in the power mix.

The dark horse underlying all of this is AI. It is already clear that AI is playing and can play an increasing role in each step of the energy value chain – including optimized design of renewable component; better renewables siting; enhanced operation of renewable generation; transmission decongestion (for example through dynamic line ratings); demand response; and, not least, end-use efficiency. The potential application of AI is so deep and wide that the world has yet to place any precision on the dimension of its impact. Nevertheless, it will be considerable, if the numbers starting to emerge about the isolated impact of AI on GDP are any indication. Intriguingly, the economic uplift promised by AI is likely to be delivered with low carbon intensity, adding momentum to an energy transition already characterised by improving carbon intensity numbers everywhere.

Ultimately however, it is policy which will have the main impact of decarbonization. One thing we can predict with confidence is that by 2040, the urgency to respond to global warming will have moved far beyond partisan debate. The DNV energy forecast to 2050, that I have used as reference throughout this article, is a 'most likely' forecast of our energy future. It is very far from a 'net zero' future, and hence leads to a global warming of 2.2°C by the end of this century. Limiting global warming below 1.5°C requires a much faster transition. That is still, barely, within the grasp of policymakers worldwide. Should they choose to do so, the trends I have outlined in this brief overview of the energy landscape in 2040 will accelerate greatly. The precautionary principle alone dictates that all stakeholders should start planning for a faster transition.

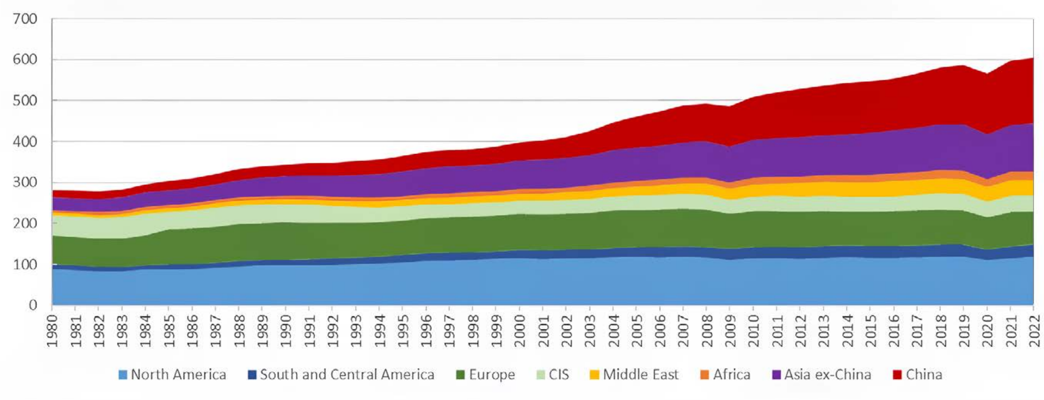
Leader, laggard, champion and challenger

CHINA AND THE GLOBAL ENERGY SYSTEM

China's position in and contribution to the global energy system is complex and often contradictory. Understanding and navigating these contradictions is essential for companies and governments looking to both engage with and de-risk from China, writes Michal Meiden, Head of China Energy Research at Oxford Institute for Energy Studies.

By Michal Meidan, Head of China Research, Oxford Institute of Energy Research

FIGURE 1: World primary energy demand, exajoules



Source: Statistical Review of Energy, 2023

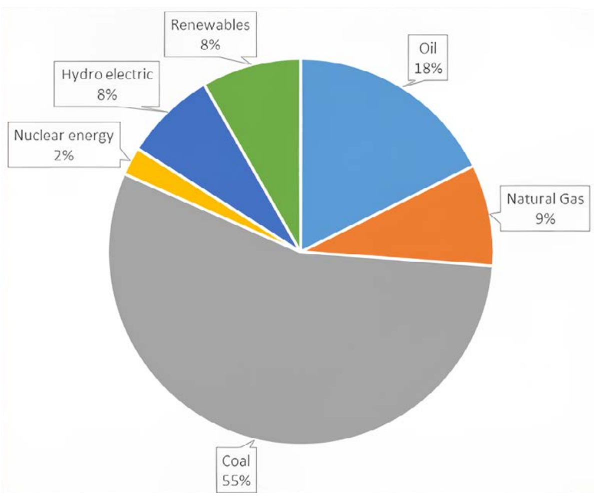
China is the world's largest consumer and importer of fossil fuels, and therefore the largest CO2 emitter today. But it also leads in the manufacturing and deployment of clean technologies. It punches below its weight in a number of global international energy fora, in part by history and in part by choice. In global climate negotiations, China looks to lead the developing world and challenge the unjust leadership of the US-led system, while also benefitting from the provision of global goods by others.

China is a key player in the global energy system: Over the course of the past two decades, since the country's entry into the World Trade Organisation, its energy demand has skyrocketed (figure 1).

Today, it is the largest energy consumer globally, accounting for over half of the world's coal use and 20% of coal trade. It is the world's largest oil importer and second-largest oil consumer, with a refining capacity that is set to eclipse that of the US. China is also now the largest LNG importer, having surpassed Japan in 2023. The country's dependence on fossil fuels (figure 2) and more significantly, the sharp increase in their use, has meant that since 2007, China is also the world's largest CO2 emitter.

In 2023, China's CO2 emissions reached an estimated 12.6 Gt[1], accounting for roughly one-third of the world total. When considering cumulative emissions (i.e. emissions since the beginning of the Industrial Revolution, between 1751 and 2020), China's share in 2021 stood at 14% compared to 25% from the United States and roughly 22% from the EU[2].

FIGURE 2: China's primary energy mix, 2022



Source: Statistical Review of Energy, 2023

At the same time, China also leads global renewable development and deployment. In 2022, China alone commissioned as much solar PV as the entire world, while its wind additions also grew by 66% year-on-year. The IEA estimates that the world is currently not on track to tripling renewable capacity by 2030, but China is expected to reach its target of 1200 GW of installed wind and solar capacity already in 2024 (figure 3), six years ahead of schedule, despite the phasing out of national subsidies. As such, the IEA estimates that China will install more than half of the new capacity required globally by 2030.

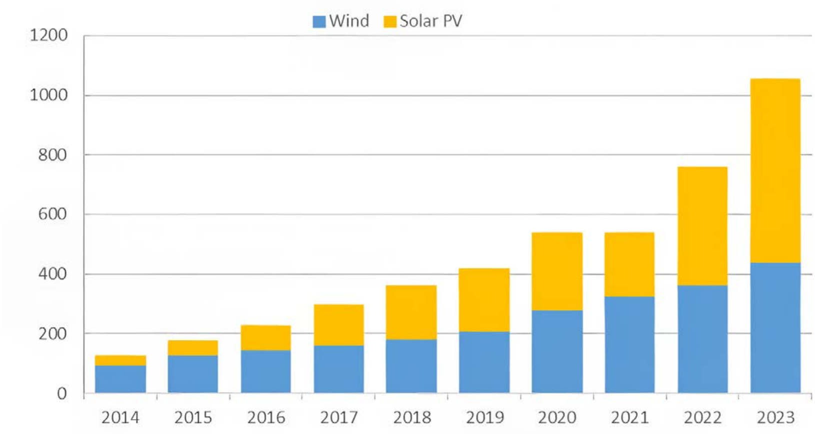
China is not only rapidly deploying renewable energy, it also a key producer of batteries, electric vehicles, wind turbines and solar panels. In 2023, Chinese carmakers produced more than half of all electric vehicles (EVs) sold worldwide. China's battery manufacturing capacity in 2023 was sufficient to meet global demand[3]. And planned capacity additions also suggest China will continue to dominance manufacturing, well exceeding projected global demand.

The buildout of solar photovoltaic cells tells a similar story: Wood Mackenize estimates that China will hold more than 80% of the world's polysilicon, wafer, cell, and module manufacturing capacity from 2023 to 2026, with Chinese capacity alone enough to meet global demand through 2032[4]. Finally, in wind turbines, China in 2023 accounted for 60% of the world's 163 gigawatts (GW) turbine capacity, and the IEA estimates that through 2025, China will remain the largest manufacturing hub for all main wind energy components. Critically, even though wind equipment production is more diversified globally than solar PV, 90% of the rare earth magnets that are used in wind turbines are produced in China (see figure 4).

A challenge to western industry

Yet, despite the fact that China has the manufacturing capacity to supply key elements for the energy transition both at home and abroad, their low cost presents significant challenges to Western industries. Western governments are introducing protectionist policies aimed at shoring up domestic manufacturing and hoping to enhance their own industrial

FIGURE 3: China's wind and solar PV installed

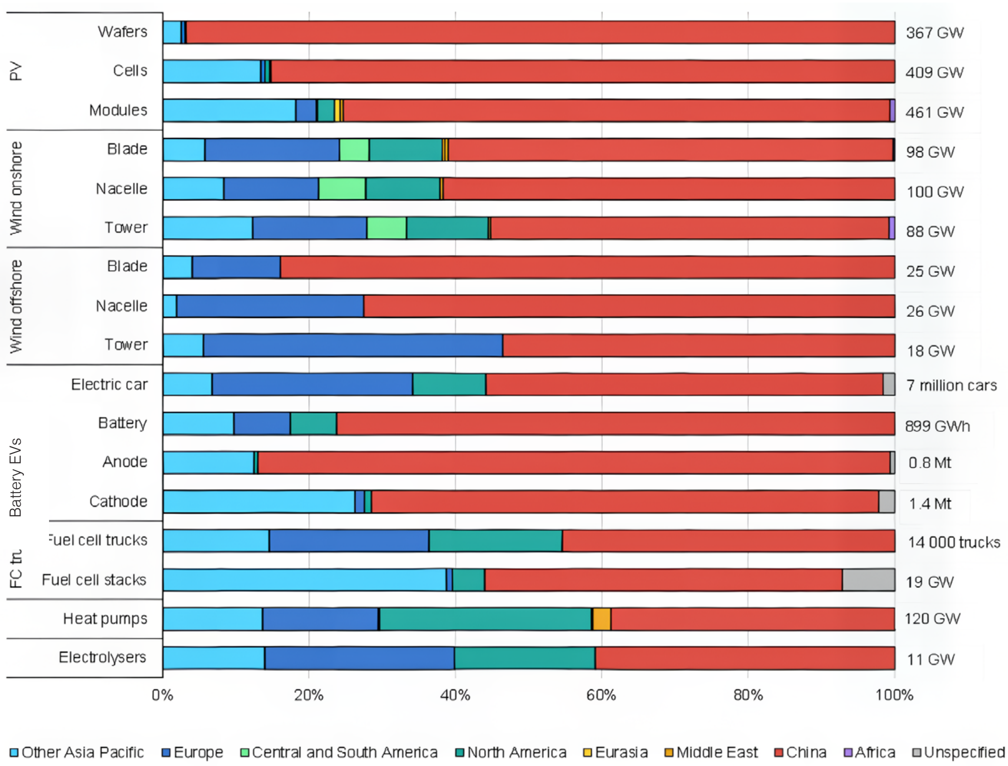


Source: China National Energy Administration competitiveness. Some policy makers also fret that China will use its dominance in new energy supply chains for political ends, much like Russia has used energy as tool of economic and political coercion[5].

A strong central government does not always mean perfect policy design and implementation. China has been making increasing use of import and export licensing restrictions, but concerns around Beijing's use of new energy supplies as a tool of economic coercion underestimate the challenges associated with enforcing controls or bans. It also overestimates coordination and regulatory capacity in China.

To be sure, the state has long played a central role in China's energy sector. State-owned enterprises dominate production of coal, oil and gas, as well as power production and the electric grid. Government agencies set prices and issue administrative quotas for fuel exports and power plant operating hours. The state's omnipresence facilitates long-term planning and can ensure resource allocation in support of these plans. This, combined with the close links between the leadership and state-owned enterprises means that corporate executives are incentivised to follow government mandates.

FIGURE 4: Regional shares of manufacturing capacity for selected clean-energy technologies and components, 2021capacity (GW)



Notes: FC = fuel cell. Heat pumps capacity refers to thermal output.
Sources: IEA analysis based on InfoLink (2022); BNEF (2022); BNEF (2021b); Benchmark Mineral Intelligence (2022); GRV (2022); UN (2022a); Wood Mackenzie (2022).

A fragmented system

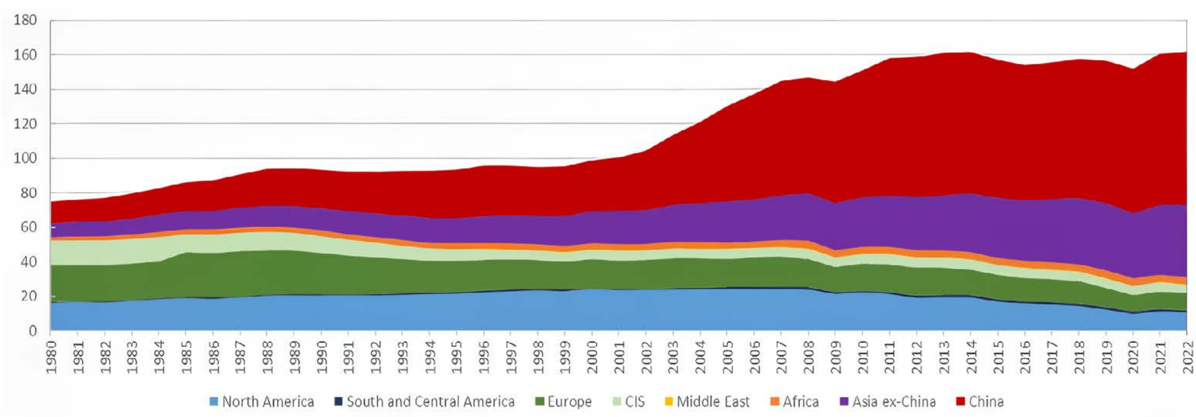
At the same time, China's fragmented governance system gives provincial and local authorities as well as corporate executives considerable implementation power. When policies are ambiguous, which they often are because they are made through consensus, local officials and energy companies can circumvent or slow-walk central policies and objectives. Moreover, limited central government capacity means that corporate actors and industry associations provide administrative support for the policy making process and provide technical inputs[6], thus shaping the policy process and often favouring incumbents. This situation has on one hand resulted in rapid build-out of new companies in sectors targeted for development, but it has also created duplication and economic inefficiencies, including over-investment in coal, steel, chemicals and renewable energy production.

Finally, poor policy coordination and clashes between market forces and administrative measures have caused energy outages in China. In late 2021, for instance, as China's economy was recovering from its first COVID-19 lockdowns, a central government mandate to cut coal production and reduce energy use led provincial government to curb power supplies. In some provinces the power outages were caused by the mismatch between state-set power prices and rising coal prices. The losses incurred by the pricing system led many coal-fired power generators to enter maintenance to avoid these losses[7].

Climate leader and laggard

Different interests and policy imperatives are also leading to ambiguity on the role of coal in China's energy system. Even though Chinese policy makers announced plans to "strictly control" coal use during the 14th Five-Year Plan period (2021–2025) and start phasing down coal use during the 15th Five-Year Plan period (2026–2030), new coal mines and coal-fired power plants continue to be built in China on a significant scale.

Figure 5: Coal consumption, select countries, exajoules



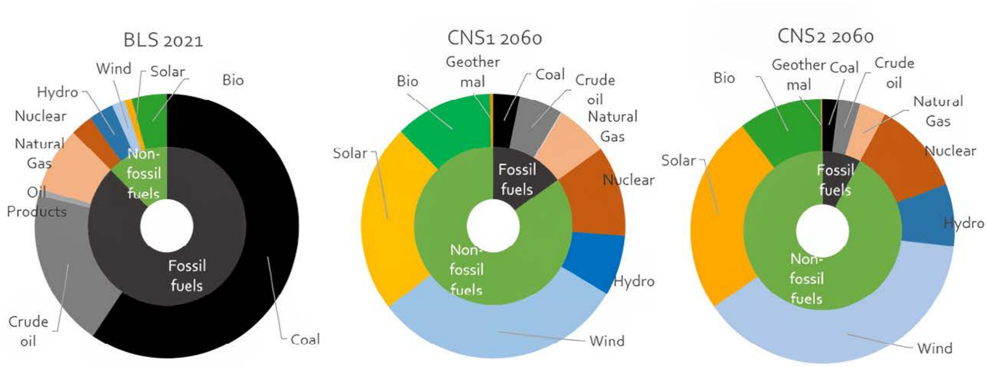
Source: Statistical Review of Energy, 2023

This is due to concerns about energy security and power sector reliability, as well local officials' desire to secure baseload power supplies because inter provincial trading systems are imperfect or non-existent. Since the beginning of 2022, authorities have permitted 152 GW of coal power and started construction on 92 GW. China's State Council has also repeatedly indicated that coal would continue to be encouraged in 2024. Major coal players and provinces have rushed to take advantage, expanding coal power before China begins to wind down new coal projects after 2025. In some cases, coal plant approvals have been justified by local officials as an economic stimulus measure.

Beijing's long term goal remains to transition coal plants from producing steady, baseload power to providing backup and peaking capacity, and then gradually phasing out coal. But capacity payments to support this transition and approvals for new plants — that should theoretically only be used as backup— raise the risk that the coal boom could continue for longer, ultimately deepening China's overcapacity and leading to higher emissions that will need to be reduced before 2060.

While this complicates China's energy transition, it has not derailed it, especially given the rapid pace of renewable additions discussed above. Moreover, China's climate pledges — to peak emissions before 2030 and to aim for carbon neutrality by 2060 — are rather nebulous. The 2030 peaking target is likely to be met since there is no firm date before 2030 or level at which emissions should peak. More fundamentally, however, several policy goals which are important to the Chinese government align closely with its climate change goals. These include efforts to improve urban air quality; a desire to dominate the industries of the future; enhancing energy security through electrification and reduced imports of oil and gas, as well as a desire to demonstrate commitment to multilateralism. This gives the climate change goals greater strength and durability[8], but like in other parts of the world, long term goals can be reframed to meet short term policy priorities.

Figure 6: China's primary energy demand structure in different scenarios (2021 vs 2060)



Source: CETO 2023

Open to the world, but cautious about its intentions

The availability of abundant coal, renewables, hydro power, large reserves of oil and gas, combined with a rapid build out of nuclear capacity means that even today, China is relatively self-sufficient for its energy supplies. To be sure , 10% of its coal comes from imports, it relies on imported oil for over 70% of total consumption and its dependence on imported gas has exceeded 40%. But the rapid electrification of its vehicle fleet suggests that its external vulnerabilities to imported oil will lessen. Natural gas currently accounts for 9% of the energy mix and will likely peak at under 15% in the 2030s. And to mitigate against its vulnerability to oil and gas import disruptions, China is building strategic stocks. Beijing's concerns around energy security are shifting from geopolitical risks around oil and gas disruptions to broader questions about system design, resilience and flexibility[9]. To be sure, oil supply shocks in the Middle East would be detrimental to the Chinese economy, mainly because of the price impact. But given that China is the largest consumer and is set to remain the largest oil importer for years to come, producers will want to prioritise supplies to their largest customer.

Nonetheless, China needs global markets to remain open for business. In addition to imported oil, gas and coal, its renewable manufacturing processes require minerals and metals such as lithium, cobalt, nickel, manganese, aluminium, and others. For many of these, Chinese companies have stakes in upstream assets overseas, but materials and ores still need to flow to China for processing. At the same time, China relies on export markets for its new energy goods and components. Joint ventures between Chinese carmakers and foreign manufacturers are also a key pillar of the Chinese auto industry. In 2022, Tesla accounted for 36.5% of all EV exports from China. In the first six months of 2023, that share went up to 39%. JVs between European and Chinese companies accounted for another 9.5%[10]. China therefore still needs these foreign partnerships. That shouldn't lead to complacency: the landscape is changing rapidly for both Chinese and Western automakers. It remains to be seen whether foreign carmakers can continue to use China as a manufacturing and export hub. Selling into China's domestic market is likely to become more challenging as local companies become more competitive, while tariffs on Chinese exports and local content requirements could change the calculus for both foreign and Chinese firms which are looking to relocate outside of China.

And even though the Chinese economy and its industry giants still need an open global system and foreign inputs, government policies are aimed at enhancing self-sufficiency and increasing other countries' dependence on China. In an article published in late 2020, President Xi argued: "We must tighten international production chains' dependence on China, forming powerful countermeasures and deterrent capabilities based on artificially cutting of supply to foreigners"[11].

The current economic downturn in China has made it more welcoming to foreign investors, but equally, Beijing is imposing greater costs on foreign companies through a variety of restrictions, and hedging against a world in which protectionism and sanctions is a more commonly used tool of economic statecraft.

A new global energy system?

Beijing's perceptions of the changing geopolitical landscape, of "changes unseen in a century" - which include the demise of the West and the related risks of protectionism and efforts to contain China - are shaping its sometimes contradictory attitudes to energy policy domestically and to global energy governance.

China has been something of a latecomer to most of the global energy institutions created in the 1970s. In the early 2000s and 2010s, recognising that it punches below its weight in many of these fora, China officially became an affiliate of the IEA in November 2015, it then became a full member of IRENA, the International Partnership for Energy Efficiency Cooperation (IPEEC), International Energy Forum (IEF) and the World Energy Council (WEG). But China's engagement with these institutions has been selective. In part, because full membership to the IEA would require deep structural reforms to its energy system and economy, as well as degrees of data transparency that currently do not exist in China. In part, because these institutions are seen as vestiges of a US-led world order. In Beijing's quest to enhance its voice and impact, it has joined these institutions while also using alternative mechanisms to promote its interests and vision.

China has increasingly been trading in its own currency and using its alternative payment mechanism to facilitate trading of sanctioned oil.

The BRICS organisation, the Shanghai Cooperation (SCO) and the Belt and Road Initiative have been ways for China to deepen trade and increase its influence[12] in its near abroad. But Beijing, despite its reliance on oil and gas from the region, has sought to keep the Middle East's geopolitical woes at arms' length. Even though it is building naval capabilities and a larger global presence, it prefers to rely on the US for the provision of freedom of navigation.

At the same time, China has sought to create pricing benchmarks that reflect its weight in global markets, but the lack of currency convertibility and data transparency in China mean that for now, the Chinese crude contract tracks other global benchmarks and fails to reflect domestic or regional market fundamentals. It will remain so as long as the currency is not fully convertible. Yet since the Russian invasion of Ukraine, with global oil markets becoming increasingly bifurcated between sanctioned and non-sanctioned oil, China (alongside India) have become key players straddling both energy trading systems. China has increasingly been trading in its own currency and using its alternative payment mechanism to facilitate trading of sanctioned oil. Not only does this allow lower cost crude to flow to China, it also supports Beijing's efforts to make its domestic economy less vulnerable to potential sanctions. But traders who can avoid the Chinese payment systems still opt for dollar-based trade. China's rhetorical stance is increasingly one that is critical of the US-led system and seeks to position itself as the leader of emerging economies. But beyond its role as critic, China has not articulated a vision for a new form of energy governance.

Rhetoric aside, China's relations with middle powers such as Brazil, Saudi Arabia or Indonesia, continue to deepen. Chinese companies are expanding their footprint in emerging markets in order to take advantage of local mineral- and ore-reserves and in order to blur their Chinese origin in the face of rising protectionism in the EU and the US. Not only is commodity trade expanding beyond oil, gas and agricultural commodities to processed nickel, as well as lithium, cobalt and other minerals, but Chinese companies are investing in processing and refining of mineral and materials. They are also investing in new energy manufacturing, financial services, e-commerce and other sectors. China offers pragmatic solutions, and is actively looking to contrast these with Western actions that it presents as warmongering and protectionism. So, in the event of deeper geopolitical tensions between China and the US or China and the EU, middle powers will struggle to choose side.

The ambiguities are also reflected in the UNFCCC framework, that China joined in the 1990s and in the COP process, where China has sought to establish itself as a champion of emerging economies.

Yet its rising emissions have been highlighted by island states as a major source of risk for them. And while presenting itself as a developing economy in terms of its responsibility for historical emissions, it is clear that strong China-US coordination on climate is capable of driving significant change.

China, the reluctant energy superpower

These contradictions are only likely to deepen before they are resolved. China's weight and importance in both fossil fuels and renewables will continue to increase. But the internal contradictions, as well as the ambiguous stances adopted by other countries toward China will not be resolved any time soon. China will be critical for achieving a low carbon transition, both in the speed in which it phases out coal and its ability to manufacture and deploy renewables. But China's "all of the above" energy policy could decimate a number of European industries. Beijing still needs an open trading system, but is equally ready to challenge it and shape it in its interests. Given the variety of those interests, this reluctant energy superpower will be more reactive than proactive, leaving a very large grey area for foreign companies and governments to navigate.

The way ahead:

THE CASE FOR OPTIMISM

History shows that progress comes in unexpected and unplanned ways, which gives us reason to be optimistic. That is the view of Lord John Browne of Madingley, Chairman of Beyond Net Zero and a former CEO of BP in his personal reflections. To deliver on that optimism we need to recognise that diversity in all its forms is a fundamental source of progress. Open and inclusive societies are good for business.

By Lord John Browne of Madingley, Chairman of Beyond Net Zero and former CEO of BP

Pessimism may be understandable, but it is neither rational nor helpful. Optimism is both essential and entirely rational given the evidence of history.

The prevailing mood of 2024 is one of pessimism. In many ways that is unsurprising given apparently unresolvable wars in Ukraine and Gaza, a retreat to nationalism and populism in the face of the impact of globalisation and new technology on once secure jobs and livelihoods and the serious challenges to public finances dating back to the spending required to deal with the Covid pandemic.

The mood of pessimism is reflected in current public attitudes:
First, is the fear that some advances in technology - and the pace at which they are happening - threaten to upend, maybe even end, life as we know it.
Second, is the argument that it is now too great a challenge to avert a climate inferno.
And third is the view that the diversity, equity and inclusion agenda has gone too far.

Pessimism may be understandable, but it is neither rational nor helpful. Optimism is both essential and entirely rational given the evidence of history.

Zoom out and think in decades

In 1948, the year in which I was born, after two world wars and the explosion of the first nuclear weapons, pessimism was certainly understandable. Despite all the circumstances my mother - from whom I take so much of my attitude to life - had lived through, her view of the world was grounded in a sense of hope. Perhaps that is what sustained her as she survived Auschwitz and found a new life as a translator for the British occupying forces - and became the wife of one of those soldiers.

To renew that sense of optimism, I think it is important in times of anxiety, to step back and to think in decades rather than years by considering how far the world has come since the end of the Second World War. When you do, you see one clear and overwhelming pattern - a pattern of extraordinary progress.

- Since I was born in 1948, almost 30 vaccines have been discovered or developed, eradicating or limiting the spread of many deadly and debilitating diseases.

- As recently as 1990, nearly one in 10 children died before the age of five. Now, it's more like one in 25—that's more than 7.5 million children saved every year.

- Average life expectancy globally has increased by around 25 years since 1950.

- Nutrition has improved because we are succeeding thanks to the green revolution to provide food supply to most of the world's population.

- And whereas more than half of people around the world lived in extreme poverty 75 years ago, less than 10% do today.

- People are healthier and wealthier. They are also better educated. Global literacy rates have climbed from just 36% to more than 86%.

- And many countries have been transformed - not least Norway which in the 1940s was one of the poorer countries in Europe and is now among the richest.

Unexpected and unplanned

The lesson of the last three quarters of a century is that progress comes in unexpected and unplanned ways – and is mostly the result of the advances in scientific knowledge translated into technology by engineers. That is true in many elements of human life – in medicine, in communications and of course in the world of energy.

> I think it is important in times of anxiety, to step back and to think in decades rather than years.

Just think of the things which in 1948 no one envisaged:

- Deep water drilling without which ONS would not exist and Norway would be much poorer.

- Drilling technology using IT which has permitted shale oil and gas development.

- The transformation of technologies capable of producing plentiful clean energy from the rotation of a wind turbine or a panel of photovoltaic cells.

- The technology of Liquified Natural Gas which has changed the whole shape of the global gas market, and which now delivers more than 50% of all traded gas worldwide.

And could we have envisaged then or even thirty years ago the social and political changes which would shape the energy market and much more?

- The emergence of China which now accounts for almost a third of daily energy use.

- The spread of a much greater understanding of impact of the forms of energy we use on the natural environment.

- The growth in population numbers – doubling in just 50 years – supported and made possible by a green revolution in the way in which food is produced. In all those areas such steps would have seemed impossible in 1948.

In all those areas such steps would have seemed impossible in 1948.

Technological advances

It would be a very depressive individual who said that progress was over. That we had reached the limit of positive change. Can we really say that in our world - the energy world - we had reached equivalent of the end of history?

It is already clear that we haven't reached any such point. Looking across the industry there are numerous examples of real progress and potential.

- Decarbonisation of oil and gas supplies through carbon capture and storage (CCS), carbon dioxide removal (CDR), and direct air capture (DAC). That starts with what has been achieved already by the oil and gas companies – some of whom are widely and very unfairly disparaged for failing to care about the environment.

- Electricity supply and distribution, intelligent control, and long-distance transmission. We no longer wholly rely on centralised systems supplying passive consumers but instead are shifting to systems in which consumers - both households and businesses - can also be suppliers sending their surplus production into the grid. As consumers we can manage our use of energy with much greater precision.

- At the same time the geography of the system has changed. Power can now be sent over long distances from areas where supply costs are significantly lower. The potential of long-distance power grids is just beginning to penetrate the market across the world.

- Battery and electrochemical storage technology not just in phones and computers, but increasingly in vehicles and many other elements of energy consumption. Grid level storage is within reach and that could transform the economics of renewables and potentially end or at least radically reduce the need for back up supplies.

- We have also begun to transform the possibilities of new sources of energy supply such as green hydrogen, ammonia, and fuels, including biologically engineered products. We are also exploring how the application of Artificial Intelligence could be used to manage the potential surge in demand.

Many of these advances are in reach today with the remaining challenge being to reduce costs to the level at which they are economically viable across the world.

Those are just the advances we can already envisage - many within touching distance - and around the world scientists and engineers are continuing to push the boundaries still further.

Grid level storage is within reach and that could transform the economics of renewables and potentially end or at least radically reduce the need for back up supplies.

Progress has not ended. Many problems remain and the successes of the last half century – with billions lifted out of poverty and therefore able for the first time to buy commercial energy supplies – have created new challenges around the fundamental question of whether eight billion, and before too long nine billion global citizens, can achieve genuine sustainability.

The evidence of the past is that we can. The identification of need leads to solutions, even if they are not the solutions we might expect. That is how we should approach the challenge of climate change.

It is now more than 25 years since climate broke through from being an academic debate to becoming a key area of public policy. I remember that period vividly - the IPCC reports, the Kyoto conference, and the recognition by the established energy industry the challenge was real. I was part of that process with the speech I made in Stanford in 1997. That speech was met by a powerful push-back from those who did not want to accept the facts, but it was important because the challenge had to be stated and accepted before change could begin.

> It is now more than 25 years since climate broke through from being an academic debate to becoming a key area of public policy.

We're on course - but lack the pace

So, a quarter of a century on, how are we doing? Well, the picture is mixed.
If you look at atmospheric concentration of carbon dioxide - the single best, real-time signal of whether the world as a whole is on track to a safe future - then it is not too rosy.

Last year, the concentration levels of CO2 in the atmosphere were 419 parts per million, a rise of some 15% on 1997 levels. Global temperatures are still rising. The ten most recent years have been the warmest on record. It is imperative for climate correction that we replace conventionally used fossil fuels with zero-carbon energies.

The good news is that surveys suggest people are most enthusiastic for innovation in green energy - above, for example, advances in artificial intelligence (AI), gene-based medicine and genetically modified foods for example.
At the same time, solar electricity costs have fallen 80% in the last 10 years. Wind power costs are down around 60%. Batteries are 85% cheaper.

We probably already have over 70% of the engineering solutions we need to eliminate greenhouse gas emissions.
Some of these, such as small-scale nuclear fission reactors and CCS, are immature and have not yet experienced the operational reality which is the source of improvement and cost reduction necessary for them to become commercially viable. Others, like fusion or absorbing carbon into the oceans, are a little bit further away but still a real possibility for the future.

So, when it comes to the direction of travel, I'd say we're on course. When it comes to the rate we're moving, the hard truth is that we're creeping along far, far too slowly.

So, what if we don't move quickly enough to prevent us reaching an irreversible tipping point?

> So, when it comes to the direction of travel, I'd say we're on course.

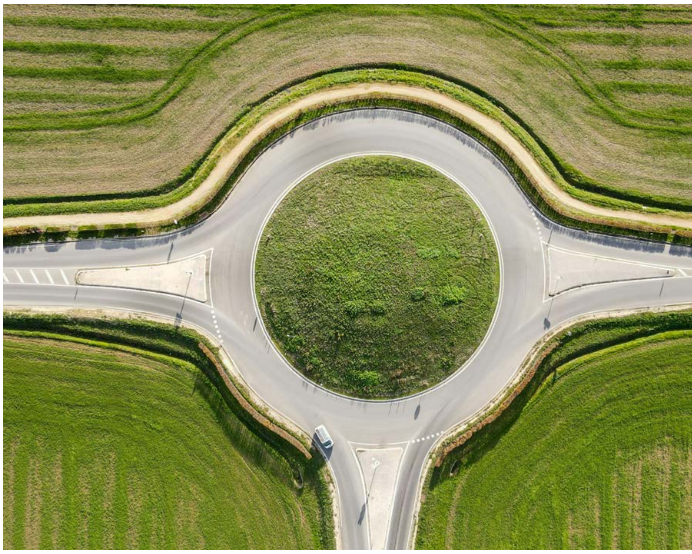
Innovative finance

The answer is that we need a radical back-up plan. That could be what is called geoengineering, for example; ways of reflecting the sun's radiation back into space using aerosols, mirrors or simply white paint. More work needs to be done to understand how to do this, and to limit the risks. Some actions may be irreversible and have dire consequences. These must be avoided. Whichever engineering solutions we pursue to correct the climate, we will need investment on an unprecedented scale.

The best estimate I've seen suggests that to limit the rise in global temperatures to two degrees, we need to invest around USD 3.5 trillion a year, every year, for the next ten years from both public and private sources. That investment must be deployed selectively, in sectors where it will have the greatest impact.
This is not just about innovative engineering but about innovative finance. An explicit or implicit global carbon price - depending on what works in national politics - would be ideal. In Europe and the United States we have seen a degree of success with such approaches. For the rest of the world, it is much more complex.

A global financing ecosystem

China and emerging economies, such as India and Brazil, are unapologetic about their desire to maintain their pace of growth and will resist anything that jeopardises this. China, for example, continues to build coal-fired power stations at an alarming rate, most probably driven by a desire for security of energy supply.



The environmental consequences will be significant, obviously. But there is an opportunity here. An essential component of climate correction - and something that is a possible development from the recent climate conference, COP28 - is to encourage emerging markets and developing economies to use clean energy to power their economic growth from the very beginning.

Many of these countries have a comparative advantage when it comes to natural capital - by which I mean carbon sinks, such as forests and mangroves. Being paid to preserve and enhance these precious natural resources can be a source of finance to transform their own energy systems.

The key is to construct a global financing ecosystem that creates these flows of investment. This is not charity. This is investment for the long term, with real returns. And it has potential to lessen the global north-south and rich-poor divides.

> If we continue the process of creating open and inclusive societies then it will be a boon to all our economies.

This is important because, in all this, we must not lose sight of fairness. Climate correction - through energy transition and the work to achieve net zero - must advance the common good and reflect the universal human values of justice and equality.

Diversity - fundamental for progress and business

So, the history of progress and the clear and obvious potential which exists to deliver more progress, are two reasons for optimism.

Then there is one further advance which has been dramatically pushed forward over the last half century which gives me cause for optimism. Again, it is a change unimaginable in 1948, and even twenty years later when I went to university; the recognition that diversity in all its forms is a fundamental source of progress.

At that time the world was largely run by and for white males. I was a beneficiary of that system. I was educated - very well educated. I enjoyed opportunities simply unavailable to most people. I was encouraged and I thrived.

Over the last three quarters of a century one of the biggest changes has been that the world has opened up and technical advances in communication have enabled more people to have a voice and to be heard.

Women, people of colour, people born outside the tracks or with different sexual orientations. There is no longer a single received accent or a single received mindset. Opening up to diversity – merit without boundaries of colour or sexual orientation.

As a gay man, I feel especially strongly about those values. But I also feel strongly about them as a businessman.

This is the third reason for my optimism. If we continue the process of creating open and inclusive societies then it will be a boon to all our economies.

No longer a secret

For years I lived in fear of rejection if people knew who I really was.

While my mother bequeathed me optimism, curiosity and courage, she also passed on two other outlooks that shaped the way in which I thought about myself. The first was her observation that when the going gets tough, the majority always hurts the minority, and so it was better to avoid being seen as an outsider. The second was that as soon as you tell someone a secret, it is no longer a secret, and it is likely to be used against you.

I lived in fear that this could become true for me - and it eventually did. After decades in the closet, I was outed in 2007 and resigned as CEO of BP as a result. Quite a large part of the world has come a long way since then.

In many countries homosexuality is now decriminalised; gays and lesbians can serve in the armed forces; men who have sex with men can give blood; and same-sex marriage is legal.

Recently, Greece became the first Christian Orthodox-majority country to legalise same-sex marriage. It's not like that everywhere, of course. In places like Uganda, Malaysia, Russia the situation is nothing short of frightening.

Even in supposedly liberal countries, we should not confuse legislative reform with broader attitudinal shifts.

DEI programmes (diversity, equity and inclusion) are in the crosshairs of critics, with Donald Trump pledging earlier this year to end all those programmes across the US federal government if he is elected.

That just doesn't make sense to me on either a human level or a business one.

Diversity is good for business

The World Bank estimates that India alone loses $32 billion a year in economic output because of LGBT discrimination. Companies with strong LGBT policies tend to innovate the most, to have loyal employees, and are positively perceived by their customers.

Long term studies show that these policies engage teams more and in turn produce higher returns.

Over a 20-year period you can assume that if you hit the high point of engagement, you should be able to make two per cent per annum higher returns on equity than those who are moderately engaged.
That's a huge amount. And you can achieve that by doing some very simple things to make people feel that they can be themselves then you're onto a winner.

There is more work to do to get there. Large institutions must increase LGBT representation at board level. If they say they are working hard to do that and to foster a more inclusive. environment, we should ask for proof.

Similarly, we need more LGBT role models. Those are critically important. When people can see how someone like themselves is successful in an organisation, it is easier to convince them that coming out is a positive career move.

There is nothing more powerful at dispelling fear.

There are many role models we could pay tribute to but there are far too few in certain sectors. I think of my own careers in oil and gas, and now in finance and private equity. There are still far too few openly LGBT people working in these sectors.

And only four Fortune 500 companies are led by openly-LGBT CEOs. By my reckoning there should be about 25 to 30. So, either people are in the closet, or they are being discriminated against, or they are opting out of the top roles.

And I want to be clear that this isn't just a "gay issue". Straight people - since they're the majority - are critical allies if we want to make it possible for people to be their authentic selves in corporate life.

Discrimination is the enemy of progress

Leaving BP was one of the lower points of my life. From there, I have lived a varied and fulfilling life and found people to be accepting of who I am. It's that kind of experience that feeds my optimism.

I remain an optimist because nothing can be achieved if we decide at the outset that we have failed. It won't always work out - but we can either do something and take our chances; or do nothing and take what's coming.

And that takes me back to where I began. My mother's unwavering faith in the human condition throughout her life - despite her experience to the contrary - can inspire us.

We need to learn again that discrimination is the enemy of progress. Whenever we open opportunity to women, Jews, Muslims, LGBT people, refugees, ethnic minorities and many others, we embrace humanity's full genius.

We need to learn again that discrimination is the enemy of progress.

And the greater the talent pool, the greater the prospect of developing the inventions and innovations necessary to take the world forward on the challenges we face. This is not about tokenism or quotas. It is about human advancement made possible by meritocracy without any boundaries.

That is what my mother hoped for. And I hope and believe it is a dream that we all can and will deliver.

Price decline for critical minerals

A DOUBLE-EDGED SWORD IN DIVERSIFYING SOURCES OF SUPPLY

Sharp declines in critical mineral prices should not mask risks of future supply strains as energy transitions advance, writes Tae-Yoon Kim, Senior Energy Analyst – Critical Minerals Lead, International Energy Agency.

By Tae-Yoon Kim, Senior Energy Analyst – Critical Minerals Lead, International Energy Agency.

Fast-growing critical minerals markets remain turbulent, with prices falling sharply in 2023 following two years of dramatic increases. Battery materials saw particularly large declines with lithium spot prices plummeting by 75% and cobalt, nickel, and graphite prices dropping by 30-45% in 2023. The IEA Energy Transition Mineral Price Index, which tracks a basket price of copper, major battery metals and rare earth elements, tripled in the two years following January 2020, but relinquished most of the increase by the end of 2023 – although copper prices remained at elevated levels.

Demand growth has remained robust. Demand for critical minerals experienced strong growth in 2023, with lithium demand rising by 30%, while demand for nickel, cobalt, graphite and rare earth elements all saw increases ranging from 8% to 15%. Clean energy applications have become the main driver of demand growth for a range of critical minerals. EVs consolidated their position as the largest-consuming segment for lithium and increased their share considerably in the demand for nickel, cobalt and graphite.

The main reason for price declines has been a strong increase in supply and ample inventories of technologies made with critical minerals. From Africa to Indonesia and China, the ramp-up of new supply outpaced demand growth over the past two years. Together with an inventory overhang in the downstream sector (e.g. battery cells, cathodes) and a correction of overly steep price rises in 2021-2022, this produced downward pressure on prices.

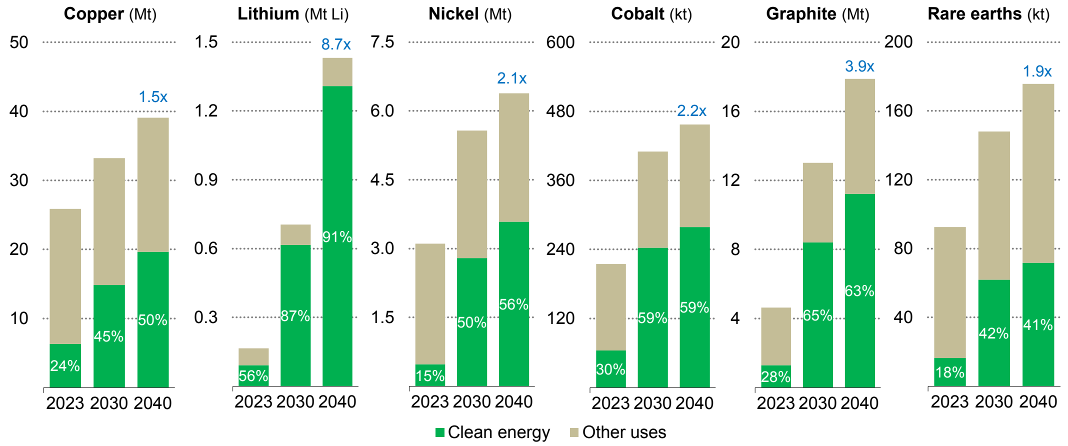
Demand more than doubles towards 2030

However, today's well-supplied market may not be a good guide for the future, as demand for critical minerals continues to rise. Following the 75% growth in deployment in 2023, solar PV and wind account for the majority of capacity additions in every region in all IEA scenarios.

This requires a substantial expansion of electricity networks, which pushes up demand for copper and aluminium. Electric car sales neared 14 million in 2023, a 35% year-on-year increase, and continued growth is projected as major markets progress and adoption increases in emerging economies. In the first quarter of 2024 the year-on-year electric car sales growth rate in China increased to 36% compared with 27% in the same period last year. Electric cars are the major source of demand for batteries, but battery storage for the power sector exhibits faster growth.

As clean energy deployment expands, so too does demand for critical minerals. Mineral demand for clean energy technologies doubles between today and 2030 in a scenario that reflects today's policy settings, the Stated Policies Scenario (STEPS). It is even higher in a scenario that meets all national energy and climate goals in full, the Announced Pledges Scenario (APS), and it almost triples by 2030 and quadruples by 2040 in a scenario that limits global warming to 1.5 °C (the Net Zero Emissions by 2050 [NZE] Scenario). Lithium sees the most rapid growth in demand, due to rising EV battery needs. In the NZE Scenario, for example, it increases by a factor of nine to

Figure 1: Global critical minerals demand in the Net Zero Emissions by 2050 (NZE) Scenario



Notes: The figures for copper are based on refined copper. Those for rare earth elements are for magnet rare earth elements only.
Source: IEA (2024), Global Critical Minerals Outlook 2024

2040. In terms of production volume, copper – which connects a more electrified energy system – has by far the largest increase. Graphite demand almost quadruples by 2040 in the NZE Scenario, while demand for nickel, cobalt and rare earth elements doubles (figure 1).

Strong growth in demand is set to produce a major uptick in the overall value of critical minerals markets. The combined market value of key energy transition minerals – copper, lithium, nickel, cobalt, graphite and rare earth elements – more than doubles to reach USD 770 billion by 2040 in the NZE Scenario. At around USD 325 billion, today's aggregate market value of key energy transition minerals aligns broadly with that of iron ore. By 2040, copper on its own attains that scale.

The multiple layers of supply-side challenges

Rapid growth in demand for critical minerals pose three layers of supply-side challenges to ensure rapid and secure energy transitions. They are i) whether future supplies can keep up with the rapid pace of demand growth in climate-driven scenarios; ii) whether those supplies can come from diversified sources; and iii) whether those volumes can be supplied from clean and responsible sources.

Expansion in expected supply volumes

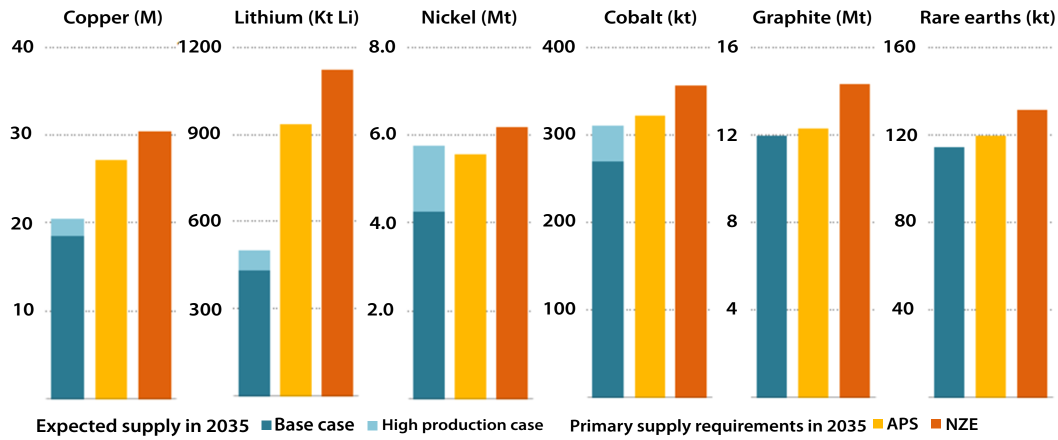
First, the recent fall in prices has affected investments in new mineral supply, but they are still growing. Increases in 2023 were smaller than those seen in 2022, but investment in critical mineral mining nonetheless grew by 10%. Investment by lithium specialists saw a sharp rise of 60%, despite weak prices. Exploration spending also rose by 15%, driven by Canada, Australia and Latin America. Venture capital spending increased by 30%, with significant growth in battery recycling offsetting reduced investment in mining and refining startups. China's spending on, and acquisition of, overseas mines has also grown significantly in the past ten years reaching record levels of USD 10 billion in the first half of 2023 with a particular focus on battery materials such as lithium, nickel and cobalt.

Substantial investments in mineral supply in recent years and an increasing number of announced projects indicate an expansion in expected supply volumes in the coming years. IEA projections show a mixed picture for future supply-demand balances. Based on a detailed review of all announced projects, in some cases such as graphite and rare earth elements, the expected supply by 2035 from both existing and announced projects aligns broadly with the projected demand in the APS. Long-term balances for nickel and cobalt look tight relative to confirmed projects, but better if prospective projects are included (in the high production case). The situation differs for copper and lithium. The expected supply from existing and announced projects falls short of the primary supply requirements in 2035, indicating a potential necessity for additional investments in new projects in geographically diverse regions, the scale-up of recycling and a range of material efficiency measures (figure 2).

Supply concentration

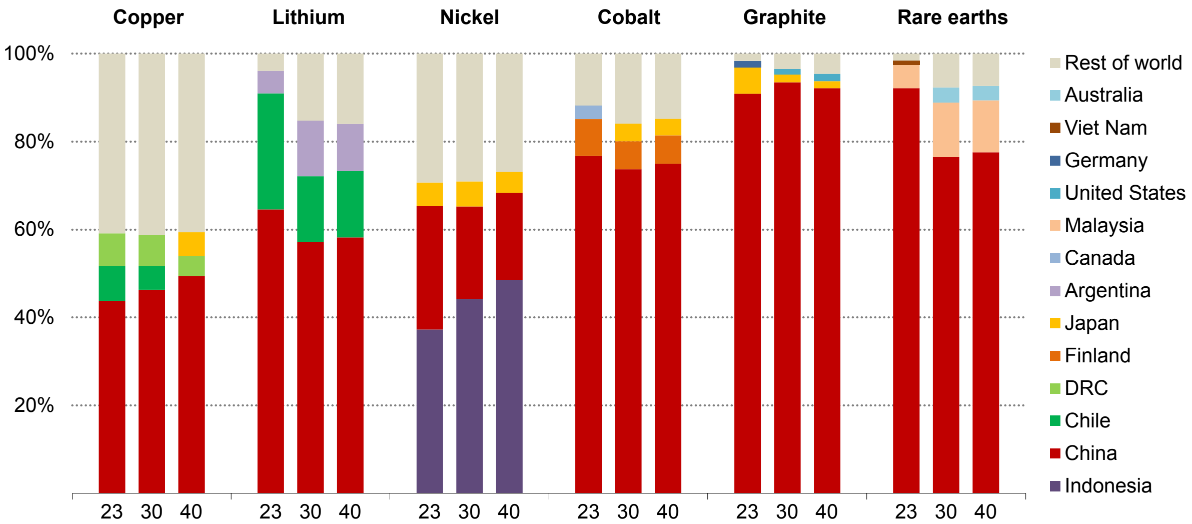
Second, analysis of announced projects shows limited progress in diversifying supply. For refined materials, the shares of the top three producing nations have all increased since 2020, with the trend most pronounced for nickel and cobalt. Between 2020 and 2023, Indonesia's share of mined nickel production increased from 34% to 52% and its share of refined nickel increased from 23% to 37%. Announced projects indicate that refined material production is set to remain highly concentrated in a few countries (figure 3). Between now and 2030, some 70-75% of projected supply

Figure 2: Expected supply from existing and announced projects and 2035 primary supply requirements for selected minerals by scenario.



Notes: Expected supply is based on mined or raw material output, except for graphite where the figure includes expected spherical graphite and synthetic graphite supplies. Primary supply requirements are calculated as "total demand net of secondary supply", also accounting for losses during refining operations. The figures for rare earth elements are for magnet rare earth elements only.

Figure 3: Geographical distribution of refined material production for key minerals



Notes: The figures for copper are based on refined copper. Those for rare earth elements are for magnet rare earth elements only. The figure depicts the value of the top three producing countries in a given year.
Source: IEA (2024), Global Critical Minerals Outlook 2024

growth for refined lithium, nickel, cobalt and rare earth elements comes from today's top three producers. For battery-grade spherical and synthetic graphite, almost 95% of growth comes from China. As a result, over 90% of battery-grade graphite and 77% of refined rare earths in 2030 originate from China.

> [...] over 90% of battery-grade graphite and 77% of refined rare earths in 2030 originate from China

The geographical concentration of mining operations is also set to rise further or remain high over the projection period in the base case. The situation improves somewhat in the high production case, indicating that many potential projects being developed in geographically diverse regions are not among the frontrunners for development. These high levels of supply concentration represent a risk for the speed of energy transitions, as it makes supply chains and routes more vulnerable to disruption, whether from extreme weather, trade disputes or geopolitics. A proliferation of trade restriction measures in 2023, including increased Chinese controls over exports of gallium, germanium, graphite and technologies for processing rare earth elements, highlights the need for strengthened actions to diversify supply chains.

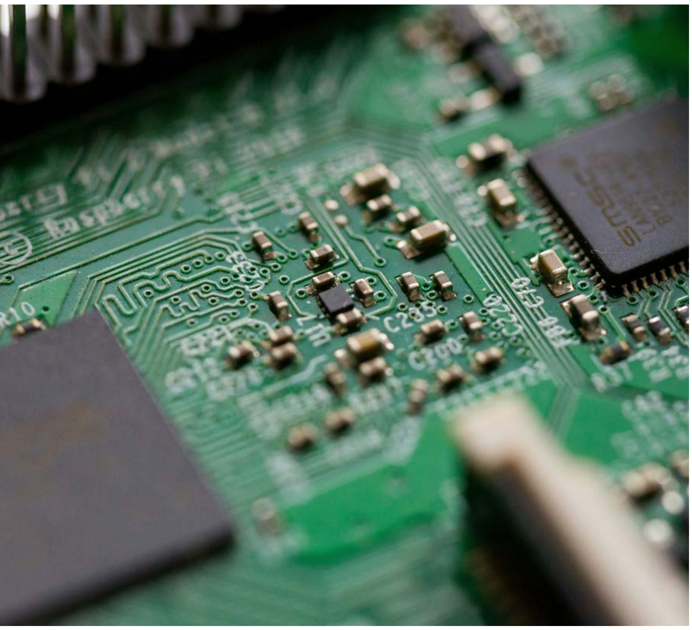
A double-edged sword

Today's price declines are a double-edged sword – a boon for clean energy deployment but a bane for critical mineral investment and diversification. Lower prices have been good news for consumers and for affordability, bringing clean technology costs back on a downward trajectory, including the 14% reduction in battery prices in 2023.

However, falling prices also make spending to ensure reliable and diversified supply less appealing to investors. This price effect has had the biggest consequences in new and emerging resource holders; in the case of nickel, three-quarters of operating or potential projects that are at risk are outside the top three producers.

> [...] new supplies must not come at the cost of local communities or the environment

Global demand and supply balances often mask significant regional disparities. From the Inflation Reduction Act (IRA) in the United States to the European Union's Critical Raw Materials Act (EU CRMA), a wave of policies is emerging aimed at diversifying sources of supply. The IRA seeks to restrict the utilisation of materials obtained from Foreign Entities of Concern, while the EU CRMA targets that no single country should supply more than 65% of Europe's annual consumption of any key materials (implying that at least 35% should come from non-dominant players). Other major consuming countries are increasingly aligned with the objective to diversify their supply sources.



However, given that the top producing nation is responsible for a large portion of global supply for most minerals, available supply outside the largest producing country may be significantly constrained to achieve these ambitions. If, for any reason, supply from the largest producing country is interrupted, then the available supply (often called "N-1" supply") of all key energy transition minerals would fall significantly below material requirements. The situation is most pronounced for graphite where the available "N-1" supply covers only 10% of the N-1 material requirements – significantly below the minimum non-single-origin threshold of 35% proposed in the EU Critical Raw Materials Act. This indicates that without urgent efforts to expedite the development of projects, achieving announced diversification goals will be highly challenging.

Sustainable and responsible supplies

Third, new supplies must not come at the cost of local communities or the environment. IEA's environmental, social and governance (ESG) performance tracking paints a mixed picture. The industry is making progress on worker safety, gender balance, community investment and renewable energy uses, but the same cannot be said for waste generation, greenhouse gas emissions and water consumption and discharge, suggesting ample scope for improvement. The benefits associated with mineral production, such as revenue and jobs, have to be felt by producer countries and communities. Voluntary sustainability standards can help actors improve ESG performance, but greater transparency, due diligence, harmonised approaches to credibility and appropriate incentives are needed to tap their full potential.

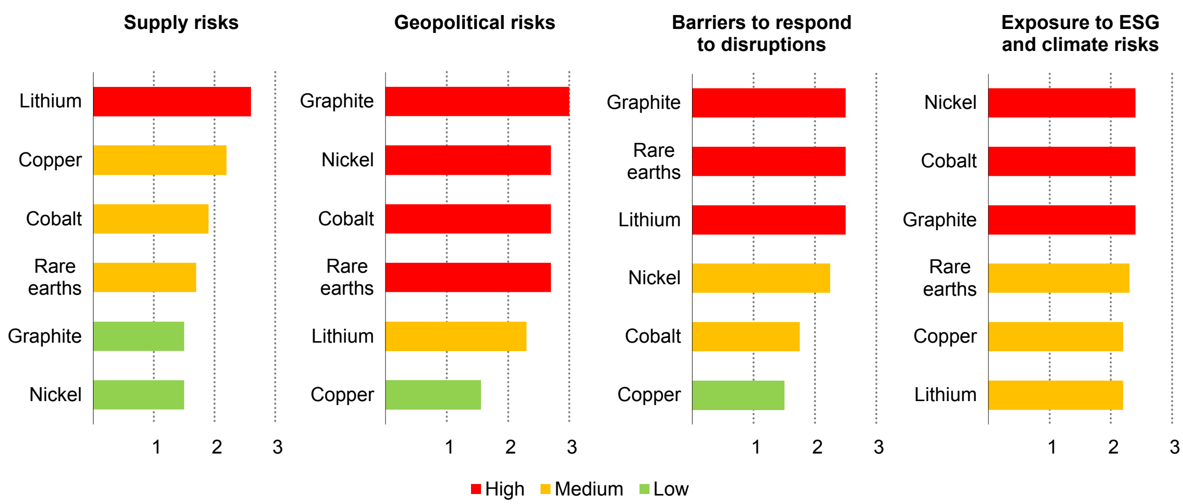
Risks to clean energy transitions

Overall, IEA's mineral-specific risk assessment reveals potential areas of weakness for each mineral in supporting energy transition goals. The framework assesses four major dimensions – supply risks, geopolitical risks, barriers to responding to supply disruptions, and exposure to ESG and climate risks – using some 20 quantitative and qualitative indicators. Overall, lithium and graphite show the highest risk scores. Lithium and copper are more exposed to supply and volume risks whereas graphite, cobalt, rare earths and nickel face more substantial geopolitical risks. Most minerals are exposed to high environmental risks (figure 4). For example, today's refining operations occur in places where grids tend to have a higher carbon intensity, relying mostly on coal-based electricity.

There are several key actions to ensure secure, sustainable and reliable supplies of critical minerals.

- **Accelerate progress towards diversified minerals supplies:** To support countries' climate and clean energy ambitions, it will be necessary to significantly increase supplies of many minerals and metals. The IEA estimates that some USD 800 billion of investment in mining is required get on track for a 1.5°C scenario. Lower, but still significant amounts of investment are also needed for new refining and smelting facilities where the

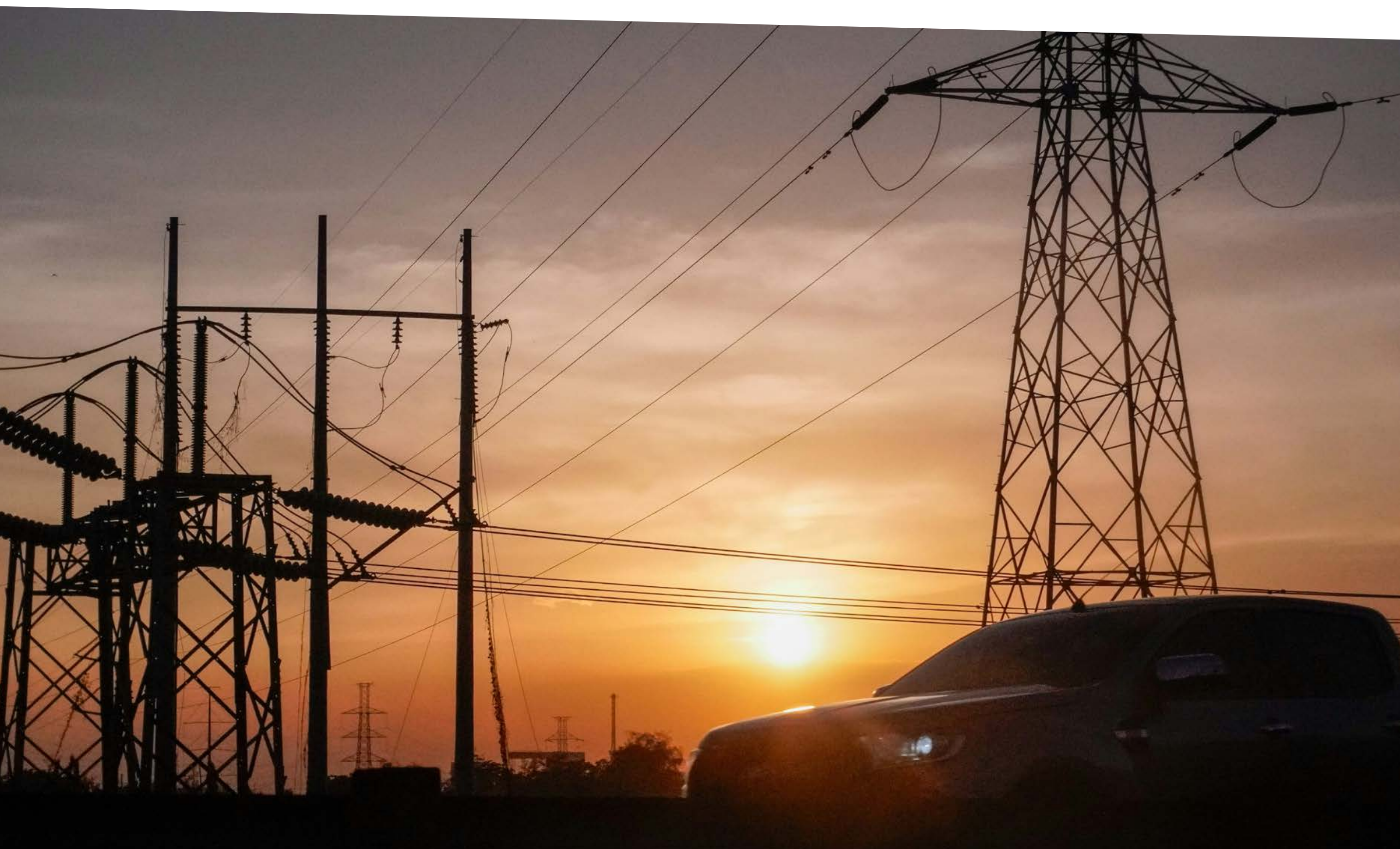
Figure 4: Mineral-specific clean energy transition risk score by mineral and category



Notes: High = score above 2.33, Medium = score between 2.33 and 1.67, Low = score less than 1.67.
Source: IEA (2024), Global Critical Minerals Outlook 2024

level of geographical concentration is greater. This needs to be made in a way that fosters a more diversified array of supply sources in the future. Financing diversified critical mineral supply chains faces numerous challenges, such as cost inflation, long-term price uncertainty and limited value placed on diversification by consumers. This requires specific policy measures to reinforce the investment case for supply chain diversification.

- **Unlock the power of technology, recycling and behavioural change:** Technology advances also have a major role in alleviating potential supply strains. For example, significant reductions in the use of silver and silicon in solar cells over the past decade have contributed to a spectacular rise in deployment of solar PV. Innovation in production technologies such as direct lithium extraction or enhanced metal recovery from waste streams or low-grade ores can also unlock sizeable new supplies. Stepping up efforts for recycling and behavioural change is also vital. In the case of lithium, the combination of right sizing EV batteries, alternative chemistries and recycling could reduce demand by 25% in 2030 in the NZE Scenario, saving an amount roughly equivalent to today's production. Recycling rates for many materials have exhibited limited growth in the past. In the NZE Scenario, however, this needs to change, with growing policy attention to stepping up rates of collection and reprocessing. Recycled quantities of copper and cobalt could reduce 2040 primary supply requirements by 30%, and 15% for lithium and nickel. Without the uptake of recycling and reuse, mining capital requirements would need to be one-third higher.



- **Promote transparency in markets:** Some critical minerals markets are characterised by limited price transparency that can introduce volatility and hinder new investments. There are also increasing calls from consumers for more information about the risks throughout the supply chain. From pricing transparency – with benefits to be drawn from efficient price discovery mechanisms and financial tools to hedge risks – to information transparency, with a strong need for increasing the availability of reliable data on consumption, supply and trade, enhancing market transparency can help facilitate new investments in geographically diverse regions.

- **Create incentives for sustainable and responsible practices:** There is growing importance of incentivising sustainable and responsible production of critical minerals through rewarding ESG efforts and speeding up approvals of new facilities without loosening legal and regulatory protections. Supply chain due diligence, with effective regulatory enforcement, can be a critical tool to identify, assess and mitigate risks, increasing traceability and transparency.

- **Foster efforts on international collaboration:** The challenges associated with increasing demand for critical minerals cannot be solved by any one country or company. Co-operation among governments, market participants, civil society and international organisations is crucial for meeting these challenges in a way that is inclusive and avoids duplication. Potential areas of co-operation include: i) sharing reliable and transparent data; ii) conducting regular assessments of potential vulnerabilities of supply chains and potential collective responses; iii) promoting knowledge transfer and capacity building to spread sustainable and responsible development practices; iv) strengthening environmental and social performance standards to ensure a level playing field, v) harmonising recycling-related regulation and waste codes, among others.

Ensuring secure and resilient supply chains requires a broad and bold strategy that brings together investment, innovation, recycling, rigorous sustainability standards and well-designed safety nets.

Imagining the future

These risks to the reliability, affordability and sustainability of mineral supply are manageable, but they are real. There are multiple conceivable outcomes that could unfold. Subdued investment in new supplies and elevated geopolitical tensions would exacerbate the supply challenges that the markets are facing.

Without reliable supplies of critical minerals, consumers could be less amenable to adopting clean energy technologies due to higher costs, leading to delayed transitions. For instance, the share of cathode materials in battery costs was under 5% in the middle of the last decade, but it has recently surged to around 25% in 2023. When anode materials and other raw material inputs are added in, the share of raw materials rises further, meaning that movements of raw material prices can have major impacts on the total cost of clean energy technologies, and in turn their affordability.

Conversely, in a scenario with support for strategic investments in mines and refining facilities in geographically diverse regions, along with strengthened policy measures to moderate demand – through recycling, innovation and behavioural change – critical minerals can be a vital enabler for affordable and rapid energy transitions. The future of energy transitions will thus hinge on how policy makers, companies and consumers address issues around critical mineral supply chains.

Super basin:

DELIVERING THE NORTH SEA INTEGRATED ENERGY SYSTEM

A new independent, transnational body needs to be established to promote the interests and advance the development of the integrated North Sea energy system, writes Malcolm Forbes-Cable, Vice President Energy Consulting Wood Mackenzie.

By Malcolm Forbes-Cable, Vice President Energy Consulting, Wood Mackenzie.

The role of the North Sea

The North Sea basin has played an important role in the global energy story of the last 50 years. The first offshore oil and gas discoveries were made in the 1960s in the Netherlands, Norway and UK with Denmark striking oil in the early 1970s. This was an exciting time for the North Sea however, it was the 1973 first oil shock with an oil embargo combined with nationalisation of Middle East oil resources that thrust the North Sea centre stage. Reduced oil supply and surging prices damaged western economies and highlighted the perils of energy import dependency.

Now fifty years on, war has once again forced energy security into the spotlight reminding a new generation of the learned (and forgotten) lessons of the 1970s. This time, natural gas been at the heart of the energy crisis with gas prices spiralling following Russia's invasion of Ukraine. The Achilles heel of the European energy strategy was the reliance on Russia for more than 40% of piped gas supplies. Whilst the decarbonisation agenda was set in motion long before 2022, this most recent existential shock has been a turning point thrusting sustainability coupled with security of supply and affordability to the top of the agenda.

Europe faces multiple strategic challenges, but addressing the energy trilemma is integral to its success. This latest energy shock must not be wasted but instead harnessed to accelerate the development of a much more self-sufficient low carbon energy system. The great progress in offshore wind development and the rapid expansion of the interconnector network across the North Sea are setting the foundations of a new regionally integrated energy system.

Europe faces multiple strategic challenges, but addressing the energy trilemma is integral to its success.

More nascent but key to the decarbonisation of Europe are carbon capture and storage (CCS) and hydrogen production, both with huge North Sea potential. Any assessment of the North Sea's future cannot ignore the role of the oil and gas sector. Long-term oil and gas remain a key part of primary energy supply however, of equal relevance are the extensive basin skills and expertise the industry brings. With more than 50 years of operating experience, extensive regional infrastructure, a skilled workforce and a sophisticated supply chain, the oil and gas sector has a major role to play in the reinvention of the North Sea energy system (figure 1).

Reinvention of the North Sea energy system

The North Sea's centrality to Europe's energy transition manifests in the multiple bodies, sector initiatives and ambitious targets that have been launched to drive the transition forwards. The energy landscape is becoming more complex by the day as the decentralisation, diversification and increasing variability of power generation necessitates greater interconnectedness across the system and between sectors. This growing system complexity with multiple sector voices makes it increasingly difficult to keep track of the big picture and the progress across all the constituent parts necessary to deliver an integrated system. Whilst politicians will rightly champion successes in specific areas, for the North Sea to realise its full potential it must deliver across multiple sectors.

A unified voice

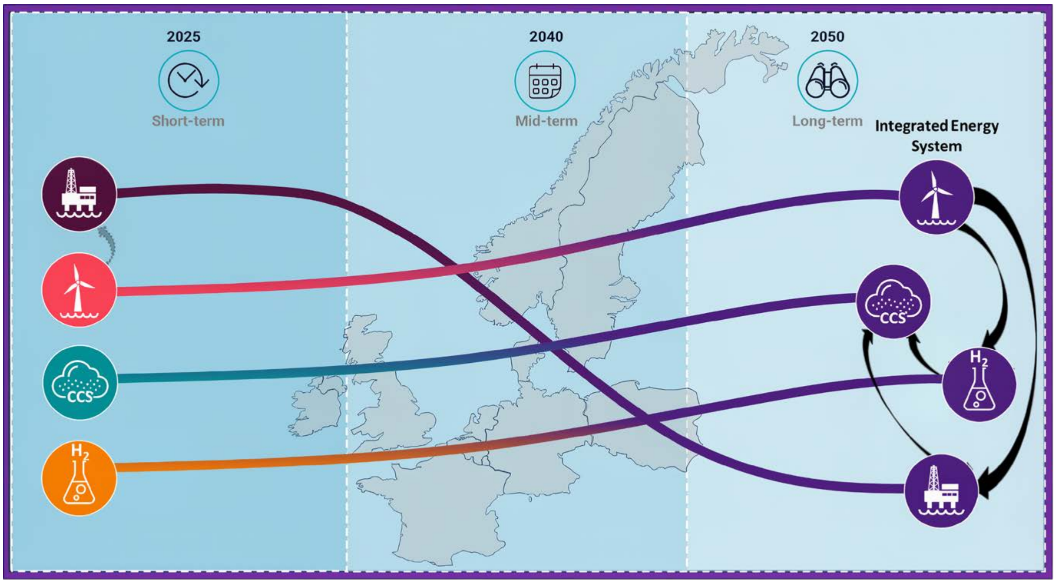
A new independent, trans-national body needs to be created to promote the interests and advance the development of the integrated North Sea energy system.

This body should work across sectors providing a unified voice for the North Sea with the objective of accelerating its development and realising its potential. Whilst such a body will hold politicians to account, they will benefit from having a clear understanding and prioritisation of what needs to be done to unlock and deliver on the promise of energy security, sustainability and affordability.

Political setting

Northwest Europe has for many centuries been one of the busiest marine trading regions in the world and with a shared marine environment there is a long history

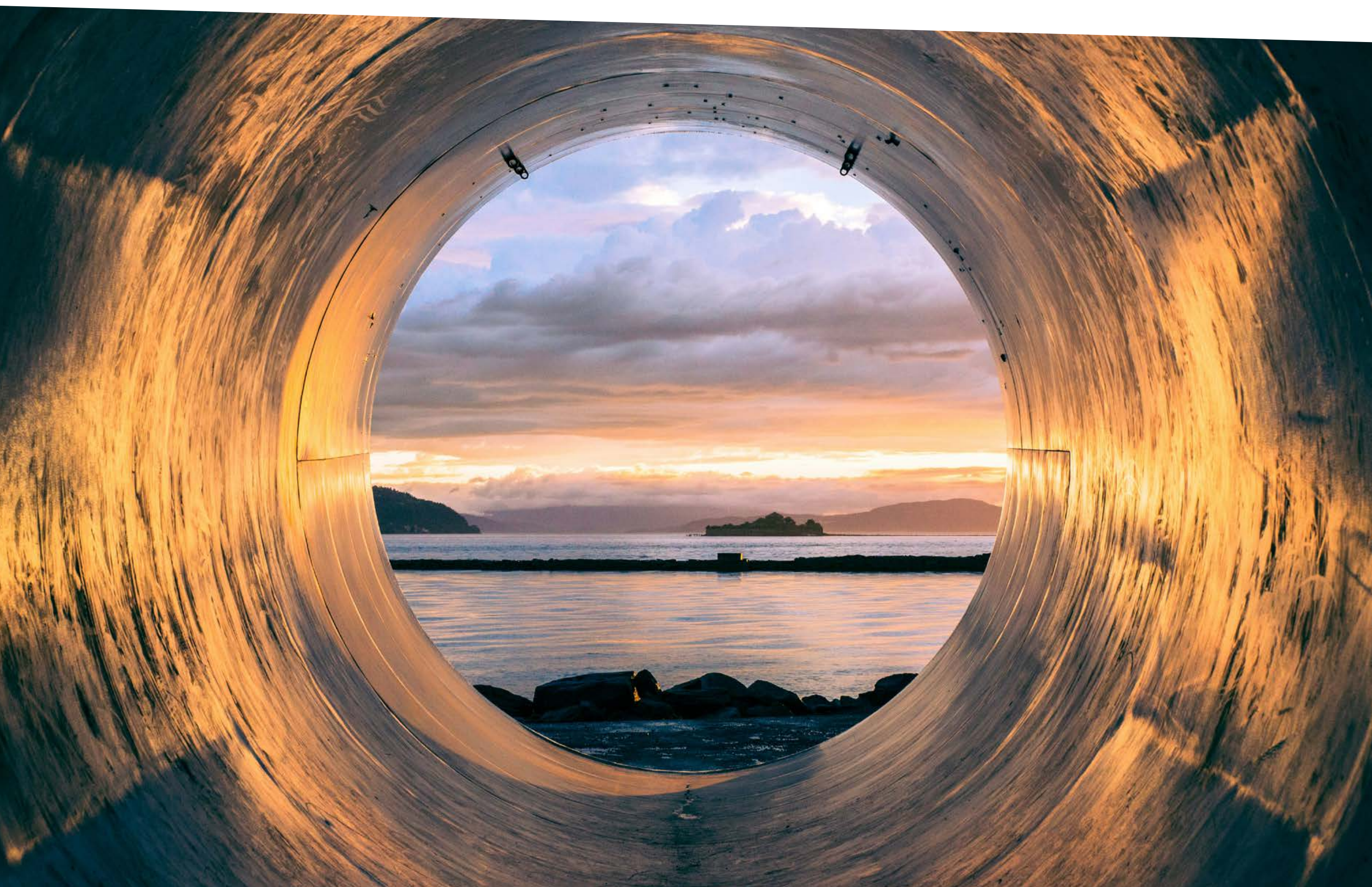
Figure 1: The Development of the integrated energy system of the North Sea Basin



of the North Sea nations working together in the common interest. This cooperation sets a good precedent for establishing the North Sea integrated energy system which by its nature will have a level of interconnectedness and interdependency that is without precedent in trans-national energy systems. This need for strong regional collaboration has been recognised by the North Sea nations.

The North Sea's Energy Cooperation joint political declaration in 2016 aimed to facilitate the cost-effective deployment of offshore renewable energy, in particular wind, and promoting cross-border interconnection in the region. In April 2022 the Esbjerg Declaration was highlighting 'the North Seas as a green power plant of Europe, delivering cross-border projects and anchoring the renewable offshore energy industry in Europe.' The declaration was signed by the leaders of Belgium, Denmark, Germany and the Netherlands. In April 2023 they were joined in this commitment through the Ostend Declaration, signed by the leaders of France, Luxembourg, Norway and the United Kingdom. At the heart of these agreements is the joint endeavour

[...] oil and gas operators and supply chain companies have a critical role to play in the development of the integrated energy system..



to ensure secure, affordable and sustainable energy. These declarations demonstrate bold intent, but what comes next remains critical and will determine what is ultimately delivered. The signatory nations need to come together and develop a joint strategy to deliver on the vision. An important first step of this is to recognise the scale and significance of the opportunity.

Super basin

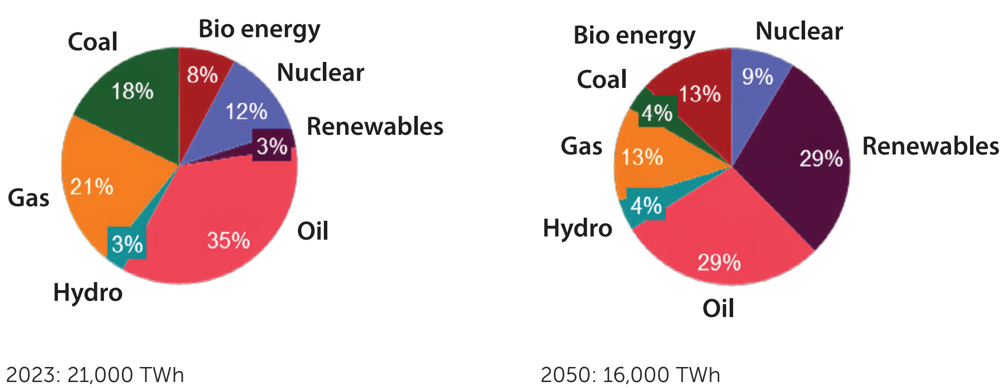
If we consider where we are today and the long-term energy potential for the basin, the main constituent sectors of the North Sea integrated energy system are oil and gas, offshore wind, CCS and hydrogen.

Oil and gas

At its peak in 2002 the North Sea[i] produced 9.7 million boe/d, (6.1 million b/d of oil and 3.6 million boed of gas). The basin is now in long-term decline as production has fallen more than 40% below its peak. Some welcome this decline as a signal of the decarbonisation of the energy system, but this ignores the critical role hydrocarbons will continue to play. Currently oil and gas account for 56% of Europe's primary energy demand and by 2050 will still be more than 40%. European domestic supply only provides for 25% and 43% of oil and gas demand on a net basis, and so Europe will be dependent on oil and gas imports in the long-term even under the most optimistic decarbonisation scenarios (figure 2).

Recognising the continued role of oil and gas in the energy mix is important and should be fully recognised in national and regional energy strategies. Furthermore, oil and gas operators and supply chain companies have a critical role to play in the development of the integrated energy system especially given their more than five decades of experience operating in the harsh marine environment of the North Sea. Expertise in the subsea, sub-surface, offshore construction and operations, technology development, marine transportation, project management etc. are applicable to the development of the offshore wind, CCS and hydrogen sectors. Above and beyond the practical benefits of having a world leading oil and gas sector the major players have capital to deploy. The transition requires all hands to the pump.

Figure 2: Europe Total Primary Energy Demand 2023 and 2050



Offshore Wind

Offshore wind has been a North Sea success story building over the last three decades, leading innovation and developing a sector that is rapidly globalising. In 2023 the North Sea[ii] had 30 GW of grid-connected capacity. By 2050 North Sea nations are targeting greater than 10-fold growth to more than 330 GW. This is a major step-up in development activity which is best highlighted by considering installation rates. In the last five years these averaged 2.7 GW/year across the North Sea nations whilst the 2050 ambition implies a rate of >11 GW/year or 13 GW/year if you consider the 2030 targets.

Offshore wind is developing in other offshore regions of Europe, but the North Sea remains in the vanguard of innovation and a critical energy corridor for the EU. Great expectations are set on floating offshore wind that would extend the envelope of operations and usher in a new phase of growth for the sector.

Offshore wind is central to Europe's decarbonisation strategy. Solar, onshore and offshore wind are expected to each

account for between 20-25% of European power supply by 2050. Europe's policy makers dependency on renewables to realise decarbonisation targets highlight the imperative for continued support for expansion and development. The North Sea's extensive wind resources give it the potential to make the single biggest impact of any region on the transformation of Europe's energy system.

CCS

A technology that has sat on the threshold of commercialisation longer than most, CCS has a vital role to play in the decarbonisation of the global energy system. Europe has geological storage in abundance, a functioning carbon market and a unanimous commitment to decarbonise.

How much carbon storage exists across Europe is under continuous revision with ongoing work to identify potential storage sites. What is certain is that the North Sea has material storage capacity combined with several characteristics that makes it a very attractive location for CCS. These inherent advantages include detailed subsurface models, existing infrastructure, an extensive oil and gas supply chain, remoteness from population and critically, proximity to industrial CO2 sources. With over 160 billion tonnes of storage capacity across the North Sea this represents more than 50 years storage for all of Europe's current annual emissions.

This potential is manifest with 16 separate storage projects[iii] announced across the North Sea with a transport and storage capacity of 260 million tonnes per annum. Despite these significant commitments, the pace of the development is slow as regulatory and commercial uncertainties hinder the investment case. The EU's 50 million tonnes of CO2 per year storage capacity target by 2030 and the UK's 20-30 million tonnes of CO2 per year will not be met. These were always stretch targets and whilst Europe does not lack of ambition, it is falling very short on delivery.

Hydrogen

Hydrogen and its derivatives have attracted a lot of attention over recent years and is pledged by some as the panacea for decarbonising the energy system. The 2030 target of a 20 million tonnes per annum EU market split between indigenous and imported supply are wide of the mark. However, momentum is building, and hydrogen remains an important part of the decarbonisation strategy especially for the industrial sector. Hydrogen infrastructure projects accounted for 40% of Projects of Common Interest (PCI) in 2023 and the launch of the Hydrogen Bank's first round auction of €800 million was a significant response to the Inflation Reduction Act (IRA) in the US.

Over the long-run green hydrogen is expected to dominate the low carbon hydrogen sector but technology development will be key to bringing down the cost. Blue hydrogen has its role to play particularly if it can be used as a bridgehead to establish hydrogen value chains. Norway currently supplies more than 40% of the Europe's piped natural gas and has a network of gas pipelines connecting it to Europe. Equinor and RWE recently announced plans to develop hydrogen production and export to Germany initially with blue and then switching over to green. Either way the

Complicating factors	Examples
Shared infrastructure	Regional pipelines, interconnector cables, energy islands
Integrated markets	Power, CO_2, H_2, hybrid projects
New technical challenges	Shipping and storage of CO_2 and H_2, floating offshore wind
New markets	CO_2, H_2 and derivatives
Cross-border trade	CO_2, H_2 and derivatives

North Sea has an important role to play in the hydrogen sector whether through natural gas supply in the mid-term or longer-term renewable power.

Delivery

Once again, the North Sea is central to solving Europe's energy challenges with its extraordinary natural resources. The North Sea is further advantaged by being close to large population centres in countries that have shared values, a common net zero vision, strong alignment and a history of collaboration. To deliver on the ambition the signatories of the Ostend and Esbjerg declarations must work together on an integrated basin approach. As a first step, this requires a joint vision and strategy.

> Ultimately the carbon price is what will unlock the funding for the transition.

Building on the recent declarations the signatories should prepare an integrated basin wide vision and strategy stating the ambition and laying out a plan of action to deliver on the aims. There are already multiple targets that have been set and these should be merged into one integrated view. An important step will be to take stock of the multiple stakeholders across the North Sea energy and CCS sectors, mapping current projects and sector initiatives to establish a common understanding of the key players and activity across the basin. This will help to build a registry of the gaps and barriers impeding the regional development of the integrated energy system. By bringing together the sectors key messages can be identified so that they can be elevated to the signatories of the declarations. Independent, clear and consistent communication with updates on the progress and challenges in implementing the strategy will support better decision making and facilitate more targeted action.

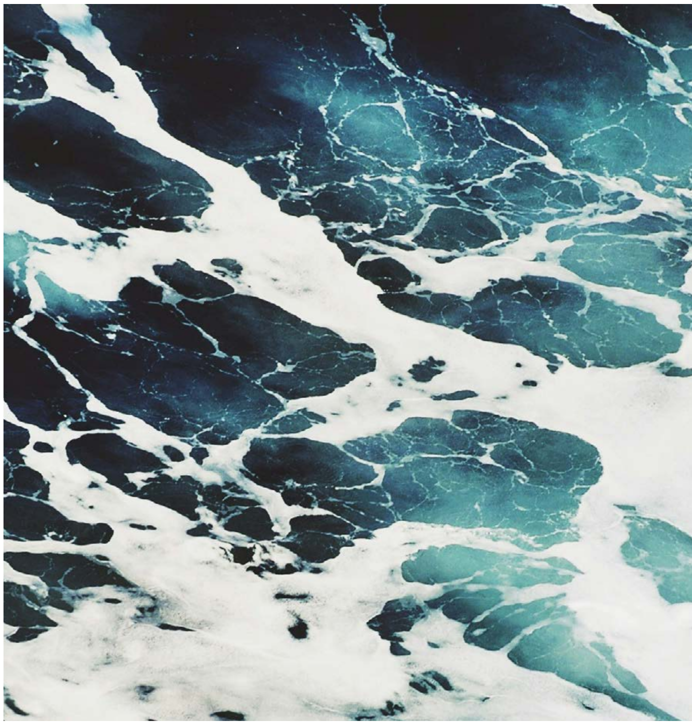
Whilst not an exhaustive list there are several work areas that the strategy would want to examine in more detail being key levers to the development of the basin:

- Legal and Regulatory
- Supply Chain
- R&D
- Markets
- Finance

- Legal and Regulatory

Legal and regulatory issues are inevitable when developing shared infrastructure, integrating markets, establishing new sectors /markets, dealing in cross border trade, addressing new technical challenges.

One focal point of removing regulatory barriers has been the cross-border shipment and storage of CO_2. Fundamental to meeting the ambitious commitments to reducing greenhouse gas emissions is the ability to trade low carbon products and waste, namely CO_2 – the EU is targeting a 90% net reduction in greenhouse gas emissions by 2040. There has been significant work in this area relating to adjusting conventions on dumping waste at sea to allow for CO_2 storage. Another key area has related to how the EU ETS accounts for ship transported CO_2 and its storage. The lack of legal clarity around this issue for the EU ETS and UK ETS systems is symptomatic of the frictions that exist. Additionally, the lack of alignment between the EU ETS and UK ETS prevents cross border trade of CO_2 between the UK and EEA countries. These are issues that require political will.



- Supply Chain

The North Sea is very fortunate to have two world leading energy supply chains in the oil and gas and the offshore wind sectors. Both have been at the vanguard of their industries through technology innovation which has shaped the global energy business, driven exports, created jobs and spurred economic growth. Within the oil and gas sector about 90% of direct and indirect jobs are in the supply chain [iv], highlighting its importance for employment and the economy within the energy sector.

The recent challenges faced by the offshore wind sector, from escalating costs and supply chain pressures, have left the European companies in a vulnerable place. At the same time Chinese companies have emerged with competitive costs, improved quality, healthier financials and an imperative to diversify their portfolios due to fluctuating domestic demand.[v] The next few years are going to be critical to the long-term future of the European offshore wind supply chain. At a time of continued growth and thin margins, the economic case for developers to increase business with Chinese suppliers is strong; however, this would be a strategic misstep undermining longer term energy independence.

> Declarations are the easy part and now it is time for a trans-national body to develop an integrated vision and strategy for the North Sea.

Governments need to take a long-term view and balance the need to sustain a local supply chain whilst not fostering undue cost inflation. The offshore wind sector is entering a period of rapid global growth – since 2021 governments globally have announced more than 130 offshore wind targets – supporting Europe's offshore wind sector through this challenging period is something that needs close attention. At a time when global markets are crying out for the expertise and equipment of the North Sea offshore wind supply chain, it would be a massive irony if the area that originated and scaled the sector were left to wither in the face of competition. Across the North Sea there needs to be stronger alignment and a collective effort to support the regional supply chain.

- Research and development

The Noth Sea has a proud history of technical innovation in the oil and gas and wind sectors. The advances made across the region have made significant contributions that have benefitted the global energy sector. This strong capacity for innovation has never been more necessary given the multiple technical and commercial challenges of the energy transition. Significant funding is being invested across Europe in energy research and development with Horizon Europe being an important source with around €5.6 billion earmarked to support the European Green Deal.

With all the R&D work ongoing across the public and private sectors there would be material benefit in mapping this out through a North Sea lens to highlight core areas of research and regional collaboration, provide a basin wide view of the investments being made, identify potential gaps or areas of weakness and to develop a better understanding of the overall picture for the region. This would improve visibility of the level of activity, the key areas of focus and enable better strategic alignment.

- Markets

There are three core factors required for an integrated North Sea market for energy and CO2 to flourish. These are regulatory alignment, infrastructure and functioning markets. The CO2 transport and disposal challenges outlined above, highlight the need for regulatory alignment to remove barriers and reduce trade friction. Infrastructure is an obvious one, and if we look at the case of cross-border power interconnectors is developing rapidly given its well-established business model.

Currently there are more than 35 GW collectively spanning 6,500 km of under-sea interconnectors under construction or in the pipeline across the North Sea region due online by 2030. Whilst a positive sign, grid reinforcement delays remain one of the key barriers to faster roll out of renewables. The recent ENTSO-E Offshore Network Development Plan[vi] report into European offshore network transmission infrastructure needs identified that Europe's offshore transmission infrastructure would need €400 billion of investment to 2050, 64% of which would be spent in the North Sea.

The European carbon market is less evolved than the power markets and is controlled by the EU ETS (UK ETS in UK) and the supply of carbon credits. Carbon prices have fallen to around €50/tonne in 2024 due to an over-supply of carbon credits. While the sale of carbon credits is a source of funding for the EU and member states the fundamental truth is that until there is a reliable carbon price, the incentive for industry to decarbonise is going to be reduced. Higher carbon prices are the only way that the carbon market will work as intended i.e. support the decarbonisation of Europe. Only then will a CCS industry truly be able to develop.

- Finance

To date, more than €100 billion has been invested in the North Sea low carbon energy system, but this is just the start. A further €1.4 to €1.8 trillion[vii] is required to deliver the North Sea's ambitious national and regional 2050 targets; equivalent to between €54 and €70 billion per annum (figure 3). To put this into context, the annual North Sea oil and gas development spend, driven by attractive returns, averaged €32 billion in the 50 years between 1970 and 2020. The funding bazooka the US has taken to the energy transition in the shape of the USD 400 billion Inflation Reduction Act has raised the ante in Europe. However, given the scale of investment required and the wider economic challenges faced in Europe finding a path to a financially sustainable model is vital to realise the potential.

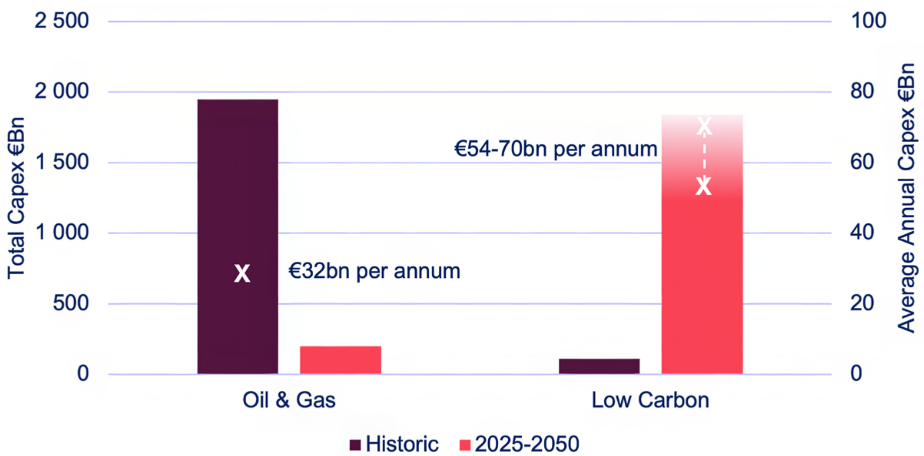
Governments have a critical role to play to support the development of new sectors and help attract investment however, the quicker these markets can be stood up on their own feet the better. Ultimately the carbon price is what will unlock the funding for the transition. This clearly has financial consequences for industry and consumers, but it is the one way to address the externalities of carbon emissions.

Conclusion

To harness this enormous potential and deliver an integrated energy system that supplies secure, sustainable and affordable energy requires more than ambitious targets. Declarations are the easy part and now it is time for a trans-national body to develop an integrated vision and strategy for the North Sea. A body which can represent the interests of all sectors and drive the changes and actions that are necessary to deliver the low carbon integrated energy system of tomorrow.

This is a too important an opportunity to waste.

Figure 3: North Sea Basin historic and future (2050) capex spend



A retrospect from 2050:

HOW WE MANAGED GLOBAL ENERGY TRANSITIONS

The future of energy is a story of energy for people and planet, written by us all. This chapter is about how we might learn to successfully manage global energy transitions – plural – with the pull of people and push of technology, as seen from the year 2050. Dr Angela Wilkinson, Secretary General of the World Energy Council, shares her thoughts.

By Dr. Angela Wilkinson, Secretary General, the World Energy Council

The turbulent twenties

Decades of unchecked consumerism and industrialisation had pushed the planet to its limits, with climate change looming as an existential threat. The increasingly frequent and uneven impacts of extreme weather and structural inequalities began to bite everywhere.

COP26: Just stop supplying oil and gas!

A frenzy of net-zero promises and pledges were made in 2021 as climate activists, investors, and entrepreneurs met at COP26 in Glasgow, and ministerial negotiations aligned with green energy business interests.

The world was still reeling from the COVID-19 crisis. Global energy demand destruction, following economic lockdowns, gave hope to some that a transition away from fossil fuels had started.

But just one year later an act of war in Europe was followed by the first global demand-driven energy shock and led to a temporary increase in global coal use – increasing greenhouse gas emissions from power production.

COP27: Compensate the vulnerable communities!

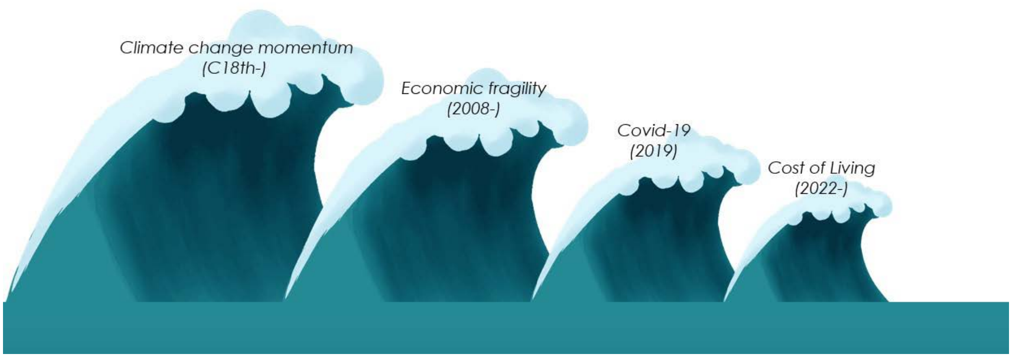
As ministers and business leads met for COP27 in Egypt in 2022, it was clear that progress lagged the political promises and corporate commitments made in Glasgow. The uneven impacts and responses to the pandemic were combining with climate change-induced extreme weather to hit the most vulnerable communities hardest across the world, especially small island states and developing economies.

As global economic growth slowed and inflationary pressures grew, an equity and affordability crisis started to unfold. Energy poverty rates rose within OECD countries. The numbers of people without access to basic electrification increased in many developing economies.

A new clarion call - "Clean and just energy transitions!" - brought added nuance in the 'race to zero'. The meaning of 'just transitions' varied across geographies and between generations.

The rising costs of capital and inability of companies and countries to manage debt servicing was a barrier to new energy developments.

Waves of global changes



New hopes for green hydrogen value chains struggled to gain a foothold, as demand failed to develop as rapidly as predicted when industrial energy users baulked at the costs.

And less than 5% of the billions of dollars of new investment in renewable energy systems went towards developing economies.

COP28: Powering new climate and energy security agendas together!

The growing tensions of an emerging multipolar world order were evident as COP28 got underway in the United Arab Emirates in December 2023.

The urgency of addressing greenhouse gas emissions associated with coal, oil and gas supply and use — without creating a new threat to global peace – was shared, yet the risk of disorderly transitions was growing.

A historic agreement to transition away from fossil fuels to ensure just, orderly, and equitable processes was agreed, with promises of new financing to help developing economies, to advance global goals of tripling both new nuclear renewable power generation and doubling energy efficiency by 2030.

Whilst some - companies, countries, and regions - wanted to accelerate the development and implementation of zero fossil roadmaps, others wished to repurpose existing infrastructures and develop wider solutions to accelerate and secure affordable and reliable flows of clean molecules and green electrons to billions more people.

The new geopolitics of energy was extending beyond oil and gas to data and non-energy resources – including the materiality of renewables at scale, which required access to critical minerals and metals - triggering concerns about continued dependency on Chinese wind, EV, and solar supply chains, especially in Europe.

The outlook for a bumpy road ahead

Climate, energy, and human security concerns were common to all regions, but priorities and pathways differed. Institutional, policy and financial innovations were also emerging as countries sought to secure national interests including economic competitiveness.

The increasingly fragmented, competitive, and polarising energy leadership landscape was impacted by the rapid increase in trade restrictions on goods, services and investments and a flurry of bilateral deals.

Energy market trading and arbitrage readily embraced new opportunities in predictive analytics and data mining. However, global energy data averages and historical projections held less value to incremental policy improvements in an era where disruptions has become the norm.

People were the biggest blind spots in actualising net zero roadmaps. New and shifting energy uses were contributing to uncertainties about the outlook for demand. Meeting these new and changing demands for energy was vital to unleashing the pull of social transformation.

The five horsemen

Ensuring renewable power generation comprised half of the global energy mix by 2050 was not straightforward and required help from other clean energy and material friends. Copper was essential to strengthening and extending transmission and distribution grids and shifting to fully electric vehicles. Not all industrial energy uses could be electrified – the energy for producing cement and steel for wind turbines and mining materials and manufacturing solar panels also needed to come from somewhere. Global energy assessments highlighted insufficient green electricity to meet all needs and uses would remain for at least another century.

The fast-growing digital economy created new demand for clean and reliable electricity. In 2022, Apple, Amazon, Alphabet, and Meta exceeded the national energy demand of Colombia. By 2026, data centre servers were surpassing Japan's energy demand. In 2028 the companies Alphabet and Baidu had entered the top 10 global demand-drivers of net zero electricity and were promoting new business models for small modular nuclear power stations.

The integration of energy transitions, youth employment and industrialisation policies was becoming urgent and pressing in all regions and particularly in the developing economies of Africa.

The late 2020s: Redesigning energy for people and planet

When the Centennial World Energy Congress opened in Rotterdam in Spring 2024, the term 'energy transition' had become one of the most politically loaded, polarising, and misunderstood phrases of the century.

Unlike previous energy transitions which had been driven by superior technologies, in terms of energy density and efficiency alone, securing more energy for sustainable development, whilst decarbonising all energy uses, presented complex coordination challenges.

Diverse and connected energy societies were at risk of swinging from one energy crisis to another. The interconnected resilience of global energy markets and communities remained at risk from extreme inequalities and uneven impacts of climate change.

A milestone was achieved as solar and wind power generation capacity exceeded hydropower and nuclear power for the first time. The overall global energy mix was 80% fossil fuels and 20% electricity, with about 8% of global energy use provided by solar and wind technologies. The renewable power revolution was gaining pace, accelerated by the falling prices and increased availability of electric vehicles, heat pumps, wind turbines and solar panels from China.

Decoupling energy from growth, whilst securing clean materials and supply chains, including new global hydrogen value chains, was not proving to be quick, cheap, or easy, nor achievable from a supply-side push alone.

The social energy agenda: A major handbrake & source of transformation

Although sunshine and wind are nearly universal, and renewable power supplies were becoming cheaper to produce than alternatives, renewable services are not 'free.' System connections, more flexible storage solutions, and billions of energy devices – stoves, cars, heat pumps, meters – incur costs.

Despite the shared benefits of cheaper and abundant renewable power supplies and the creation of hundreds of millions of new green jobs, social issues of affordability and equity remained key for political agendas.

Decades of underinvestment in energy infrastructure, especially electricity grids, had become an impediment for connecting new renewable power generation and enabling flexible storage solutions.

Delays in utility scale wind farm developments showed how uncertainty, public acceptance and affordability could collectively impact the speed of energy transitions in wealthy and industrially advanced societies.

Securing more energy for billions of better lives whilst decarbonising all energy uses

Managing global energy transitions provoked great discomfort. No one had managed a successful energy transition before, let alone one at the scale, speed and scope required then to avoid conflicts and catastrophic climate change.

The rapid transition from coal-to-gas in 20th Century Europe could not be easily replicated elsewhere, especially in regions lacking existing large-scale energy infrastructure. Stopping gas supplies without transforming demand also proved to be a recipe for disaster in Europe.

The socially messy and technologically complex process of making faster, fairer, and more far-reaching energy transitions happen required new ways of aligning diverse needs and interests and radical forms of collaboration.

The focus on climate change mitigation alone was insufficient. All signals pointed to an overshoot of 1.5 degrees by 2050, increasing the demand for climate adaptation, direct carbon removal, and climate repair solutions. Without new models of regional cooperation – transmission, clean hydrogen, supply chains global energy transitions would take longer.

The World Energy Council supplemented its World Energy Congress with an innovative series of regional conversations aimed at better engaging globally underserved populations and re-connecting the global energy dots between multiple UN Conventions – climate change, sustainable development, and biodiversity.

As the Turbulent Twenties progressed, competition, contestations and collaborations between nation-states and global networks continued to oscillate. The search for new and better ways to compensate the losers and to lubricate social and political friction points began to intensify.

The transformational thirties

In 2030, the UN issued its 21st Code Red for 21st Century Humanity: and assessed six billion people in over 200 countries as being 'at risk' of climate change impacts and social unrest.

Despite meeting COP28 goals, the size of world energy systems had almost doubled to meet the needs of developing economies. Massive volumes of minerals, metals and materials had been mined, processed, and manufactured, bringing renewed focus to the wider ecological footprint agenda – land, water, forests, climate, and other planetary boundaries.

A step change in energy literacy

On the brighter side, a multi-pronged worldwide push on energy literacy was engaging and enabling billions of people and diverse communities to better understand their roles and choices in making faster, fairer, and more far-reaching energy transitions happen.

Wider appreciation of the opportunities for demand transformation through energy literate societies enabled better quality conversations on system-wide costs and the shared benefits of greening everything. This was pivotal in addressing deeper structural, behavioural, and cultural barriers to accelerating decarbonisation of the economy.

World energy trilemma 2.0: Transformational performance tracking and path finding

The 25th Global Stocktake on energy transition performance by countries, regions, and cities was presented at the 2034 World Energy Congress.

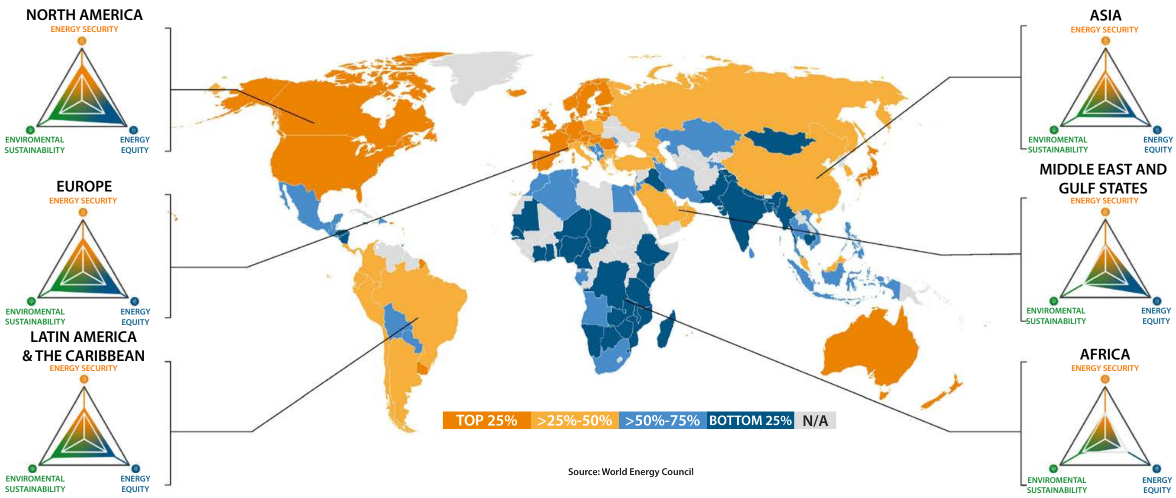
Digitalisation of the World Energy Trilemma framework in 2026 had enabled real-time performance tracking.

Regions and cities created their own Energy Trilemma frameworks to complement global and national assessments over 200 governments and 20,000 cities were using the tool to lead and learn with each other about how to manage increasingly diverse energy transitions pathways.

The progressive and practical approach to management of the connected energy transitions challenges – security, affordability, sustainability - evolved with new demands for justice and resilience – and supported the introduction of a new standard of modern and productive energy access which replaced UN sustainable development goal 7 – "affordable and clean energy".

Energy security dimensions also broadened beyond natural endowments and fixed stocks to include new metrics for grid reliability and extreme weather resilience and to reflect new opportunities for demand side management and dynamic grid storage.

2024 World Energy Trilemma Map



Managing policy trade-offs – e.g. carbon pricing, renewables incentives and energy efficiency – was still important, but the evolving toolkit was increasingly used to identify transformational synergies enabled by new combinations of policies, incentives, and collaboration choices.

Energy in a globally warmer, socially wobblier, and statistically weirder world

The contours of a new world energy landscape emerged from developments in digitalisation, decarbonisation, de-centralisation, supply-side diversification, and demand-led disruptions

Digital data has enhanced the transparency of energy systems and significantly improved efficiency and productivity across the board. But the exponential energy demands of digital technology services has necessitated a massive reallocation of capital and breakneck speed in developing modular nuclear power generation and continued trade in net zero LNG alongside green hydrogen-based fuels. As the fields of cybernetics, energy engineering, and sustainability sciences blurred, a new community of generative sustain-AI-bility solutions and practices emerged.

Diversification of global energy systems, including energy supply mix, storage solutions and end-uses continued. The wider demands for modern energy access and resilience were met by combinations of green and net-zero electrons and molecules – diverse pathways and different paces. Investment in grids had to be significantly increased to keep pace with the scale-up of renewables capacity and storage, and further innovations in blended finance emerged to enable significant investment in Direct Carbon Removal, Carbon Capture, Utilisation and Storage, and SMR nuclear power generation technologies.

Globally, new patterns of centralised, decentralised, hybrid, and off-grid power systems were established. Financial innovation could also be found in energy insurance, mortgages, and community-backed loans. Repurposing existing energy infrastructures, where possible, proved attractive to blended finance.

Two futures, two modes of cooperation: Collaboration and alignment

The World Energy Council is currently developing two versions of the future in two scenarios, differentiated by two modes of cooperation.

ROCKS is a world of new modes of collaboration within or between familiar established institutions that have power over financial, natural, military, or human resources, many of them becoming platform-based and operating at different scales. These may be focused on national sovereignty, or within a single company or companies within an industry, or within a country, region, or international 'circle of cities' sharing best practices.

RIVERS is a world of new modes of alignment, often more suited to the digitally enabled economy. These can be rapidly scaled in aggregate to reach transformative impact at the system level – such as happened in the telecommunications, media, and virtual-working domains, and in the energy system, the explosive take-off in light-duty electric vehicle sales and wind/solar power generation. These alignments form not simply among actors in the same region or industry, but also among diverse actors recognizing emerging opportunities and common interests from their diverse perspectives.

For further information visit https://www.worldenergy.org/transition-toolkit/world-energy-scenarios.

Rock & Rivers, 2024 World Energy Scenarios Foundations

	ROCKS	RIVERS
GEOPOLITICS	Blocs	Shifting alliances
TRADE	Blocs with leaky barriers	International in principle, but with security carve-outs
ENERGY SYSTEMS	A long tail of fossil fuel use with deep electrification and decarbonization in some blocs	Turbulent but swift fossil fuel substitution (electricity, hydrogen, biofuels) and cross-border connections enabled by technology
AGENTS OF CHANGE	Mission-oriented government leaders collaborating to design policy for national interests	Entrepreneurs, CEOs, policymakers, and consumers with aligned emerging interests
MODES OF COOPERATION	Policy convergence and deliberate collaborations among like-minded powerful actors with common interests; community collaborations at multiple levels	Emerging alignments driven by common pressures, markets opportunities, and innovation

Demand disruption and, in some places, overall reductions were enabled by a combination of demand-side management solutions and innovation by industrial energy users. Wiser use of and access to energy directed attention to willingness and ability to pay. Reconnecting price and value became instrumental in progressing beyond net zero energy transition models—non-toxic industrial revolution, a regenerative food systems revolution, sustainable fuels supply chains, and, of course, the bottom-up step change in global energy literacy.

The continued divergence of regional energy transition pathways remained more notable and reflected diverse demographic patterns – ageing societies vs. youth bulges, urbanising vs. depopulating societies, as well as the uneven starting points and significant differences in capabilities for de-industrialisation, re-industrialisation and securing the leapfrogging opportunities of the 4th Industrial Revolution.

Navigating the rapids of global energy transitions

Markets are conversations – and new market designs were needed to better anticipate disruptive and fundamentally shifting demand dynamics and engage missing voices of underserved populations. Women, workers, youths, indigenous and vulnerable communities, citizens and cities are engaging in the changemaker process as visionary and practical energy transition leaders alongside government ministers and CEOs

The disruptions and tensions of 2025-35 precluded a harmonious globalised world. But new, diverse modes of cooperation have emerged regardless.

There is still 'no one size fits all' solution; but opportunities for leading with diversity as a source of innovation and learning have never been greater.

The fit-for-purpose forties

As highlighted by the 26th World Energy Congress on Redesigning Energy for

Map of World energy congresses

People and Planet in 2024, there is no civilisation without energy; and what got the world to 2050 has been very different from our pre-2024 assumptions of what would unlock the greening everything revolution.

As visionary and practical world energy leaders reconvene for the 39th World Energy Congress, themed 'Energy – And Beyond', in 2050, what would we have learned about aligning diverse needs and interests, anticipating new and better energy uses, and, making faster, fairer, and more far reaching energy developments happen for all?

Energy is a system which includes people and connects everyone to natural ecosystems everywhere. Energy transition is a socially messy and complex process; and success involves the pull of societal transformation as well as the push of technological innovation.

There is no single story of success. Learning with failure is never easy, but it is essential. Progress towards our common global future continues to emerge from multiple places and develop at different paces, enabled by a series of smaller steps.

Renewable power systems now meet half the total energy needs in a much less wasteful world. Increasingly diverse and regional power systems support billions more productive lifestyles and livelihoods.

The shift in leadership mindsets from supply-side security to user-centric resilience has involved demanding transformations and: enabling wider energy access in underserved communities and wiser energy uses in wasteful energy societies.

More diverse, dynamic, decentralised, and distributed change agents have emerged to forge a global movement towards a sustainable and equitable energy future, guided by the transformational World Energy Trilemma framework.

More integrated and transformational policies have had to do some heavy lifting alongside institutional innovation. The fundamental reform of national tax systems is still in progress. Consumer rights have been supplemented with community rights and demands for environmental justice are driving legal system reforms.

"Bladerunner" beats "The Matrix"

Humanity has responsibly harnessing developments in Artificial Intelligence to transform its collective capabilities for making and managing progress in a new era of energy for people and planet. Peaceful coexistence depends on SustAInability – ecological civilisation is AI-augmented.

Towards a safe operating space - social floors and planetary boundaries

The overhaul of outdated GDP calculations has been enabled by the mainstreaming of wellbeing frameworks and now includes the cost of using up what remains of planetary boundaries, including global greenhouse gases. It's remarkable to reflect on the reduction of structural inequalities which has been achieved through global energy transitions, with 20:80% rather than 1:99% global wealth concentrations.

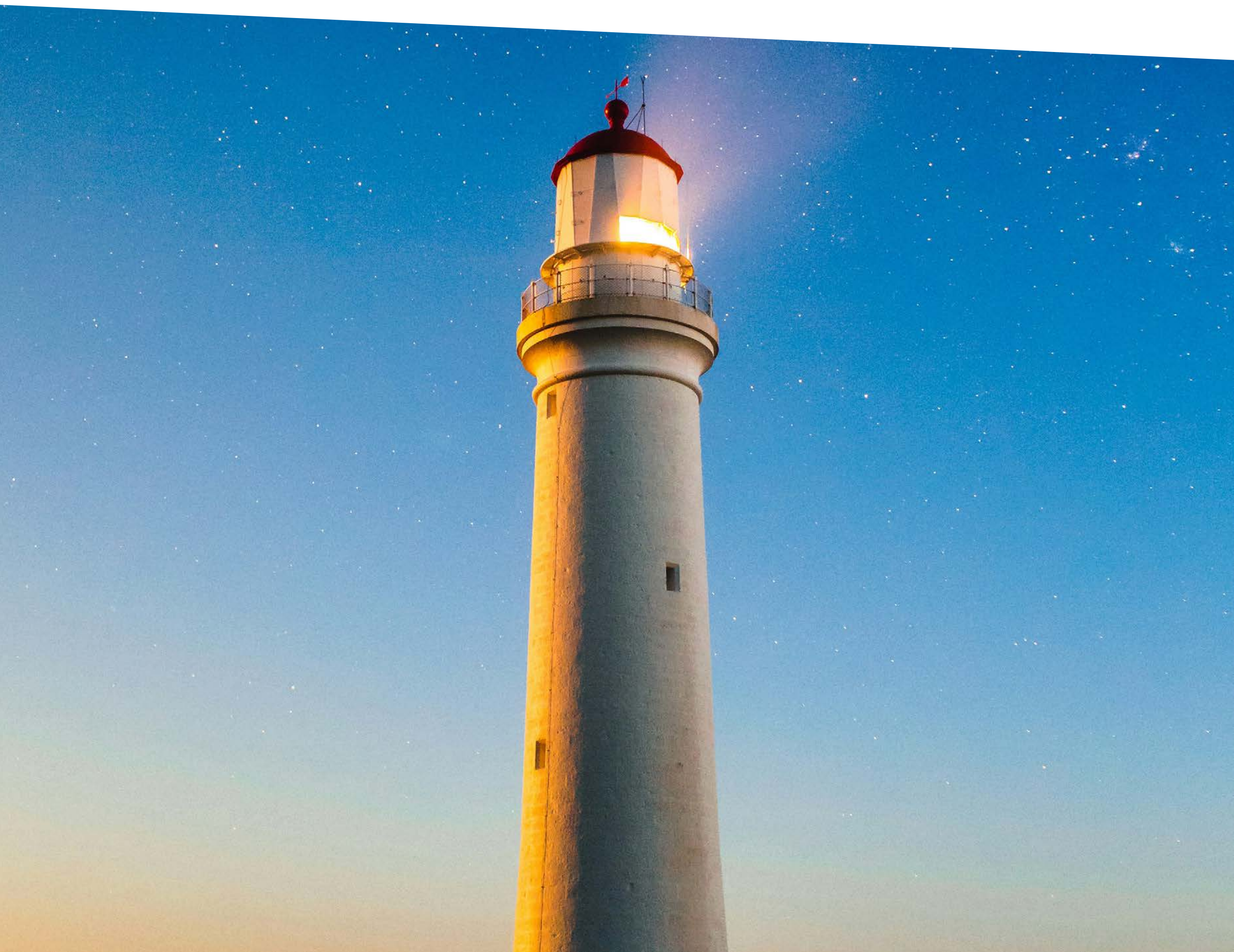
There is wider awareness of upstream

environmental impacts of renewable power and storage systems, from the importance of cloud forests to hydropower. The polarising narratives about good vs. bad energy have faded, but stories of heroes and villains still make headlines.

The socio-techno-economic paradigm shift towards ecological civilisation is well underway, prioritising human wellbeing and environmental stewardship. A new space in energy for people and planet is emerging as a design envelop rather than a clear pathway – an imaginable new paradigm of peaceful coexistence and sustainable wellbeing with enough energy for billions of prosperous lives on a healthy world.

We may be on different boats and moving along turbulent rivers, but the future of energy is a boundless ocean of new and better possibilities.

As we look beyond, humanity is still reaching for the stars, but we are humbler astronauts, who have learned hard lessons about not poisoning our own air supply, as we invent new means to develop energy from space.



Energy transition roadmap to 2050

STRATEGIC PLAN-NING TODAY FOR FUTURE PROSPERITY

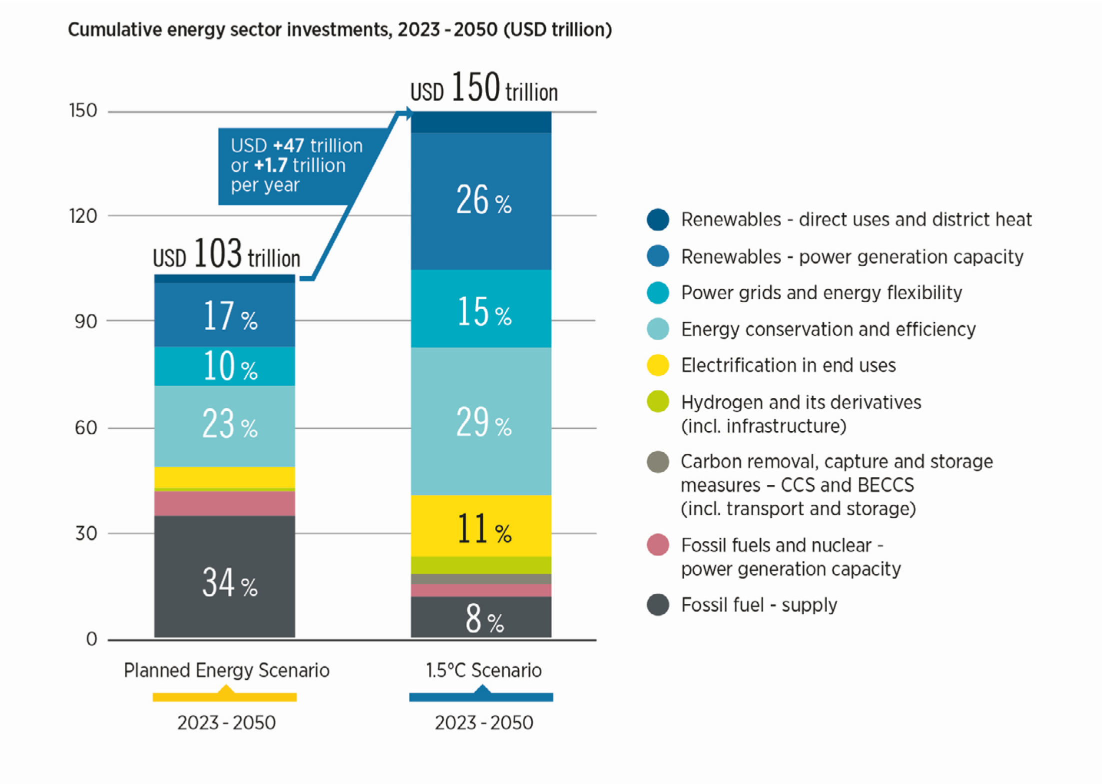
Companies that have for decades produced strong revenues based on fossil fuel will need to rethink their business models. Unprecedented investments in green technologies and infrastructure until 2050 will be necessary. Otherwise, our common future, including the value of business, is at risk, warns Ricardo Gorini, Senior Programme Officer, Roland Roesch, Deputy Director at the Innovation and Technology Center and Anke Schoenlau, Associate Programme Officer at International Renewable Energy Agency (IRENA).

By Ricardo Gorini, Senior Programme Officer, IRENA,
Roland Roesch, Deputy Director, Innovation and Technology Center, IRENA
and Anke Schoenlau, Associate Programme Officer, IRENA

“We are in a race against time,” said UN Secretary General Antonio Guterres at COP28 in December 2023, urging the global audience to understand that “our planet is minutes to midnight to the 1.5°C limit.” To keep the consequences of climate change in check by keeping the global temperature increase below the 1.5°C scenario , significant CO2 emissions reduction this decade is required.[ii]

The challenges humanity is currently facing raise awareness of the limits to growth. Our common future, including the value of business, is at risk. The IPCC has issued many warnings regarding the potential consequences and costs of not following an emission reduction pathway. Limited resources, lack of private sector engagement, insufficient resource mobilization, and a low sense of urgency are among the key barriers to climate change adaption, according to IPCC, with severe implications for the most vulnerable nations. In the absence of mitigation, IMF warns of long-term GDP-losses in the global economy at a magnitude of 25%, though climate change

Figure 1: Global investment by technological avenue: Planned Energy Scenario and 1.5°C scenario, 2030 - 2050



Notes: BECCS = bioenergy, carbon capture and storage; CCS = carbon capture and storage.

Source: IRENA World Transitions Outlook 1.5°C Pathway will affect individual countries differently and will have a disproportionate effect on the lesser and least developed.[iii]

IRENA analysis shows that emission reduction pathway implies a decrease in fossil fuel supply and use, but will also create new business opportunities. Climate change mitigation is a game changer for the energy landscape that will affect the power and fuel markets, and thus shape the future for fossil fuel companies. According to IRENA's World Energy Transitions Outlook and 1.5°C scenario, unprecedented investments in green technologies and infrastructure until 2050 will be necessary. Across the world, 150 trillion USD[iv], or 4.4 trillion USD per year on average, must be devoted to the transition. This will require the redirection of investments of about 26 trillion USD from the fossil to the renewable sector. All statements in this article on renewables development and investment needs for the energy transition are, if not stated otherwise, based on IRENA's World Energy Transitions Outlook 2023.[v]

Companies that have for decades produced strong revenues based on fossil fuel will need to rethink their business models to adjust to the new conditions imperative not only by climate change itself but also changing client needs, boosted by the gradual cost increase of emissions through regulatory measures[vi]. New policies, regulations and innovations are being promoted by governments to enable and foster the deployment of renewable solutions.[vii] Forward looking strategic management is needed to review core competences, actions and deploy resources in a way that contributes to society over time.[viii]

COP28 ended the year 2023 with new momentum for the next years: The COP28 UAE declaration and Global Stocktake (GST) signal the "beginning of the end"[ix] of fossil fuels, recognizing that GHG emissions need to be cut 43% by 2030 (compared to 2019) to keep 1.5°C within reach. The document calls on Parties to transition away from fossil fuels and to triple renewables and double energy efficiency globally by 2030.[x]

Some actors in the oil and gas industry have started responding to the challenge, with different strategies emerging whichaim to increase the efficiency of production processes and avoid unnecessary CO2 emissions (scope 1), adopt corporate energy sourcing with renewable energy as a solution to reduce emissions (scope 2), and push for low carbon technologies through diversification of investment in biofuels, renewable energy generation and end-use power markets (scope 3).[xi]

While these immediate emission reduction actions in scope 1 and 2 are important to meet the immediate emission reduction needs towards 2030, there is also significant potential for repositioning for fossil fuel companies. Today's strategic decisions will determine the energy companies' futures.

For governments and businesses alike, it is thus of utmost importance to address the global challenges posed by climate change by transforming to climate friendly modes of operation. Governments and companies in emerging markets and developing countries (EMDE) in particular will need to mobilise low-cost sources of finance to scale up the deployment of renewable power generation and fuel capacities.[xii] While direct use of electricity will need to account for over 50% of final energy consumption, up from today's 20%, the entire energy system will not be able to benefit from direct electrification. Hard to abate sectors – such as steel and chemicals, but also overseas shipping and aircraft – will rely on indirect uses of electricity via green hydrogen, hydrogen derivatives, and sustainable fuels such as biofuels. Additionally, a just and inclusive energy transition implies that the benefits of the transition are distributed across regions and societies.

> [...] blended finance is an important tool to make financing accessible.

Due to the international character of many energy commodities and building blocks, international collaboration on finance, knowledge-sharing, capacity-building and standardisation is a key aspect of realising the just and inclusive energy transition. Supply chains for the technologies that are key for emission reductions are often globalised. Geographical regions with cheap and abundant renewables may be in the best position to reduce no- or low-carbon commodities. Established and developing economies can work towards mutually beneficial partnerships to decarbonise supply chains for industrial commodities, based on assisting these countries in identifying their own decarbonisation pathways, and support "high impact" initiatives such as integrated grid planning, system operation, or regulatory reform.[xiii]

For instance, international finance cooperation in alignment with the African Union Climate Strategy in support of the UN Sustainability goals 2, 3 and 7 will be crucial in strengthening overall economic development of the region to achieve a fair and just energy transition.[xiv]

Upscaling and removal of barriers as well as identifying instruments to bring down the cost of capital for EMDE will be crucial to deploy large-scale production sites for these crucial transition technologies.[xv] Amongst others, blended finance is an important tool to make financing accessible, i.e., through "co-financing of projects among multiple parties. On--lending transactions, whereby a DFI (Direct Foreign Investment) lends its low-cost capital to local institutions; and the use of subordinated debt and convertible loans or grants provided by other public or philanthropic sources",[xvi] with a crucial role for local investors. Private business will thus not only need to adapt their business models to a low-carbon energy system but will also play an important role in establishing that system through collaboration with governments and international financing institutions.

Renewable energy related technologies and services are competitive, available and contribute to job growth

The past decade has shown tremendous growth in renewable energy, with renewable energy solutions today being available for almost all energy services. Electrification becomes more prominent not only in railways but also cars, with large potential benefits for the entire power system.[xvii] There are renewable solutions both for buildings and industries via electrification or bioenergy. And for the hard-to-abate sectors - such as shipping and the decarbonization of steel and chemicals - indirect electrification via hydrogen and derivatives such as ammonia emerges as a widely accepted solution, though yet in need of acceleration.[xviii]

> The share of renewable energy in total final energy consumption via direct and indirect electrification would rise to 82% by 2050.

Despite supply chain disruptions-induced cost increase for solar and wind power in some regions, 2021 to 2022 period saw one of the largest improvements in the competitiveness of renewable power in the last two decades due to soaring fuel prices.[xix] In 2023, 473 GW of Renewables were added to global energy generation – which makes a share of 87% of all capacity additions.[xx]

From 2010 to 2021, the renewable electricity generation share increased from around 20% to nearly 28%. IRENA's cost report also shows that the global weighted average cost of electricity from all commercially available renewable power generation technologies continued to fall. For example, the global weighted average levelized cost of electricity (LCOE) from utility-scale solar photovoltaic (PV) projects fell a remarkable 89% between 2010 and 2022, reaching USD 49 per megawatt-hour (MWh), while the cost of electricity from onshore wind declined 69% to USD 33/MWh. Renewables can also gradually contribute to local economic growth and green recovery.[xxi] Renewable energy technologies create jobs throughout the supply chain and can spur broad and sustainable social and economic development, accounting for an estimated 13.7 million jobs worldwide in 2022, a year-on-year increase of 1 million jobs.[xxii] To support this trend and ensure availability of workforce for the energy transition, early and later-life education, re-skilling and capacity building are needed.

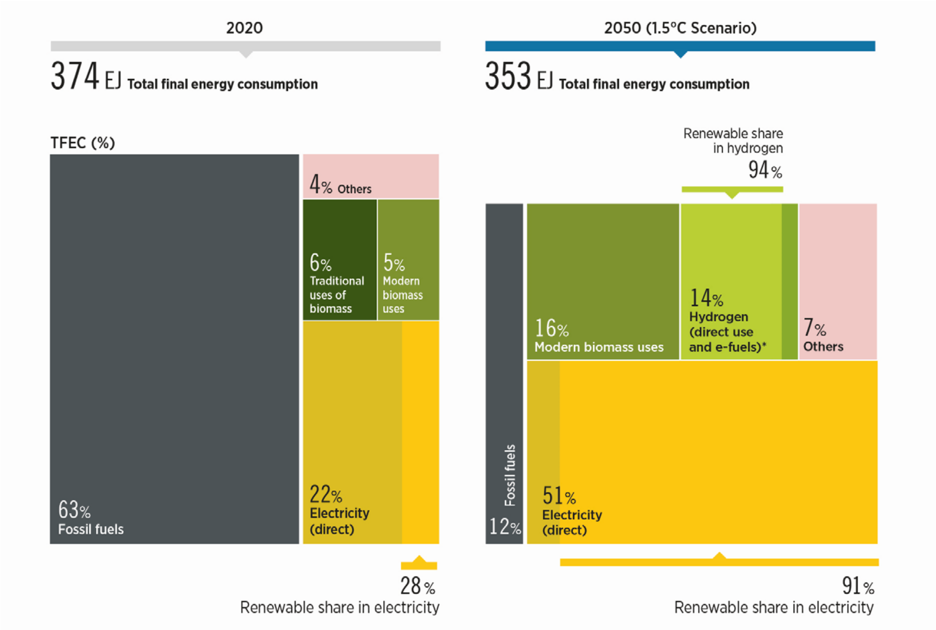
Electrification, hydrogen and bio-energy are business opportunities

Renewables are transforming our energy system as it exists today: According to IRENA's 1.5°C scenario, by 2050, electricity would be the main energy carrier with over 50% (direct) share of total final energy use – up from 22% today. The share of renewable energy in total final energy consumption via direct and indirect electrification would rise to 82% by 2050. By that time 91% of direct electricity needs would be supplied by renewables. Electricity demand, including for green hydrogen production, would nearly triple compared to 2020 and reach circa 75 000 TWh by 2050.

Accordingly, the importance of fossil fuels in the energy mix will decline. The shift away from fossil fuels towards renewable energy will unfold over time, but for certain sectors and countries, this shift can occur swiftly. Currently, fossil fuel operation and consumption (scope 1,2 and 3) is accounting for 55% of total annual CO2 emissions.[xxiii] Under the IRENA 1.5°C Scenario, with an accelerated uptake of renewables, fossil fuel use would drop significantly from 235 EJ in 2020 to 42 EJ

Figure 2: Electricity, Hydrogen - derivates and Bioenergy dominance by 2050:

Breakdown of total final energy consumption (TFEC) by energy carrier in 2020 and 2050 (EJ) in the 1.5°C Scenario (1.5-S)



Breakdown of total final energy consumption (TFEC) by energy carrier in 2020 and 2050 (EJ) in the 1.5°C

in 2050, a reduction of more than 80%. Oil demand would decline significantly by around 85% between 2020 and 2050. The transport sector is already experiencing such changes, notably in the electrification of road transport. However, fossil fuels would still have a role to play, especially natural gas, which would primarily be used in power plants mainly for flexibility purposes, industrial processes and for blue hydrogen production (coupled with CCS).

Many actors in the fossil fuel industry understood the winds of change; major global oil companies have publicly acknowledged through their annual reports and statements that climate change is one of the major threats of our times, and that they have a role in contributing to the energy transition. However, there is not a clear pathway or strategy these companies seem to share, with European and US-based companies adopting different approaches. While efficiency gains and a pushing for low carbon technologies such as CSS are common, Europe-based companies more eagerly proceed towards liquid biofuels solutions, synthetic fuels and also the electricity market via investments in renewable power generation. Eni, Shell and Total become active along the entire electricity supply chain. BP and Equinor[xxiv], are focusing on diversifying their portfolios by including investments in renewables (for instance, solar, wind and biofuels) as well as hydrogen and EVs.[xxv]

Thus, IRENA sees five pathways emerging as future opportunities for oil and gas companies, based on today's expertise and established relationships with other players in the global energy and mobility community:

1. Power generation and offshore technologies

Investments towards electrification may enable oil and gas companies to transform to electricity companies and play a significant international role in the production and supply of renewable electricity, as well grids and charging infrastructure. Every year until 2050, more than USD 1300 billion investments

Every year until 2050, more than USD 1300 billion investments in renewable power capacity and USD 800 billion in grids are needed.

in renewable power capacity and USD 800 billion in grids are needed, plus circa USD 300 billion per year in charging infrastructure for EVs. Wind and solar power have been dominating capacity additions in recent years, with a record of 473 GW additions in 2023, making up 87% of total additions in 2023. This is because renewable power becomes increasingly cheaper than traditional sources. In 2022, the LCOE of solar PV was 29% cheaper than the cheapest fossil fuel option.[xxvi] In addition,oil and gas industries can leverage their knowledge in offshore exploration by transferring this knowledge to the offshore wind industry. Existing infrastructure from the offshore oil, gas and shipping could be upgraded and converted for renewable energy technologies like offshore wind. Approximately USD 280 billion per year of investment is needed in wind offshore alone over to 2050.

2. (Liquid) biofuels

Bioenergy, including solid biomass, biogas and biomethane, and liquid biofuels, would represent 16 % of total final energy consumption by 2050 in IRENA's 1.5°C Scenario, or 135 EJ of biomass primary supply. Biomass can play a role across the energy system by addressing gaps that other options can't fully resolve. A bigger role is expected particularly as feedstock and fuel in the chemicals sectors.

Since primary biomass supply is already

at 56 EJ today, many oil companies have already been investing and gained experience in the field for decades. In 2019, aviation accounted for roughly a tenth of global transport emissions and for 2% of overall emissions. The aviation sector, in turn, was responsible for 8% of global oil consumption. By 2040, the demand for aviation is expected to double from today's levels. This makes aviation not only a priority sector to decarbonize, but also a promising sector for liquid biofuels in the absence of promising electrification options for long-haul flights. Three options could substitute jet fuel in the future: 1) biojet fuel, using fuels produced from sustainably sourced biomass, 2) e-fuels use, using synthetic fuels produced from cleanly sourced CO2 and green hydrogen, and 3) battery-powered small aircrafts with renewables.[xxviii] More than USD 110 billion per year investment for the biofuels sector would be needed over to 2050 to develop the SAF supply chain. Some of the largest players in the sector, including aircraft manufacturers and airlines, are already making investments and partnerships in SAF production. Examples include the memorandum of understanding signed between Air France-KLM and Total Energies for the provision of 800,000 tons of SAF over a 10-year period, more than three times the amount of SAF the whole industry consumed in 2022[xxix].

3. Hydrogen and storage solutions

As global economies strive for carbon neutrality, competitive hydrogen and its synthetic derivatives—such as ammonia, methanol, and kerosene—emerge as crucial components of the energy mix. Hydrogen plays a pivotal role in achieving net-zero CO_2 -emissions in energy-intensive, hard-to-decarbonize sectors like iron and steel production, chemicals, long-haul transport, shipping, and aviation. Additionally, hydrogen and its derivatives contribute significantly to balancing renewable electricity supply and demand by absorbing short-term fluctuations and serving as a long-term storage option to mitigate seasonal variability. In IRENA's 1.5°C Scenario, green and blue hydrogen production is projected to grow from negligible levels today to over 63 EJ per year by 2050, an equivalent to 523 million tonnes. Nearly USD 170 billion per year must go to hydrogen and and related infrastructure over to 2050. Some oil and gas companies have started investing in hydrogen or hydrogen-ready gas-infrastructure, which is one of the new markets in which oil companies could establish themselves using their existing expertise in transporting and selling gas.[xxx] Moreover, hydrogen storage may in the future take up a critical role in the energy system as gas storage does today, thus critically contributing to energy security.[xxxi] This is a field, too, where today's fossil companies can play a role due to significant prior experience.

> **Geothermal will play a supporting role in the energy transition, accounting for characteristics for power system flexibility at later stages of the energy transition.**

4. Geothermal

Geothermal power and heat generation is another good example of the application of existing skills from oil and gas companies in a renewable energy market. Geothermal will play a supporting role in the energy transition, accounting for characteristics for power system flexibility at later stages of the energy transition. As of today, private investors remain hesitant, supplying on three per cent of funding, with the major share coming from public source. Nearly USD 25 billion per year should go to geothermal generation over to 2050, needing substantive commitment from private investors. There is much potential for synergies with other sectors as well as advantages from within the oil and gas sector, i.e., making use of data on sub-surface distribution of temperatures and geological formations, as well as drilling.[xxxii]

5. Carbon Capture and Storage

Carbon removal, storage and usage are areas in which oil and gas companies are already investing today. CCS deployment, mainly for process emissions in industry and blue hydrogen production, and bioenergy with carbon capture and storage, will require over USD 100 billion worth investments annually over to 2050. Carbon capture may allow to reduce emission reductions short term and driving new business fields. While the ambitious expansion of renewable technologies would account for the major share of emission reductions, some industrial processes and areas of transport would still require CCS technologies together with CO2 removal measures, mounting to 109 Gt of CO2 removal from 2023 to 2050. Captured carbon needs to reach 2.2 Gt by 2030 for industrial processes.

Concluding remarks

The global energy landscape will change, and with it, business models will need to change. Global capacity additions in renewables show that these technologies are not only competitive but will – through smart approach and deployment of different technologies – achieve an energy system that could be more sustainable, climate-friendly, secure and affordable than today's, with access to many more people.

Achieving this energy system, however, will require massive investments today, that cannot be born by the public sector alone. Instead, companies particularly from today's oil and gas industries should take advantage of these business opportunities in front of them. Governments need to develop schemes that spur private investments, for instance through blended finance and other instruments tailored to local contexts.[xxxiii] Another important component is the availability of workforce for the energy transition, where governments and private sector need to partner to establish education programs including globally certified up- and re-skilling trainings. These will be important especially in areas where large shares of the working population are in the fossil industries, to ensure the employment benefits of the transition are extended to a wide subset of the population. Such measures need to be embedded in broader regional economic revitalisation programmes and investments.[xxxiv]

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FOOTNOTES

Chapter 2: How much can change? The shape of the energy industry in 2040

[i] Goldman Sachs estimate generative AI could raise global GDP by 7%

Chapter 3: Leader, laggard, champion and challenger. China and the global energy system

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Chapter 6: Super-basin: Delivering the North Sea integrated energy system

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[ii] Source: Wood Mackenzie, Offshore Wind Service. Includes: Belgium, Denmark, France, Germany, Ireland, Netherlands, Norway and United Kingdom

[iii] Source: Wood Mackenzie, LENS Carbon. Project ≥1 million tonnes per annum capacity.

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