ONS 2022 TRUST

ONS Energy Agenda 2022

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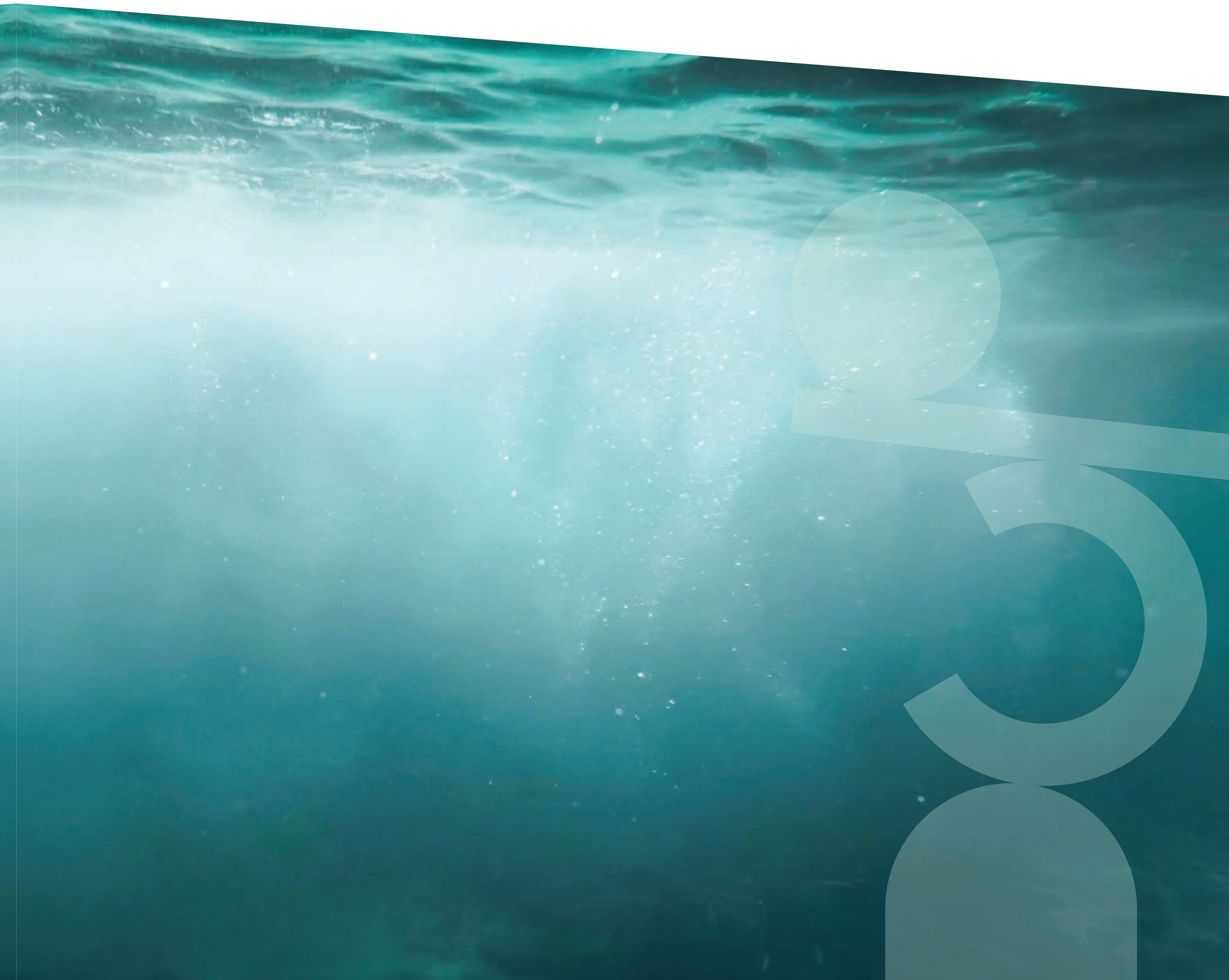

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ONS ENERGY AGENDA

Events over the past year have confirmed the importance of trust to the workings of the global energy market. Without trust it would not have possible to achieve as much progress as was done at the COP 26 meeting in Glasgow. Unless that trust is maintained and strengthened it will be difficult to deliver on the ambitious pledges made at that meeting.

Trust matters too in maintaining open trade in all forms of energy supply and investment. For the last 30 years since the collapse of the Soviet Union both physical trade and financial investment have flowed freely across almost all political borders. That trade has supported both the necessary development of resources and the technology transfers which have made energy supplies available at affordable prices to an ever-increasing number of people across the world. Trade has also supported the first stage of the energy transition – reducing costs and making wind and solar power available even in low-income economies. But part of that trust has now been broken by Russia's attack on Ukraine. In place of an open and functional global market we face a renewed search for energy security. The resulting fragmentation of the market will inevitably produce continuing price volatility with the consequence that some of the world's poorest citizens will face reduced access to affordable supplies.

The chapters in this year's Energy Agenda range widely from developments in Asia – now the centre of gravity in the global energy system - to the emergence of new legal challenges to the role of energy companies and their responsibility for the emissions generated by their products.

The Agenda reflects the diversity of views about the future of the energy sector. There are notes of optimism about the prospect of containing the impact of climate change and a bold view looking back from 2050 on how net zero was achieved. But there are also notes of caution, particularly on the prospects for energy security in a divided world where trust in the major energy producing companies has been diminished. There is also an independent analysis of what all this might mean for Norway – a country in which finds itself at the heart of all the international debates on the energy transition and security.

Given everything which has happened over the last year, a degree of uncertainty is inevitable. We cannot know the future but as many of the articles stress much of that future will be shaped by the choices to be made by those attending ONS 2022 – in their various roles in business, Government, academia or wider civil society.

As an independent foundation ONS takes no collective position. The authors of the chapters in this Energy Agenda speak for themselves. The role of ONS is to stimulate debate, to improve understanding and to provide a platform for open dialogue. This agenda is published in that spirit.

We hope that you will enjoy the articles, even if you do not agree with them all, and we look forward to seeing you in Stavanger at the end of August.


Leif Johan Sevland
Nick Butler

Energy insecurity

BEYOND TRUST – ENERGY SECURITY

We already had the biggest challenge at hand – solving the climate crisis. But when war in Europe and rapidly changing energy politics came knocking on our door this spring everything changed. Where do we go from here, and is all hope lost? ONS asks the questions, and Nick Butler, editor of the ONS Energy Agenda, energy economist and visiting professor at Kings College, shares his insight.

By Nick Butler, editor of the ONS Energy Agenda,
energy economist and visiting professor at King's College, London

Trust is lost.

> The trust which shaped the open international energy market of the last three decades has been broken and will not easily be restored.

The Russian invasion of Ukraine on February 24th provided a sharp reminder of the risks which accompany dependence on imports of commodities crucial to the working of a modern economy. In Europe, and around the world, the search is on for measures which can restore energy security. Few are simple or easily implemented. The energy transition which is beginning will bring its own security challenges – not least the question of access to the limited supplies of minerals crucial in batteries and other parts of the products essential to delivering a low carbon economy. The energy market of the 2020s and 30s will be fragmented, politicized and volatile

Since the collapse of the Soviet Union thirty years ago the world has come to take for granted an open global market in most goods and services. Importers and exporters alike have in the main been able to rely on open trade even for essential commodities, including energy. The ease of that reliance has encouraged a dramatic growth in volumes.

> Oil crude trade last year amounted to over 70 million barrels a day, 50% more than twenty years ago.

Natural Gas trade has grown by almost as much with the development of seaborne trade in liquified natural gas (LNG) now accounting for more than half of the total. Countries such as China, once largely isolated from the international economy have thrived on the basis of ever-growing imports of crude oil up from 1.8 million barrels per day twenty years ago to over 11 mbd today. German imports of gas, mainly from Russia have provided relatively low-cost energy to industrial and domestic consumers. In the circumstances both China and Germany must have felt that the choices they were making made economic sense and posed few political risks. In Europe the construction of infrastructure such as pipelines and power grids has provided a sense of continuity and permanence. All this has discouraged the search for diversity of supplies. Confidence in the open market has also been supported by the argument that trade created a balance of interests which overrode all political differences. Surely neither producers nor consumers could do anything to damage a relationship from which both benefitted.

Until recently experience has justified such complacency. Even at moments of maximum stress in the relationship between Russia and the European Union the flow of gas through the pipelines from Western Siberia has proceeded without any political interruption. The Middle East has experienced one war after another but trade in oil from the region has been largely untouched other than by the sanctions imposed on Iran. The open market has been largely effective in discovering and developing supplies, advancing technology, and reducing costs.

The impact of the war in Ukraine

Over the last six months, however, the situation has changed. The invasion of Ukraine by Russian forces in February 2022 provided the sharpest possible reminder that with trade comes risk. Two distinct risks have already been confirmed by events. Physical supplies to Poland and Bulgaria have been cut because of their unwillingness to pay in roubles. Russian exports to Finland have been cut because of the country's application to join NATO. The Russian decision to cut off supplies to three individual companies unwilling to pay in roubles has put Dutch and Danish supplies at risk. The risk of wider retaliation against those imposing sanctions on Russia or supplying arms to Ukraine remains live and has been heightened by the Russian announcement that supplies to Germany through the NordStream 1 line will be cut for maintenance reasons. This unexpected cut in supplies has led the German Government to press ahead with its emergency plans including potentially the introduction of rationing. In May a UK Government report concluded that up to six million UK consumers would face blackouts if Russia were to cut off all gas exports to Europe.

A second risk which has already become real is that importers largely dependent on a single source of supplies have found themselves funding the very war they oppose at prices which the war itself had helped to push up. According to EU foreign policy chief Josep Borrell by the end of May Europe had paid €35 bn to Moscow for energy supplies since the war in Ukraine began.

In the longer-term high prices could mean that Europe, as a major energy importer, will find its industrial base losing international competitiveness. The economic impact of what has happened is likely to grow if Europe fulfils its pledge to reduce oil and gas imports from Russia and finds itself desperately competing for resources in a global market where few spare supplies are available in the short term.

The distrust extends to investors. Companies such as BP and Shell had trusted the regime in Moscow sufficiently to make major investments in the development of Russian resources – investments which they have now been forced to write off. They and many other western investors will not be rushing back to Russia, even if some form of cease fire is established in Ukraine.

Events have forced a renewed focus on energy security - a topic largely neglected over the last decade during which the prices of oil, gas and renewables had all fallen dramatically. The age of plenty is over, and the trust and open trade which shaped the world cannot easily be re-established. The central question now is how energy security can be restored.

The pursuit of energy independence

The initial short-term response to the loss of security has been a revival of the concept of self-sufficiency. If trade cannot be relied upon, nations must reduce their dependence on imports by producing more at home. Different countries have identified their own distinct paths to self-sufficiency. In Germany Robert Habeck, the Vice Chancellor and Minister for for Economic Affairs and climate action has promoted the development of renewables with 2 per cent of Germany's land area to be devoted to onshore wind projects and a new network of hydrogen supplies to be created over the next decade at a cost of € 9bn. The German government has also expressed support for the development of gas resources through joint German/Dutch venture in the North Sea.

In the United States, which is largely self-sufficient in energy the challenge for President Biden focuses on rising global prices and their impact on American consumers. His response has been to encourage additional production – internationally from countries such as Saudi Arabia and at home by opening up federal land in the US for oil and gas exploration reversing a policy on which he won the Presidential election just two years ago.

In the UK the Government has used the threat of increased taxes on windfall profits to push the oil and gas industry to invest more to develop the remaining resources of the North Sea. The targets for offshore wind capacity have been raised by 50 GW by 2030, along with an aspiration to build 24 GW of new nuclear plants capable of meeting around 25 per cent of UK electricity needs by 2050.

President Macron has committed funds to the renewal of the nuclear sector despite the persistent delays in the construction of EDF's first new generation reactors at Flamanville in Northern France and Hinkley Point in the UK. 14 new nuclear facilities are to be built in France by 2050.

In each case the language of policy has focused on independence from the volatility of the world market, and on government intervention to promote new supplies.

The common thread across all these countries has been the push to electrification with the sources of the additional power dependent on national circumstances and preferences. Germany for instance will not embrace new nuclear but onshore wind, clearly the lowest cost source of additional home-grown supplies, is favoured with planning regulations likely to be softened to overcome opposition from local communities.

Beyond energy independence

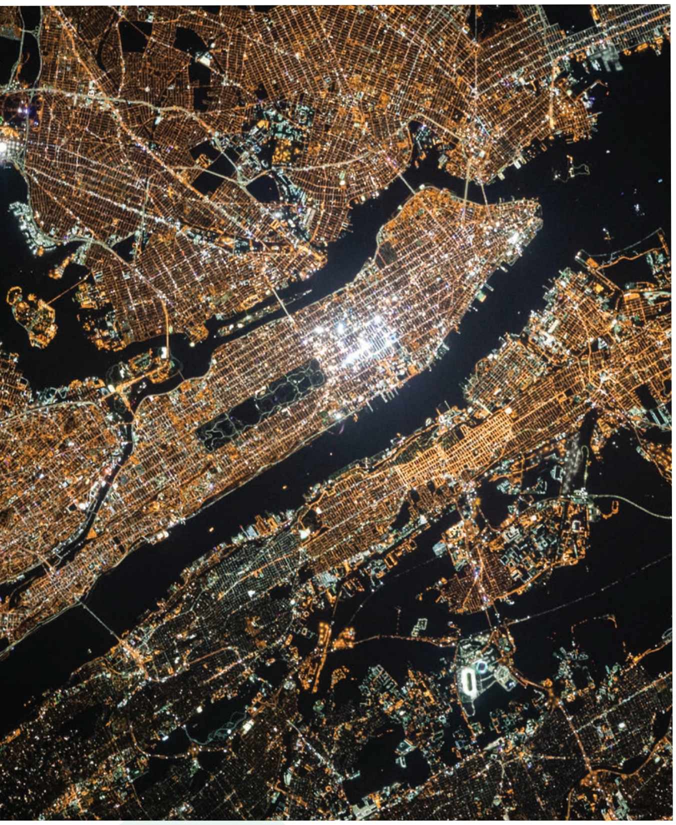
The search for independence and self-reliance will no doubt continue but for many countries full energy independence will remain an impossible goal. For the moment the reliance on oil and gas for transport and in much of industry remains strong. Across Europe 94 per cent of the energy needs of the transport sector - from cars and freight lorries to ships and aircraft are met by hydrocarbons. In Germany natural gas remains the main supplier of energy to industry. Electrification is possible for some activities such as light road vehicles. For other activities such as heavy industry, electrification is still only a remote possibility and will require further advances in technology and serious reductions in costs.

In the short-term oil and gas remain essential to the European economy and with domestic sources of supply, such as the North Sea, in decline that means a continuing requirement for imports.

The challenge is not restricted to Europe.

China is a leader in much clean energy technology from long distance grids and electric vehicles to batteries where the country accounts for over 90 per cent of total global production and electric vehicles. Despite all these achievements, however, China remains dependent on oil imports now running at over 11 million barrels per day. As China grows, with the middle class set to rise from around 300 to 800 million by 2035 under the terms of the most recent five-year plan that level of dependence can only grow. Over the last year Premier Xi has encouraged increased use of coal as the main source of short-term energy supply needs with the removal of import duties. Electrification will grow and wind, solar and nuclear capacity is expanding. For the moment, however China remains dependent on hydrocarbons and on imports.

Many other emerging economies find themselves in a more difficult place. Across Africa and much of Asia coal remains



the dominant source of energy supplies particularly in power generation. Beyond some initial wind and solar projects few countries have the financial resources or technical ability to invest in other forms of low carbon supply in the short term and will face rising import costs.

The case for an energy NATO

If full energy independence is unattainable for most countries the logical response to the loss of security is the creation of alliances of neighbours and political allies to share supplies, for instance through fully connected gas and electricity grids, along with agreements which pool resources if any particular country finds itself in need. This approach is at the heart of the proposals put forward by the European Commission which include an extension of budget limits to allow investment and the creation of a common buyer structure for gas. Beyond these initial steps a true collective solution to energy insecurity is likely to require participation by countries which have their own resources of oil and gas and are prepared to share those resources when necessary. It is not inconceivable that a full-scale international energy alliance could include countries such as Kuwait or Qatar. Both could consider that their long term political and economic interests lie with Europe and the United States rather than with OPEC.

This approach depends critically on trust – in particular the belief that participants will put the collective interest above national needs in times of stress.

In some ways such a defensive alliance can be compared to the NATO security alliance created at the end of the 1940s.

An energy NATO need not follow the same geography. As well as the US and Europe an energy alliance might include the countries of Central Asia with their extensive oil and gas supplies, Ukraine which could provide substantial volumes of power from wind and solar as well as biofuels and Israel which holds large volumes of undeveloped gas in offshore fields beneath the Eastern Mediterranean. Comparable trading alliances could be created in Asia building for instance on the existing Japanese links to Australia and the Indian proposals for a power linking the Gulf states to India and other parts of South Asia which could be extended to South East Asia.

State to state deals

Increased local production and enhanced regional partnerships are both part of the solution to energy insecurity but will not be the whole story. Specific state to state deals in which energy supplies form one part of wider relationships involving financial, political and security support already account for a material share of global trade. The best current examples of this are Chinese links to Venezuela, Angola and Iraq and India's deals with Russia on oil and nuclear and with Middle Eastern oil producers including Iran.

The return to state to state transactions will not be limited to Asia. Even as the European Union was preparing its collective response it was clear that individual countries were reaching out to create bilateral deals. Germany's renewal of links with Qatar has secured increased LNG trade between the two countries which will begin as new floating LNG facilities are put in place around a number of German ports. Italy has initiated a bilateral gas trade deal with Algeria.
At the same time state to state transactions are attractive to producers as well as importing countries. If Russian energy trade to Europe is severely reduced as now seems likely Russia will be looking for every opportunity to build a new set of trading relationships with countries in Africa and Asia.

In many cases these bilateral links will be managed by private energy companies restoring the role they held a century ago as the agents of national energy security, but now working both for buyers and sellers.

The energy market transformed

The result of the various security led initiatives now being taken will profoundly change the energy market.

Much of the future trade in energy will be government led. Energy security is too close to national security and too important for modern economies to be left entirely to the open market. Individual deals will be private with the prices of the traded oil and gas opaque and dependent on the specific nature and scope of each transaction. The links between China and Venezuela for instance involve extensive Chinese loans as well as other physical trade and wider political support for the current Government in Caracas.

In this environment open trade will become a residual element of the market, making spot markets more volatile and putting countries who remain outside what could become closed trading relationships at a considerable disadvantage.

The impact of heightened insecurity on

the parallel challenge of climate change remains uncertain. The loss of Russian supplies has transformed the economics of the oil and gas industry, making many previously marginal undeveloped fields viable, so long as investors believe that prices will remain high. The production of US shale oil has grown by 720,000 bd in the first half of this year. Projects such as the development of Shell's Jackdaw field in the North Sea are now being brought on stream. In Asia coal consumption has surged over the last year as a low cost alternative to imported natural gas, with the result that Asian benchmark coal prices have tripled. If energy security requires fossil fuels in the short term the longer-term impact looks likely to be more favourable to the climate agenda in both Europe and Asia.

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Electrification is the new priority and although some sectors remain beyond reach there is now a reasonable expectation that electricity's share of final energy demand could double in the next twenty years with large scale wind and solar providing a low cost alternative to both gas and coal.

The impact of the transition to low carbon on energy security

The energy transition is not in itself a solution to the challenge of energy security. As an important paper from the International Energy Agency makes clear key elements in the energy transition require substantial increases in the use of minerals including Lithium, Nickel and Cobalt. Electric vehicles use six times more minerals than conventional vehicles and onshore wind facilities use nine times more than a comparable natural gas facility. The energy sector will become a key consumer of minerals, including rare Earth elements such as Neodymium and Praseodymium, with demand potentially doubling by 2040.

Supplies of many of these minerals are concentrated with China the main supplier of at least six of the most important minerals, followed by the Democratic Republic of Congo. Processing facilities are also concentrated. Matching the agenda of decarbonisation to that of human rights and strong labour standards will not be easy. Cooperation in securing the necessary supplies and in research to identify substitutes and to enable substantial recycling of scarce minerals could provide another task for a collaborative energy security agency.

The imperative of cooperation

The climate agenda as a whole of course relies on global cooperation. National and even regional efforts are necessary but can never be sufficient.
A clean Europe in a dirty world would be a pointless achievement.
Despite the apparent progress made in Glasgow genuine cooperation remains elusive. Tensions over the different approaches to climate issues will become more important as the challenges of climate change become more obvious. As

> A clean Europe in a dirty world would be a pointless achievement.

Europe pursues it's ambitious objective of net zero at a material cost to consumers including businesses ever more attention will be paid to the areas where emissions are still rising.

The proposed European Carbon Border Adjustment Mechanism, designed to protect European industry from the risk of activity being displaced to countries with lower environmental standards and objectives could become a vehicle for trade conflict. If the objective of CBAM is to encourage lower income countries to identify ways in which to decarbonise, direct investment in such activities and technology transfers might provide be a more constructive approach.

Energy and politics remain inseparable

Energy security is a geopolitical issue as events in Ukraine have shown. The insecurities involved can be managed through cooperation but they cannot be eliminated. The world's reliance on hydrocarbons will persist for some considerable time to come. But even as that reliance is balanced and eventually overtaken by the transition to a lower carbon world the concentration of resources – of hydrocarbons and of the minerals required for decarbonisation - will ensure that energy security can only be restored if there is cooperation between nations. Until trust is restored energy security will remain fragile with trade and investment restricted and the energy market fragmented and volatile.

Climate change

IS THERE STILL HOPE FOR LIMITING GLOBAL WARMING TO 1.5 DEGREES?

The gap between aspirations and reality. COP26 set high ambitions for the delivery of net zero but by the time ONS 2022 kicks off it will be clear that the transition has barely begun. Oil, gas and coal use will still be meeting 80% of global energy needs – and potentially rising – as the global economy tries to move on from a Covid-induced recession. Emissions will be on track to produce 3.5 degrees of global warming. What can be done to change course? What are the realistic prospects for reaching peak global carbon emissions? Jarand Rystad, CEO of Rystad Energy shares his thoughts, and the data to back it up.

By Jarand Rystad, CEO, Rystad Energy

There is apparently a huge gap between the "current track" that will lead to 3.5 degrees of global warming and the COP26 ambition to limit global warming since the industrial revolution to 1.5 degrees Celsius. So, which trajectory should we expect? The high end of the range, the mid-point or the low end? What evidence should we look for that will enable us to take a stance on this important question?

In Rystad Energy we are investigating all aspects of the current energy system and the energy transition ahead. We look at the status of key technologies and policies that will be needed to deliver on the 1.5-degree ambition. We also use data pertaining to the historical speed of change to provide an evidence-based forecast of how the situation is likely to develop going forward. All things considered, we end up with what could be seen as an optimistic view – that the 1.5-degree ambition is still within reach – and that it is highly unlikely that global temperatures will rise by 2.0 degrees or more. In the following few paragraphs, we lay out the evidence that leads us to this conclusion.

> [...] we end up with what could be seen as an optimistic view – that the 1.5-degree ambition is still within reach.

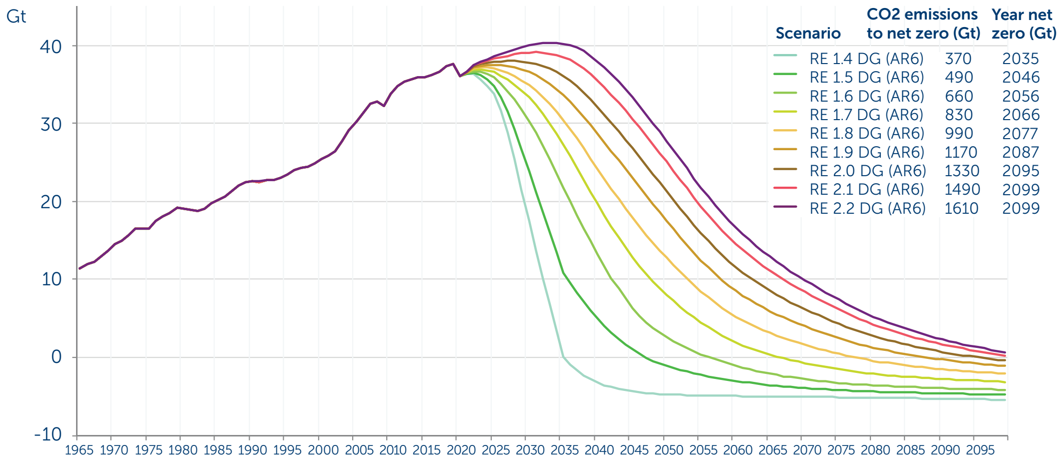
The speed of change

Our starting point is from the carbon budgets spelled out in the IPCC report from 2021, called "The Physical Science Basis". The report lays forth carbon budgets for 12 different scenarios – ranging from 1.3-degree global warming and rising sequentially by 0.1 degree to reach a maximum scenario of 2.4 degrees. These budgets are based on the historical observations that global warming has caused temperatures to rise by 1.07 degrees when comparing the average for the period from 1850 until 1900 versus the average for 2010-2019, and that total human-induced CO2 emissions have reached 2,390 gigatonnes (Gt). Another observation is that this relationship is linear.

The IPCC then conducts a straightforward calculation, concluding that every 1,000 Gt of CO2 emissions produce 0.45 degrees of global warming. Based on this fact alone, one can deduce that there is a remaining budget of about 1,000 Gt to generate the additional 0.45 degrees of global warming that will bring us to a 1.5-degree rise in temperature. However, the IPCC elects to reduce the budget by around 500 Gt to compensate for emissions since 2015, the so-called earth system feedback (methane from tundra and more) and non-CO2 forcing (methane, nitrous oxide and other GHG emissions) after net zero CO2.

1.6 DG GLOBAL WARMING LIKELY AND 1.5 DG WITHIN REACH IF NET ZERO IS ACHIEVED BY 2056 OG BEFORE

Global CO_2 emissions 1965-2100



Source: Rystad Energy "Energy Scenario Cube" version Sept 12th 2021

For the mean case (the 50th percentile), the resulting carbon budgets start at 150 Gt for the 1.3-degree scenario and rise sequentially by 150 Gt with each scenario, reaching a maximum of 2,050 Gt of CO2 for the 2.4-degree scenario.

Rystad Energy has examined the speed of change that would be required in the energy system in order to reach net zero emissions between 2055 and 2075, with associated CO2 emissions of between 600 and 1,000 Gt. This implies that the solution window for global warming is 1.6 degrees to 1.8 degrees, based solely on the IPCCs CO2-budgets. Should notable improvements also be achieved within other greenhouse gases in coming years, there would be an upside to the global warming levels indicated here. This upside was acknowledged during the COP26 summit through the methane pledge, targeting a 30% reduction of human induced methane emissions, which was stated to reduce global warming by 0.2 degrees. Other upsides have also been identified. Given these observations, what will it take to land at the emission levels indicated above?

Decarbonization of the power sector

First, we need to see decarbonization of the power sector, bearing in mind that it will take over for fossil fuel in supplying end users. Electricity will increase its share of the energy carrier segment from 20% to 60% by 2050. The key driver of the decarbonization of the power sector is, quite simply, cost. Solar and wind power stand not only as the most sustainable source of electricity, but also the cheapest, even when including the cost of storage that will be needed to back up the intermittent nature of these sources. By 2030, the cost of storage will likely be less than 25% of the cost of generation. Solar and wind power also provide the energy security that all nations are seeking these days, as the acreage used in most cases will be under domestic control.

The solar PV industry would need to achieve annual deployment of 1,100 gigawatts (GW) of new generating capacity by 2030 in order to reach the 1.6-degree scenario, while the 1.8-degree scenario would require 400 GW of deployment by 2030. By comparison, 160 GW of capacity was installed last year, whereas solar PV manufacturing capacity stood at 400 GW. We now observe that all major solar PV manufacturing companies are in the process of expanding their capacities significantly. Despite temporary supply chain capacity limitations, there is good visibility indicating that 600 GW of annual deployment can be reached by 2026.

Thus, the 1,100 GW deployment level needed in order to realize the 1.6-degree target seems to be within reach by 2030. Similarly, for wind turbine deployment, 300 GW and 110 GW of annual deployment must be reached by 2030 for the 1.6 and 1.8-degree scenarios, respectively. The supply chain for wind turbines seems capable of delivering on the upper end of this range, and acreage could be made available for these turbines, including vast growth within the offshore wind sector.

Decarbonization of the transport sector

Another necessary step is the decarbonization of the transportation sector. For the 1.6 and 1.8-degree scenarios, respectively, our models show that 70% and 42% electric vehicle (EV) penetration for new

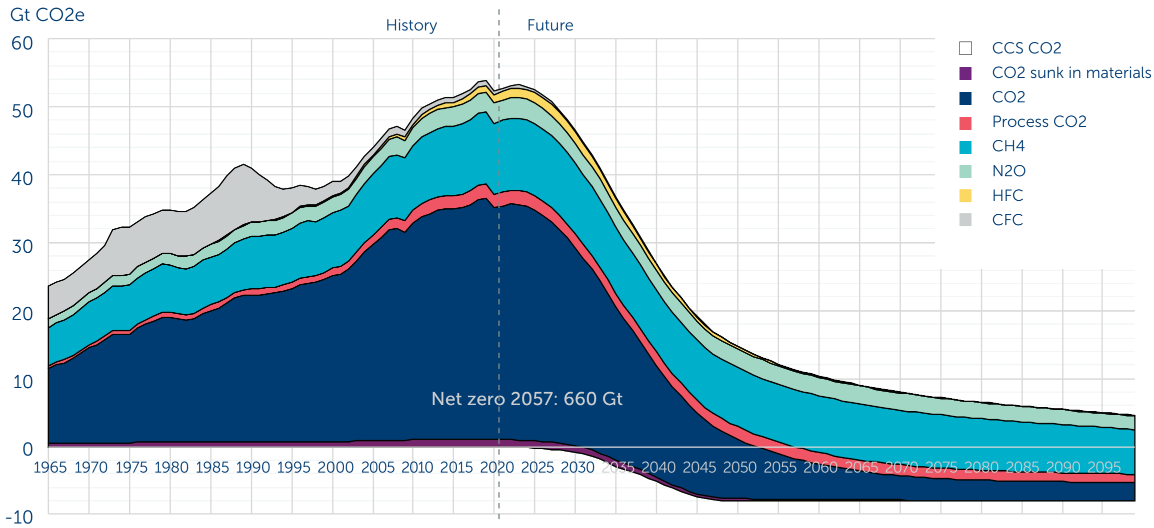
> […] there is good visibility indicating that 600 GW of annual deployment can be reached by 2026 [PV].

sales of passenger cars is needed by 2030. Over the past two years, the global share of EVs has surged from 2% to 13% of new sales, and is now restricted only by the supply chain, with customers queuing up to trade in their piston engines and go electric. EVs now offer lower lifecycle cost of ownership in most geographies. This will be the main driver behind an S-curve development for EVs, delivering a global share of new sales closer to 70% than 42% by 2030. We also need to see decarbonization of buses, motorcycles, trucks, rails, ships and aviation, in that order, which is likely to happen over the next three decades – through electrification, hydrogen, ammonia, biofuel and e-fuels.

Furthermore, we need to see decarbonization of the buildings sector. Quality of life will improve through more cooling, more space and higher service levels. Still, emissions will be reduced by 80% by 2050 through a combination of energy efficiency and substitution of fossil fuel. Rooftop solar, rooftop hot water, heat pumps, electricity and hydrogen will replace much of the coal, gas, oil and traditional biomass currently used in the buildings sector.

GLOBAL GREEN HOUSE GAS EMISSIONS, INCLUDING CARBON CAPTURE AND STORAGE

Man-made GHG emissions in the 1.6 DG (AR6) scenario, by Greenhouse gas



Source: Rystad Energy Energy Scenario Cube Sept 2021 – 1.6 DG (AR) scenario

The industrial sector and CCUS

We also will need to see a decarbonization of the industrial sector, where three key drivers have generated plenty of optimism. First, we see that secondary sourcing of raw materials will grow in all industries, as more materials will be recycled, and annual production will thus represent a smaller share of accumulated historical production. Secondary steel, aluminum, pulp and other raw materials require only a fraction of the energy needed by primary processes. This, together with energy efficiency, will reduce the per-unit energy consumption level considerably. Second, new processes have been invented using hydrogen or other low-carbon fuels as reduction agents. And third, the rising implementation of carbon capture is reducing emissions in the processing stage, for instance in the cement sector, stimulated by technology advances and policies.

Finally, carbon capture, utilization and storage (CCUS) is taking off, with multiple capture and injection projects currently underway. The volumes are still relatively small, but technologies are maturing and will scale as policies are implemented to punish all point sources of CO2 emissions. In our scenarios, we see CCUS growing to 475 megatonnes (Mt) by 2030, 3,600 Mt by 2040 and 7,800 Mt by 2050, thereafter remaining steady for the rest of the century.

In short, our analysis shows that net zero could be reached between 2055 and 2075 with technologies already identified, and with new innovations representing an upside to this range. With the non-CO2 upside mentioned above, the 1.5-degree target is still within reach even if the CO2-target slips. The 1.8-degree scenario appears to be a conservative estimate representing the downside of the technology and policy advances mentioned above. In our view, predictions of global warming surpassing of 2.0 degrees do not reflect the reality on the ground as exposed through current technology and policy trends.

The future of gas

A QUESTION ABOUT SUPPLY GAP

When everything seems up in the air, and new energy policy and goals are written every day, what role will gas play in the energy mix? Affordable, flexible, available and with lower emissions than other fossil fuels, but still not really wanted by many. But as Europe pushes forward due to both security issues and climate change, the situation is quite different around the world. Senior Vice President and Chief Economist, Head of Global External Analysis in Equinor, Eirik Wærness, describes different scenarios for the future. Common for them all – a supply gap.

By Eirik Wærness, Senior Vice President and Chief Economist,
Head of Global External Analysis in Equinor

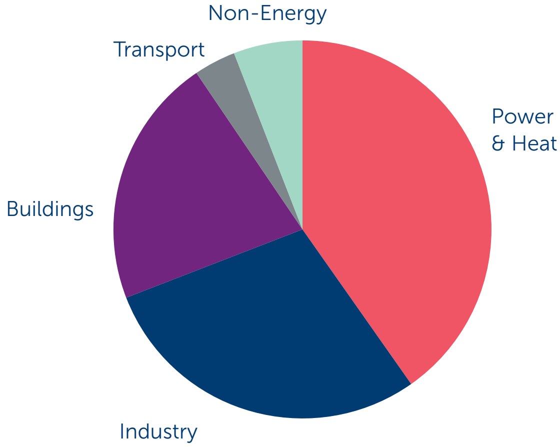
Natural gas constitutes around 25% of global primary energy demand. Over the last 50 years, use of natural gas in our energy systems has increased significantly – the world now demands almost 4 times more natural gas than in 1970. Annual growth has been 2.8% on average, compared to growth in overall primary energy demand of 2%. In an energy system that is 2.7 times larger than in 1970, gas has grown in importance relative to oil (which is "only" 1.8 times larger than in 1970) and coal (2.5 times larger).

Gas is a very versatile source of energy that is used for many purposes. 40% of global gas demand is used in the power and heat sectors, where gas meets competition from the largest source of power and heat generation, coal, as well as from many other energy sources, increasingly also from new renewables. 19% of global gas demand is used in different industrial processes, while 15% is used directly in office and residential buildings for heating and cooling. Gas is also used in the transport sector and as direct input in the petrochemical industry. This complex set of sources of gas demand, and the multidimensional competitive space, entail that the future of gas depends on the development in many different industries and energy sectors, as well as the development and costs of other energy sources, especially in the electricity sector.

Sustainability requires energy supply and demand that address the trilemma of affordability, security/resilience, and low carbon in a balanced manner. The tragic war in Ukraine has clearly illustrated that concerns other than low carbon has risen in priority, dictating decision-

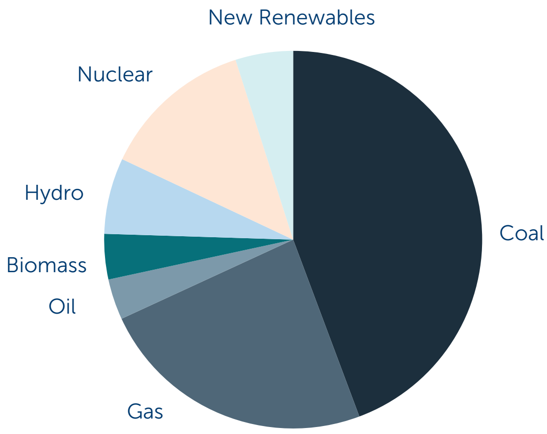
GAS DEMAND IN 2019

Gas demand was 4,000 bcm, with 1,600 bcm going to power & heat



POWER & HEAT FUEL MIX

Gas is 24% of the fuel supply for the power & heat sector

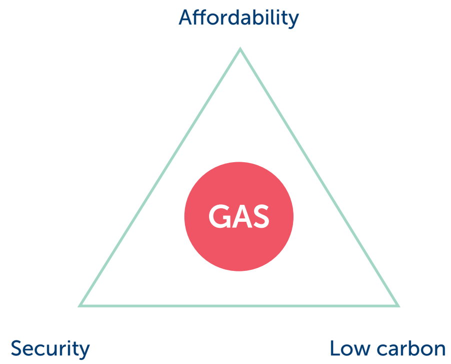


Source: IEA

making that is likely to influence the speed of the energy transition.

As a starting point, gas is generally well positioned in the energy trilemma: Gas resources are ample and geographically dispersed, even if Europe's dependence on Russian gas has become very evident as Europe now targets to wean itself off it. Gas can be stored and serve as a flexible, dispatchable fuel for power and heat production, and as such be an important co-player with renewables in the efforts to reduce the carbon content of electricity generation. In a situation where the resilience of our energy systems is questioned by the combined growth in electricity demand and increased share of intermittent renewables, gas becomes valuable. And estimates indicate that vast resources of gas exist globally, at reasonable extraction cost levels, e.g., in North America, providing the foundation for affordability.

However, given the regional differences in gas balances, gas is also, like oil and some of the minerals needed for the energy transition, exposed to geopolitical interference in security of supply. In a situation where Europe has not invested sufficiently in storage and depends on Russia for close to 40% of its gas supply, political conflict leads to a significant reduction in the security of supply and affordability of gas. Similarly, natural gas' characteristics in terms of delivering on low carbon depends on how supply chains are set up to handle methane leakages and exports of associated gas to avoid flaring, and what energy sources gas is replacing in the different regions where it is used. And finally, affordable availability of gas is challenged in a situation with insufficient investments in supply and infrastructure. The "generally" good position that gas possess in the energy trilemma is therefore very situation dependent.



What does the future hold?

No one really knows. But some things are reasonably certain:

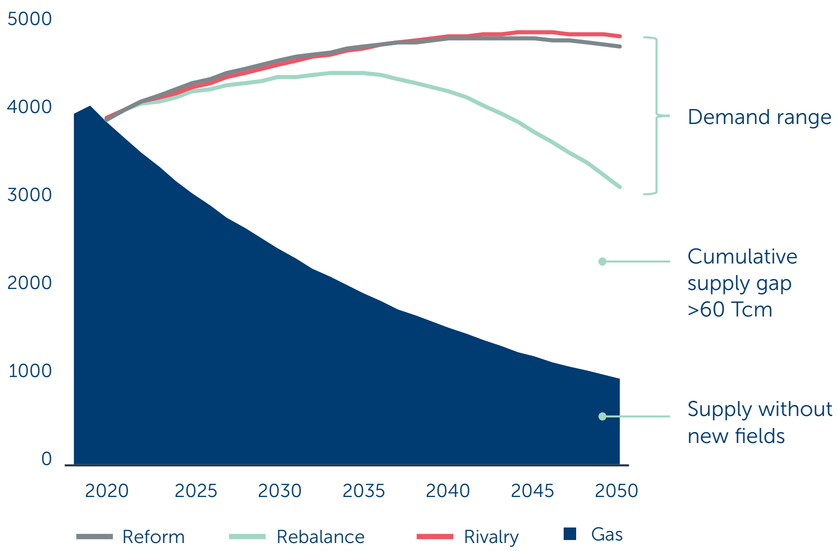
- Over the next decades, we will be 2 bn more people, and possibly 3 bn more have entered the global middle class, as measured by consumption patterns and habits.
- Demand for energy services associated with those consumption patterns will grow massively.
- Electricity will be a much more important part of our energy mix, due to its fantastic characteristics in terms of varsity in use, energy efficiency, and small external effects when being used.
- New sources of electricity will be intermittent and with low marginal costs, so flexible backup, storage and sufficient infrastructure capacity will be important, as will changes in market design ensuring investment incentives.

- Technology improvements, cost development and policy will combine to drive the energy mix in a more efficient and low-carbon direction – but it is very uncertain whether the Paris Agreement ambitions and targets will be met.
- Even with significant growth in electricity, molecules will remain an important part of the energy mix. These will increasingly be low carbon such as hydrogen and biogas, but replacing oil and coal entails a large room for natural gas as well, either directly or as a source of low carbon hydrogen and ammonia.

Based on different assumptions for economic growth, energy efficiency, technology and cost developments, and energy and climate policy, projections for gas demand development going forward vary significantly. In Equinor's Energy Perspectives 2021, the outcome space for global demand to 2050 ranged from a decline of some 20% in the Paris-aligned Rebalance scenario (but where demand grows by 13% to 2034, before starting to decline significantly) to a growth of 20-25% in the Reform and Rivalry scenarios, respectively. The Rebalance scenario is a "well below 2D" scenario, but not a net zero emission scenario consistent with 1.5D global warming. The Rivalry scenario builds on assumptions of lack of cooperation, geopolitical conflict, sanctions, and trade issues resulting in lower economic growth and moderate penetration of technology – much like what we have seen over the last years (but not assuming outright war in Europe). The Reform scenario is a "middle of the road" scenario assuming benign geopolitics, continued economic growth, and significant tightening of energy and climate policies.

GAS DEMAND AND SUPPLY FROM EXISTING FIELDS

Bcm



Source: IEA, Equinor

Irrespective of scenario, demand will stay much above supply from existing fields, meaning that significant investments in new production capacity will be needed. Currently, according to IEA, investments in new oil and gas supplies are consistent with what is needed if the world develops according to their 1.5-degree NZE scenario. That is not the case, so we are heading for an energy squeeze, which we saw the start of during 2021.

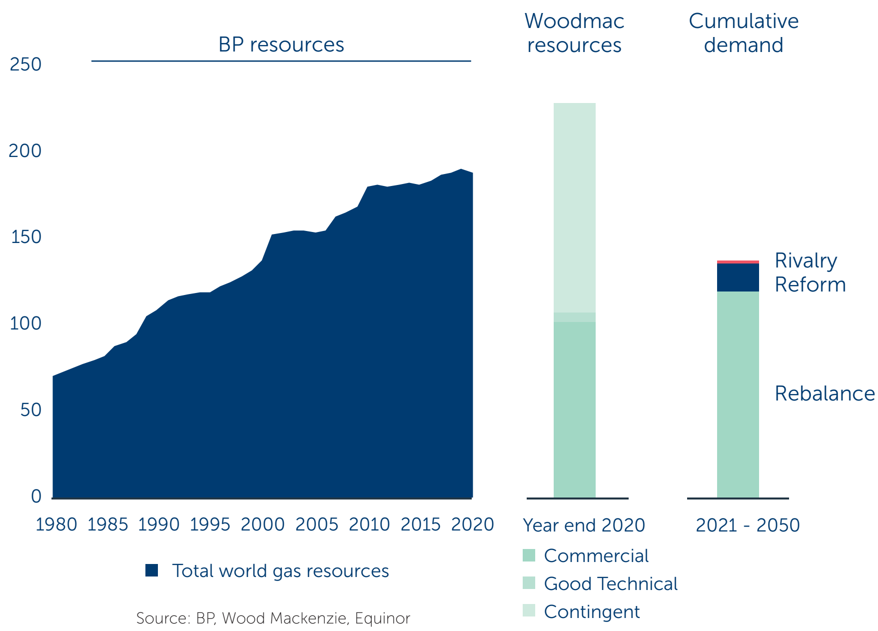
There is enough gas around the globe to satisfy demand in these different scenarios in a competitive, affordable manner, but investments are needed. Technical and commercial challenges will affect timing and costs of such resources reaching global markets. Recent developments also illustrate very clearly that geopolitics will play a role in terms of facilitating, or hampering, development of resources that can be transported and traded between regions.

The regional balance for gas, with supply surpluses in North America and CIS*, and deficits in Europe and Asia, as examples, also entails that transport, LNG, distance to markets, etc. are issues that will affect market prices and affordability. In the current geopolitical situation, we also clearly see how security of supply issues and lack of resilience in energy systems can become acute in markets depending on a regional supplier.

The European discussion on the future of gas takes as a starting point that gas demand will decline. This is consistent with the development in all the scenarios in Energy Perspectives 2021, where European gas demand declines between 27 and 65% from 2020 to 2050. This is important and significant, especially for Europe and suppliers of gas to this region. However, in a global context, the scale and direction of the European demand development is less important. In

GLOBAL REMAINING GAS RESOURCES AND TOTAL CUMULATIVE DEMAND

Tcm



Source: BP, Wood Mackenzie, Equinor

* Commonwealth of Independent States – Armenia, Azerbaijan, Belarus, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, Uzbekistan.

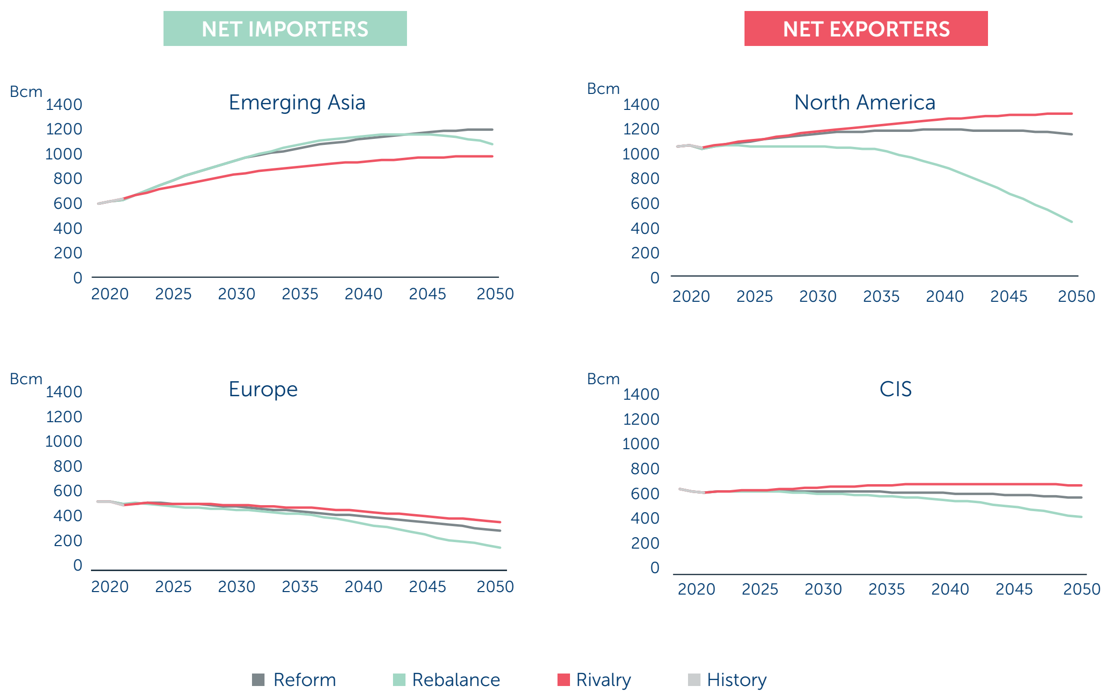
Emerging Asia, where demand in 2020 was some 20-25% higher than in Europe, demand grows between 57 and 90%. In the Paris-aligned Rebalance scenario, growth in gas demand in Emerging Asia is around 460 bcm, or 90% of current European gas demand. So, when evaluating the future of gas, a global perspective is important. The largest region for gas demand currently is North America. Depending on the scenario drivers, gas demand in 2050 here varies significantly, from 440 to 1320 bcm, a decline of 57%, or an increase of 27%. Given the massive gas resources available at reasonable costs in North America, development in local/regional demand and policies on natural gas exports to other regions will be very important for the availability and prices of gas delivered to import regions across the globe.

The role of gas in the energy transition

The global energy system is large and growing, providing energy services to a growing and gradually more affluent population that becomes more mobile

REGIONAL DEVELOPMENTS IN GAS DEMAND VARY DISTINCTLY ACROSS SCENARIOS

With implications for interregional gas trade



Source: IEA, Equinor

and has lifestyles requiring constant access to more and more advanced energy services. At the same time, the use of fossil fuels, which constitute 80% of the primary energy needed to run this vast machine, entails emitting unsustainable volumes of CO_2 into the atmosphere. So, the energy system must radically and rapidly transform to ensure lower emissions while continuing to provide increased deliveries of energy services.

This energy transition will entail a shift away from capital intensive, inefficient, and polluting use of energy. For this to happen with impact and speed, there is a need for a combination of alternatives that are scalable, available, affordable, and reliable, on the supply side as well as on the demand side of the energy system. These alternatives only exist in part or in patches but are fortunately holding the promise for future growth in scale and decline in system costs. Transforming the energy system will therefore require massive efforts, demand massive investments and proper policy frameworks and entail continued reliance on current dominant energy sources and energy-demanding equipment for decades to come. Replacing a lot of current primary energy sources while allowing for growing demand for energy services will take time. So will replacing all the capital equipment that depends on these primary energy sources, such as steel furnaces, ship engines, jet engines, car engines, cooking facilities in billions of homes, power stations, and district heating systems. There will therefore be a substantial role for the least polluting and most flexible source of fossil fuels for decades, even if the energy transition speeds up. This role will be played by natural gas.

Furthermore, the role of natural gas will continue to be important as a balancing source of stored energy in combination with renewables, dispatchable at short notice in electricity markets characterized by increased intermittency and volatility. Over time, gas coupled with carbon capture and storage will contribute to carbon-free electricity 24 hours a day, 365 days a year, in competition with batteries and other electricity storage. This role for gas in the electricity system will continue to be important and valuable, providing electricity when it is most valuable for consumers.

Providing energy 24 hours a day for 365 days a year is challenging. Especially when energy demand keeps growing. Or when investments in infrastructure are lacking. Or when the source of energy is located far away from where demand is and depends on decisions taken far away. Or when the output of the energy supplying infrastructure cannot be controlled. Or when natural variations in demand and supply over the day or the season are unsynchronized.

The future of energy will be more electric. And it will be more intermittent, so the need for infrastructure capacity, backup, storage and flexibility of both supply and demand will increase. The resilience of the system and security of supply therefore call for multiple sources of supply. Given its availability in many regions, its flexibility and its usefulness in many different sectors, gas will fill a crucial role in the energy system of the future.

As part of the energy transition, and because we cannot eliminate the use of molecules to provide energy services any time soon, natural gas in combination with carbon capture and storage will be the fastest way to clean fuels like hydrogen and ammonia in the "blue" version of these fuels. Successful development in these areas, assisted by targeted changes in energy and climate policies across the world, will contribute to building the markets for these fuels in manufacturing, heating, and cooling, and transport. Starting with existing gas supply chains and infrastructure, the possibility exists for a gradual transition to blue hydrogen and ammonia as carbon capture and storage chains are built out and gas/fuels customers transform their energy-using capital equipment to use the new blue fuels. This will then serve to incentivize development of gas resources to future gas supplies for blue hydrogen and ammonia value chains, facilitating sufficient line of sight for investors to make the necessary investments for decades of energy supplies, even in a situation where there is uncertainty about the long-term viability of investments in unabated natural gas. In turn, these markets for "blue" fuels will stand ready to buy the "green" versions of the same fuels if and when we reach a state of surplus renewable electricity.

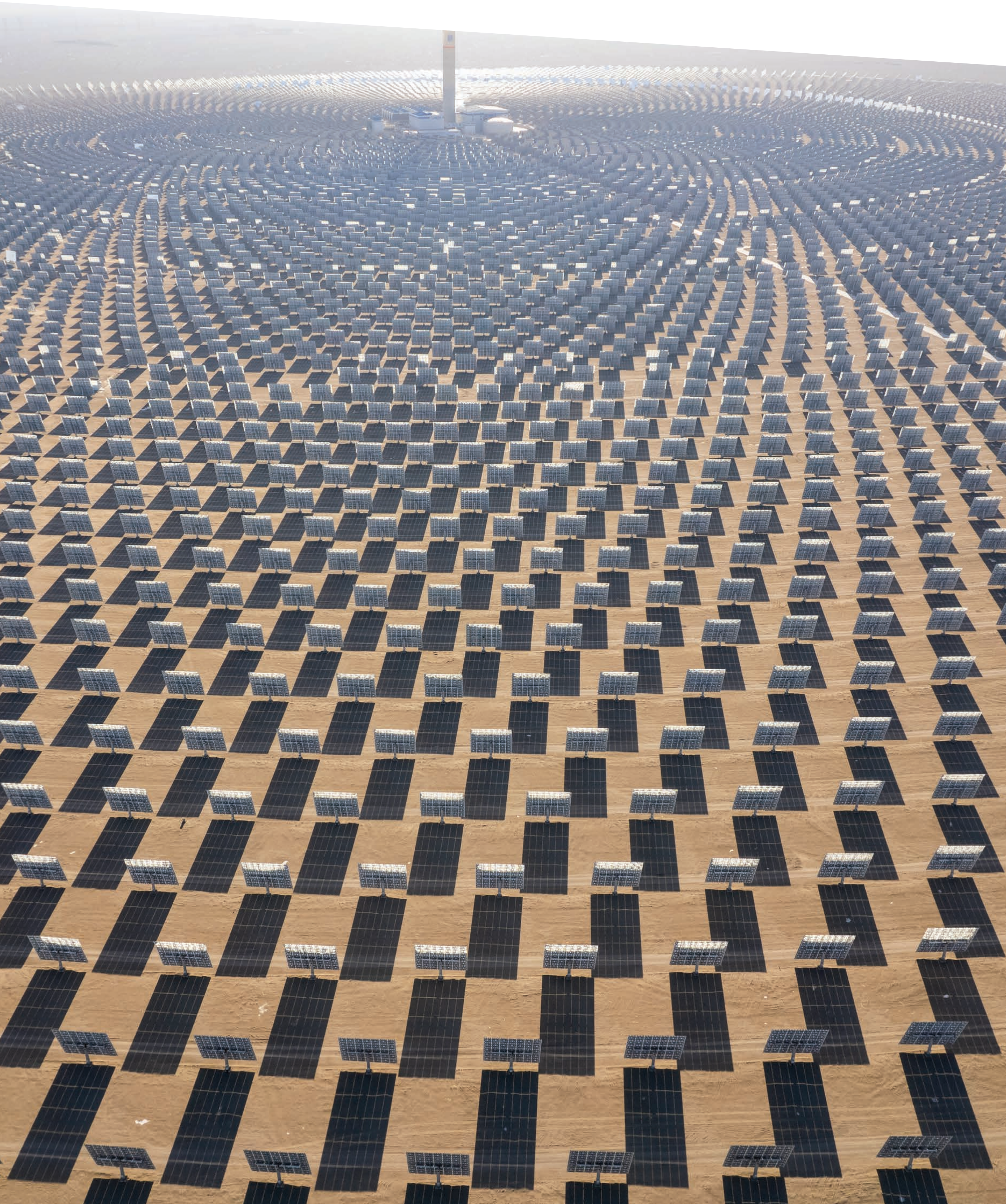
"The energy transition" has become a common phrase. However, there is not one, but many possible transitions or transformations of the global energy system. THE energy transition that we most often discuss is the combination of fuel changes and efficiency improvements that deliver on one of the 17 sustainability goals, that of addressing climate change by limiting greenhouse gas emissions to a carbon budget consistent with limiting global warming at 1.5 degrees above pre-industrial averages. THIS particular energy transition is a massive challenge that is unlikely to be materialized completely over the next decades. This is partly because of the necessary speed of change, where each year's result is disappointing, partly because of the need for changes across many elements that cannot be controlled by any central planner with good intentions, and partly because of the need for a globally, coordinated approach towards this goal, to some extent at the expense of other important and legitimate goals. Furthermore, the challenge of providing affordable, clean, secure and reliable energy to an energy-poor and growing population (one of the other sustainability goals that is often overlooked), makes this particular energy transition even more challenging.

While the long-term goal of limiting greenhouse gas concentration to sustainable levels stands firm in global discussions, the last years have demonstrated that other important and legitimate concerns also dominate developments and policy, which in turn makes the achievement of the carbon emissions goal more difficult. Lack of trust, deglobalization, protectionism, sanctions, short-termism in politics, ensuring economic growth, fighting the COVID-19 pandemic and other drivers are factors that in different ways slow down THE energy transition.

Most likely, therefore, the ACTUAL energy transition will be slower than required to attain climate goals, less efficient than ideally envisaged, and with less global reach than hoped for. Still, we will probably see a massive transition of the global energy system, moving us in the right direction in terms of lower emission intensities and improved energy efficiency. In a version of this transition where we deliver as much good as feasible, even if we do not achieve the best theoretically possible, natural gas has a lot going for it, in terms of availability, costs, flexibility, environmental consequences, and emission levels compared to current alternatives and considering future opportunities for becoming carbon free. What the exact level of natural gas demand will be, is impossible to predict. Which is why Equinor, and others develop scenarios with different outcomes.

However, it is a robust prediction that natural gas will play a crucial role in the global energy system also in 2050.

Hammerfest LNG plant at Melkøya. Foto Harald Pettersen/Equinor



Better Believe It:

ASIA IS THE NEW HEART OF GLOBAL ENERGY

So, what if Europe manages to reduce emissions and reach net zero fast? The main part of the global population lives far away from Brussels, and the amount of energy consumed in Asia every day is in ranges a Northern European hard could fathom. But does it bring forward possibilities we haven't really thought of, and will the realization of Asia's significant role ever really sink in farther west? Narendra Taneja, energy expert and commentator and Chairman of the New Delhi think tank, Independent Energy Policy Institute, certainly provides food for thought in the following chapter.

By Narendra Taneja, energy expert and commentator and
Chairman of the New Delhi think tank, Independent Energy Policy Institute.

"Asia's $350 Billion Gas Buildout Stirs Energy Debate. Region's projects are triple the investments planned in Europe."
Bloomberg, June 15, 2022.

"France's TotalEnergies SE and (India's) Adani Group have agreed to invest $50 billion over the next 10 years in India to produce green hydrogen and develop an ecosystem around it as they seek to cut their reliance on fossil fuels and transition to zero net carbon emissions."
Hindustan Times, June 15, 2022

"China and India added 136 GW (gigawatts) and 15.4 GW renewable power capacity respectively in 2021, together overtaking many countries in the Western world last year."
A media report quoting the REN21's renewables 2022 global status report.

More such reports are emanating from Asia than ever before, asserting its arrival as the new heart of global energy growth, activities and events.

The reason is simple: Most countries in the region are expanding economically rapidly, driving the demand for every source of energy up and further up. Unsurprisingly, therefore, energy players and corporations from all over the world are gravitating to Asia to make higher sustained profits from new opportunities and, even more importantly, to secure their own long term future as a business. "The present is here in Asia. The future is also here. I have in fact temporarily moved my global headquarters to Singapore and Dubai," the CEO of an American energy multinational energy services company told me recently.

Centre of gravity has shifted

Yet, many in the Western world are not able to recognise this historic development: that the global centre of gravity as far as energy is concerned has already shifted from the Atlantic region to Asia, or, as the majority of geo-strategic experts prefer to identify it, the Asia-Pacific region.

Asia comprises of the fast growing and most populous economies, like China, India, Indonesia, Bangladesh, the ASEAN countries, South Korea, Japan and Saudi Arabia, to name a few. Expand it as the Asia-Pacific: the immensity is mind blowing, ranging from the vast Indian Ocean to the Pacific, including the United States and Canada.

However, the rise of China –– or, rather the "belligerent" China –– has, geopolitically speaking, unfortunately, divided Asia into two informal blocks, with Beijing and a few others on one side and Japan, India, Australia, the United States and other democracies of the Asia-Pacific region on the other. This may still be a work in progress, but, fortunately or unfortunately, Asia is fast splitting into camps: with the smaller one anchored by China, and the other, bigger one led by the USA and comprising mostly democracies, including India, Japan and Australia. For most, therefore, Asia now has many names, including the Asia-Pacific and the Indo-Pacific, depending on convenience or even belief and ideology.

While China has branded itself as the Belt and Road Initiative (BRI), with the energy sector at its core, across Asia and beyond, the democracies have dubbed themselves as the Indo-Pacific group, with the United States as the chief anchor. They recently even formed the Indo-Pacific Economic Framework, or IPEF, which has energy cooperation at its core.

BRI or IPEF, the fact remains that it is all happening in Asia, only further strengthening the region as the new global gravity centre as far as energy is concerned. Countries such as Iran and Pakistan may benefit from BRI, but it is IPEF and other similar initiatives, which will eventually draw in the majority of Western democracies, and which has more potential to further enhance the role of Asia as the undisputed global energy capital of the world.

In any case, it will be a mistake to look upon the BRI or IPEF dissensions in Asia as something cast in iron. The ambiguity and overlapping interests and shadows will always be there in abundance. For

> [...] to say that Russia will always be on the side of China in this new great Asian game will be a mistake.

instance, to say that Russia will always be on China's side in this new great Asian game would be a mistake, because there is a huge trust deficit between Moscow and Beijing, especially when it comes to the massive hydrocarbons reserves in the remote Eastern and offshore regions of Russia.

The need for energy – and the size of it all

There is no dearth of experts in and out of Russia who claim that the economically and militarily more powerful China might, someday in future, want to cut the mineral rich eastern Siberian away from mainland Russia. Similarly, to expect that democracies like South Korea and India and fiercely independent countries like Vietnam will have no energy ties with China –– or for that with Russia –– whatsoever will be a mistake. The Asia of tomorrow may look Red (under the Chinese influence) and Blue (the US zone of influence) on the surface, but "swing powers" like India will focus more on carving out their own areas of energy, economic and political influence in the evolving multipolar world.

Geopolitics apart, it is the sheer size of the need for energy that is transforming Asia into the new powerhouse. Many experts estimate that Asia is still home to over 1.3 billion energy poor, meaning the people who can not afford or do not have access to more than a few electric lamps and a basic television set and a very limited supply of cooking gas, mostly liquified petroleum gas. Per capita energy consumption in many Asian countries is among the lowest in the world, making energy poverty a hot political issue in most South Asian countries and beyond.

However, most energy companies, Asian and global alike, look upon the widespread energy poverty as an opportunity. "Because this is Asia, unlike some other geographies, the hunger for economic growth, the hunger for energy here (is) unprecedented in human history," a European economist associated with the Manila-based Asian Development Bank told me, requesting anonymity.

Just a quick glance at the size of some of key Asian economies is enough to grasp

the full story: the GDP of China is $17.7 Trillion; Japan's is $5.06 Trillion; ASEAN countries' $3.2 Trillion; India's $2.76 Trillion; and South Korea's is $1.7 Trillion. Asia is also home to the largest number of energy consumers on the planet: 4.6 billion. Fast growing economies, rising demand for energy and market dynamism are what makes it the most desired destination for anyone and everyone in the global energy business, from oil and gas to renewable to technology developers to hydrogen innovators, bankers and so on.

Today, China, India, Vietnam, Indonesia and Bangladesh are amongst the brightest economies in the world, showing an ever growing appetite for a better quality of life and, therefore, for more energy. China and India are already the second and the third largest consumers of oil globally. Their demand for natural gas is growing at a rapid pace. India alone will have in total of 15 LNG import terminals by 2030, if not sooner. China, Pakistan, Myanmar and Bangladesh are also building more such terminals. The Arabian Sea, the water body between India and eastern Africa, is fast emerging as the future "LNG Lake."

India is also fast emerging as a world leader in renewables, thanks to multiple policy initiatives on the part of the Indian government, including the New Delhi and Paris-anchored intergovernmental International Solar Alliance. Billions are being poured into building new nuclear power plants all across, from China and India to Bangladesh and the United Arab Emirates. There is hardly any country in Asia which has not already announced ambitious plans for hydrogen. There are also plans to wire up the entire continent with a power grid. There is now a growing realisation, even at the level of the ordinary citizen, that there is no safe future without first mobilising a sufficient amount of energy. The people want more energy –– conventional or unconventional. The level of energy consumption is the new barometer of prosperity, even in remotest areas, a rather new development in this part of the world.

The dragon and the elephant

However, eventually, what happens in China and India, the two most populous countries on the planet, often called the Asian rivals, will determine the future of the continent's energy universe.

> [...] China and India, together with Indonesia, probably, will be enough to sustain Asia as the global energy gravity centre for decades to come.

China and India enjoyed the highest share in the global GDP from 1 AD to 1820s AD, according to celebrated British economist Angus Maddison. Nationalists in the two countries are desperate to get their lost economic glory back. Several new studies, including one by international consulting giant PwC, project China and India to reclaim their status as the largest economies on the planet by 2050. China's phenomenal growth story is already well known. India –– despite her habit of moving three steps forward, one step backward like a dancing elephant –– is projected to average 5 per cent growth in GDP over the next three decades, overtaking the United States as the second largest economy in the world by 2052. It is a no brainer that these countries have already emerged as the biggest guzzlers of energy. In other words, China and India, together with Indonesia, will likely be enough to sustain Asia as the global energy gravity centre for decades to come.

However, challenges are aplenty. Most large Asian economies are energy deficit. India imports 85 per cent of its total requirement of oil. The country's dependence on imports for solar panels and cells for its booming renewable sector is as high as 90 per cent. China's dependence on imports for oil and gas is the stuff of energy folklore. The story is no different for South Korea and Japan or Pakistan and Sri Lanka in South Asia.

> Many in Asia, including this writer, are, however, sceptical and would prefer Asia to take a lead in setting up rather an altogether new world organisation for energy,[...]

In spite of their size and prowess, China and India still have little influence in the global energy governance, that is, if there is anything like global energy governance. Oil producers have their own captive tiger, namely OPEC, to hunt for and protect their interests. Rich countries have their International Energy Agency, which has managed to lure China and India in as Associate Members –– meaning no real place in the decision making cockpit as such –– as part of its suspected ambition to become the global inter-governmental body on energy. Many in Asia, including this writer, are, however, sceptical and would prefer Asia to take a lead in setting up rather an altogether new world organisation for energy, preferably headquartered in New Delhi, Shanghai, Singapore or even Sydney.

Unfortunately, Asia still lacks the diplomatic and marketing skills needed to construct new energy narratives and push them through successfully across the world, a skill that is available abundance across Western Europe and the United States and Canada. Unsurprisingly, therefore, almost all narratives on energy –– and the climate –– in circulation globally have originated in the OECD and are allegedly designed to protect its interests first and foremost. It will, however, be in the rich Western countries own interest that they co-opt Asia and work together to build a new and more just world energy order for a safer future for all.

Big Asian oil importers like Japan, China, South Korea and India have for years talked about forming an OPIC, or Organisation of Petroleum Importing Countries, but to no avail so far, mainly because the energy world view of China and India is less compatible than required for such a project to come into existence. OPEC, too, understandably, does not want any such idea to come to fruition.

The condemnable Russian invasion of sovereign and democratic Ukraine has, however, forced many energy strategists to revisit issues such as energy security and economic security. There are suggestions that big oil and gas importers such as India should consider opening dialogues with neighbouring energy giants like Saudi Arabia and Qatar to build some kind of energy security mechanism on the lines of the QUAD, that is, Quadrilateral Security Dialogue mechanism between Australia, India, Japan and the United States. The energy markets and supplies disruptions have jolted energy-deficit economies, including the four QUAD countries, like never before.

The core fundamentals and structures of most Asian economies are robust. No Asian democracy wants the United States and the countries of European Union to get bogged down in and over Ukraine. They want an early resolution of the Ukrainian crisis. They want Ukraine's sovereignty fully restored. They want bigger and wider American and European participation in the Asian energy arena for their own growth and energy and economic security. China is, arguably, the big elephant in every energy room in the Asian democracies.

Participation by Western companies in Asian efforts to meet the dual challenge of climate and energy transition is crucial. Most Asian oil and gas companies, including CNPC and CNOOC of China and the New Delhi-based ONGC and Indian Oil Corporation, have already begun investing heavily in rethinking and reworking towards a newer and greener future. However, for a bigger and deeper change, the rich countries must deliver on the promises made in the Paris and Glasgow climate summits in terms of funds and technology transfer.

Despite the unequalled disruptions caused

by the Covid onslaught, and now by the Ukraine crisis, Asian energy policy-makers and players are more invested in their aspiring future plans than anything else. They have no time to dwell indefinitely over what they have lost since the Covid first hit the world. The hustle and bustle continues at the headquarters of energy corporations across Asia, from Mumbai to Beijing to Jakarta.

If the growth of energy companies in China, India, Indonesia, Vietnam and others countries of the region in the past ten years is any indication, most large energy corporations of the world in 15 years from now will either be Asian or be making most of their money in Asia. The Sun is truly rising in the East.

Welcome to the new cockpit of the world's energy universe.


CLIMATE
JUSTICE
NOW!

The pressures for climate action

CLIMATE – THE NEXT BATTLEGROUND WILL BE IN THE COURTS

What happens when climate activism is becoming a new normal, and protesters are tired of not being heard? Sophisticated methods of sounding the alarm and pushing for change are appearing, and new tools such as finance and the law are being explored in full. But what happens when the battlefield moves into the courtroom? ONS asks the questions, and Nick Butler, energy economist and visiting professor at Kings College, shares his insight.

By Nick Butler, editor of the ONS Energy Agenda,
energy economist and visiting professor at King's College, London

The challenge of climate change is unresolved. Declarations of intent about net zero have not yet changed the pattern of energy use. The use of hydrocarbons looks set to grow for at least another decade, and possibly longer. Emissions continue to rise and evidence of their impact grows. The situation is inherently unstable. The energy industry, already distrusted, is likely to bear the brunt of the increasing sense of risk and frustration. Now, however, debate has moved into new territory as campaigners seek to attribute liability for any damage done. The battleground has moved into the legal system. This may not resolve the climate challenge but could fundamentally change the industry.

2022 is proving to be a year of disappointment for those who believed that with COP26 the world had taken a major step forward in combatting climate change. The meeting in Glasgow, however successful in its own terms, did not alter the inconvenient facts about the world's use of energy or halt the growth in emissions from the use of hydrocarbons. By the end of 2021 emissions had resumed the upward trend interrupted by the pandemic and were back above the levels of 2019. 2022 is likely to see emissions rise again.

This year emissions are being pushed up by the increased use of coal in Asia as economic activity recovered after the pandemic. Growth this year has been further increased by a switch from natural gas to coal driven by the sharp increases in global gas prices. Sanctions on Russia will further increase prices over the next year as Europe fulfils its commitment to reduce imports of Russian oil and gas and is forced to compete for supplies in a market which is already tight with only limited spare capacity. Fears of a shortage of supply coupled with high prices is encouraging new development of both oil and gas around with Governments in Europe and North America pushing companies to increase investment. Around the world from the Eastern Mediterranean to East Africa to the US shale producing regions such as Texas and North Dakota additional production of hydrocarbons is likely to be brought onstream in the near future.

The age of hydrocarbons is far from over

Renewables, led by wind and solar are growing and providing an increased share of demand, with reduced costs making them more economic even if the costs of intermittency and the requirements for back supplies are taken into account. But wind and solar still account for less than 5 per cent of final energy consumption across the world and the world energy mix remains dominated by hydrocarbons.

In 2021 over 80 per cent of global energy consumption was accounted for by coal, oil and natural gas – the same percentage as in 2001. Fossil fuels still account 80 per cent of energy consumption in Germany and the UK – both countries which like to consider themselves client leaders. In Europe emissions are likely to continue to decline as they have over the last twenty years but Europe accounts for only 10 per cent of the global total and any reductions achieved will be easily out weighted by the emerging economies of Asia.

At the global level although the mix should now slowly begin to change there is little sign of the use of hydrocarbons peaking when measured in absolute terms.

Climate Change remains an unresolved challenge

The result is an inherently unstable situation. We already see extreme weather conditions and rising concerns about substantial areas becoming uninhabitable. Commitments to net zero have not in most cases been matched by detailed funded plans for the transition required. There is yet no clear path to climate safety. As the physical impact of climate change becomes more obvious frustration at the lack of progress is likely to cause conflict between countries moving at different speeds and between campaigners and the energy industry.

Protest campaigns will no doubt continue and will be focused on companies who continue to develop and sell hydrocarbons despite the fact that they have accepted the reality of climate change and the dangers associated with the use of fossil fuels.

The challenge to the energy industry

For the industry such campaigns have become the new normal – with all the associated costs in terms of security and diminished reputations. Several, led by the energy majors located in Europe – including BP, Shell and Equinor have begun to diversify away from oil and gas and to develop new low carbon supplies. Some have limited new oil and gas exploration activity and have made specific commitments to raise the low carbon share of annual capital expenditure over the next decade – a process which will be set back by the current demands for more oil and gas development to replace supplies from Russia.

For the moment however the overwhelming majority of capital expenditure is still devoted to hydrocarbons. The industry's transition to a low carbon world has begun but the pace of change is not likely to satisfy campaigners.

Street protests and disinvestment have had only a limited effect. Campaigners are therefore seeking more sophisticated means of achieving their goals – taking the challenge to the companies involved in the sector and putting in jeopardy their fundamental business model. Their tools are finance and the law.

The new dimensions of climate activism

The financial challenge to the fossil fuel sector has grown steadily in both scope and scale over the last decade. The challenge consists of both a carrot and a stick. The

positive side is exemplified by the offer of access to capital for decarbonisation as set out in the Glasgow Financial Alliance for Net Zero which brought together over 250 financial institutions responsible for $ 80 trillion dollars in assets. The stick is based on the work of the Task Force on Climate Related Financial Disclosures established after the Paris meeting in 2015. Seven years on in the words of Mark Carney 'virtually the entire financial sector demands TCFD disclosures and over 2000 major companies around the world are responding'.

The legal challenges

Alongside these financial steps an increasingly active legal campaign has been established over the last few years. According to the authoritative analysis produced by the Sabin Centre for Climate Law at Colombia University over two thousand cases are being pursued through courts around the world on different aspects of climate change, over 1300 of which are in the United States at federal and state level. In Europe the case which has attracted most attention was the judgment of the district court in May 2020 in The Hague which ordered Royal Dutch Shell to reduce its global carbon emissions by 45 per cent from the 1990 level by 2030 and insisted that the company was responsible for emissions from its suppliers and customers.

> [...] over two thousand cases are being pursued through courts around the world on different aspects of climate change

The legal challenges are supported and coordinated by groups of legal specialists such as Client Earth – an environmental charity working in 50 countries and committed to using the law 'to protect life on Earth'. As with the financial challenges the scope and scale of the legal issues being raised has grown and is now entering territory which poses fundamental risks to the established energy industry, including the international oil and gas companies.

The question which brings together the legal and financial issues is that of liability – can the companies who provide and sell oil and gas be made liable for the danger done to the environment and to particular communities by climate change?

The issue raises complex and so far, unresolved questions of causation and responsibility. Can the heat waves which damage health or cause drought which hits crops be attributed to the use of oil or gas produced by one international oil company or another?

In one of the best known continuing cases a Peruvian farmer, Saul Lusiano Lliuya, backed by environmental groups, is challenging the German energy company RWE over its long term contribution to emissions and to the damage done to his home community in Huarez which is threatened by the prospect of a glacier lake overflowing. In another case the local authorities in San Francisco, Oakland County and other areas in California have sued multiple oil companies over the damage being done by rising sea levels.

All the issues raised by the numerous legal actions will be vigorously defended by the companies who will argue that they were acting within the law at all times, but their case is jeopardised by the fact that they have acknowledged the reality of climate change and the contribution to emissions made by human activity through the burning of fossil fuels.

The possibility of new legal action

The legal position has yet to be resolved but the possibility that laws can be changed to incorporate the concept of liability is real. Individual national governments or US state authorities could decide to pass new legislation which attributes some share of responsibility for damage resulting from climate change and therefore a proportion of the costs, to the energy industry. The strength of green opinion in areas such as Germany and California could provoke a change in the law imposing liabilities which if not retrospective could be tied to future corporate activity with the action of continuing to produce and sell such products to be judged as an act of knowing, wilful damage.

> Investors in particular will be more wary if the possibility of a successful legal claim has to be factored into corporate valuations.

The impact of the issue of liability casts a shadow over the energy industry even before any legal judgments are made. The possibility of liability being applied in the future adds to the sense of unsustainability which characterises the industry today. Investors in particular will be more wary if the possibility of a successful legal claim has to be factored into corporate valuations. The nagging and growing concern that the assets they believe they hold could turn into liabilities implying vast payments to innumerable claimants will discourage long term investors.

The parallel with tobacco industry is tempting but inadequate. The consequences in the energy world would be much more profound. Oil and gas are more important than cigarettes and as the last few months have shown us the continuity of secure supplies is inextricably linked to economic activity and geopolitics.

The irony of the current situation is that the new challenges to the role of oil and gas sector come just their importance has become more obvious. Events in Ukraine have reminded the world of the importance of energy security and of the industry on which that security depends.

Reliance on hostile or unstable regimes for supplies of essential resources carries risks. If supplies from offending countries cannot easily be replaced, sanctions and trade restrictions can rapidly become acts of economic self harm.

The risks involved have served to demonstrate the value and importance of the energy businesses, particularly the oil and gas majors who alone have the capacity to deliver supplies from multiple sources. Their role and function as agents of energy security has been re-emphasised echoing the history which saw many of the companies develop in the 20th century as extensions of the national interests of their home states. In the UK in 1914 Churchill, as First Lord of the Admiralty bought a crucial stake in BP six weeks before beginning of the First World War to secure oil supplies for the Royal Navy. In the 1970s Statoil – now Equinor – was created by the Norwegian government to ensure that the resources of the North Sea would be treated as a national asset.

Now in the 2020s the reality is that the oil and gas industry is needed but not wanted.

The exit of few – and a power hand-over?

The exit of any or even all of the major companies from the sector would, however, do little to alter the climate equation. Total demand for oil is unlikely to fall significantly below current levels over the next twenty years.

The major privately owned European and American international oil companies account for only 15 per cent of current production. Even if they all chose to drop

> Now in the 2020s the reality is that the oil and gas industry is needed but not wanted.

out of the oil market the resulting demand would soon be picked up by others. OPEC and other producers would be more able to manage production to sustain relatively high prices – effectively imposing a resource rent tax on consumers.

For obvious reasons the targets of the legal actions promoted by Client Earth and others do not include Saudi Aramco or the leading Russian energy companies such as Rosneft. They and the many others typically state-owned companies who provide the bulk of current oil supplies will remain immune to legal action and will benefit financially as they continue to supply a world which has not moved away from oil and gas. A successful legal campaign could remove some producers from the market but would hand over power and trade to those least likely to support the energy transition. That is hardly the best definition of climate justice.

Changing corporate structures

WHO WILL BE THE WINNERS IN A CARBON NEUTRAL ENERGY SYSTEM?

Traditional ways of doing business in oil and gas does not necessarily work when embarking on renewable energy projects. But how do companies adapt, and who will end up as winners in a carbon neutral system? Johannes Wiik, Phd, and Nordic Lead Partner Energy Resources and Industrials in Deloitte, highlights some of the game-changing corporate structures we see appearing in the energy industry.

By Johannes Wiik, Phd, and Nordic Lead Partner
Energy Resources and Industrials in Deloitte

With increasing pressures to limit global warming, the energy industry is undergoing rapid change. Value chains that have delivered value, economic prosperity, and wealth for decades and even centuries are being fundamentally reshaped, more so than in the previous transition from coal and steam to oil and gas. Whilst fossil fuels, most notably natural gas, will stay with us for a very long time, the growth of other areas will destroy old business model and create new ones. A fundamental question is, who will be the winners? There is probably not a single, clear answer to this, but we can break it down to try to understand how new winning business models can be shaped.

1. What are key dilemmas energy companies and various stakeholders have to deal with?

2. How is the energy structure changing as a consequence of low carbon world, and what are the potential implications for business models?

3. How can new winners be shaped?

> " To any complex problem, there is an answer that is clear simple and wrong ."
>
> -H L Mencken

Key dilemmas

Whilst pledges, regulation, maturing technology, ESG, societal pressures and other drivers all move us towards a lower carbon world, it is certainly not a linear process. These and other forces are reshaping the relative balance between priorities for various players, and we constantly see a battle between cleaner energy and other priorities. To name a few, we have:

- Clean energy/low margin vs high margin/fossil energy.
- Clean energy versus affordable energy.
- Clean energy versus energy security.
- Clean energy versus other sustainability goals.
- Clean energy versus tax income.
- Clean energy vs job creation.

This is not an exhaustive list, but it does illustrate the point that to any complex problem, there is an answer that is clear simple and wrong. Used wisely, recent crises such as covid-19 and the war in Ukraine, can build significant momentum for clean energy long term. Fortunately, renewables energy is by its very nature much harder to weaponize, and as a consequence caters very well for energy security provided it is economical and sanctioned in sufficient volumes by regulators.

Potential business implications of the change in energy mix

The structure of the future energy industry is very much dependent on how energy demand and supply will change in tandem towards cleaner energy system. There are many forecasts and normative scenarios for how, how much and how fast the energy mix will change, but the direction of travel is clear. As an example, BP Energy Outlook for 2022, describes several scenarios with different pace of change towards a lower carbon world. Fossil fuels share of final consumption will drop from around 65% in 2019 towards 30-50% in 2050. Electricity will increase from around 20% in 2019 to 30-50% by 2050. The most extreme changes indicated the net zero scenario.

In very simple terms, to create a long term carbon neutral world will mean:

1. Electrification of everything
2. Alternative clean fuels in hard to abate sectors
3. Negative emissions

What may be the potential business implications for changing in this direction?

Electrification of everything

Electrification will mean rapid growth in renewable energy. The cost curves for solar, wind, and battery technology have now become highly competitive compared to other types of energy. One might consider this growth area a huge business opportunity, but there are challenges as well. Given the growth rate, subsidies are now being scaled back, and increasing competition with several new players has made it harder to maintain competitive edge. Historically, margins have been generated by taking on risks of projects with subsequent farm downs, rather than electricity production itself. What the future will hold, is of course dependent on regulation, but in the big picture, one way to look at this is that "electrification of everything" will lead to a totally commoditised electricity energy market.

Traditional fossil markets such as oil and gas have been highly attractive. Scarce resources provide high margins over time. Renewable energy cannot be considered a similar scarce resource. To be a winner in an energy abundant renewable future, the obvious way to "win" is to generate economies of scale. Scale, however, has its own challenges when electricity markets are much more localised than for example global oil markets. To generate scale, one has to handle multiple local markets from development through to production. Each market may have its own dynamics, regulation, and business culture.

Also, the supplier market looks increasingly commoditised with low-cost Chinese solar panels dominating, whilst wind turbine manufacturers are struggling with earnings in a growing market due to supply chain constraints.

An obvious scarce resource in the electricity market is the grid, and this is typically controlled by Transmission System Operators (TSOs) and utility companies, who are regulated accordingly. Another scarce resource is critical minerals to produce electrical components, but with technology development some of these may have several substitutes over time.

Given these reflections, are there other business opportunities to be found? Electrification of everything based on renewables, causes several issues, for example intermittency and mobility.

The increasing use of renewables will lead to intermittency challenges, with variation in supply on an hourly, weekly, and annual basis. Finding ways to balance the grid via various means such as energy storage, technology and flexible production is clearly a significant business opportunity. For example, one MWh of flexible hydropower, will likely be more valuable than one MWh of wind or solar in the future. It is therefore an interesting observation to see how many companies set production targets rather than value targets for production.

The ability to let demand meet supply and not always supply meet demand might be another solution than can lead to new forms of value capture. By stretching it even further, one might ask if the future will be dependent on the grid with centralised energy production as it is today, or whether we will see increasingly distributed structures in the future. In practice it is likely to be a combination of both, and it very much depends on existing infrastructure or lack thereof. As we have seen in telecom, some areas might leapfrog into the future as they are not bounded by legacy infrastructure.

Another problem and therefore business opportunity is related to mobility and the need for better batteries to enable longer range transport. No surprise we see significant investments flowing into

> [...] one MWh of flexible hydropower, will likely be more valuable than one MWh of wind or solar in the future

battery technology and factories. The big question is how to maintain a competitive advantage as competition is fierce and technology evolves quickly. The business opportunity may be found in providing supporting infrastructure and services. Charging infrastructure can serve a similar function as today's petrol stations where companies can make their earnings on food and beverage rather than the energy itself. We already see that some companies are enabling consumers to connect their electric vehicles to the grid and act as either batteries on the grid or to charge them when the price is forecasted to be low. This shows a way of capturing value by solving combined issues such as mobility, energy storage, and smart energy management.

To summarise potential business implications of "electrification of everything", a potential pattern emerges. With the falling cost curves of renewables, we are moving from a world of scarce natural resources upstream with high margin into a world of energy abundance, low cost, and low margin. In value chains with such commodities, the competitive power typically switches from controlling resources to become much more customer centric.

If we look at how other industries have been upended by new tech companies, we often see that such companies are based on highly customer centric business models. Tech giants like Amazon, Apple, Google, Alibaba, and others, have created platform business models and built and ecosystem around them in a "winner takes all" disruption of multiple markets. They are asset light and rather rely on data, standards, and added value for their combined customer and supplier bases to thrive. This enables them to be much more agile and adaptable to changing circumstances. Will we see a similar disruption in the energy markets?

Perhaps a valuable approach to address this question is to look at what customer needs are out there based on electrification and other changes and what it might mean in an energy abundant world. A few examples solving real problems could be:

- smart energy management for various entities from households to municipalities
- smart mobility
- smart buildings

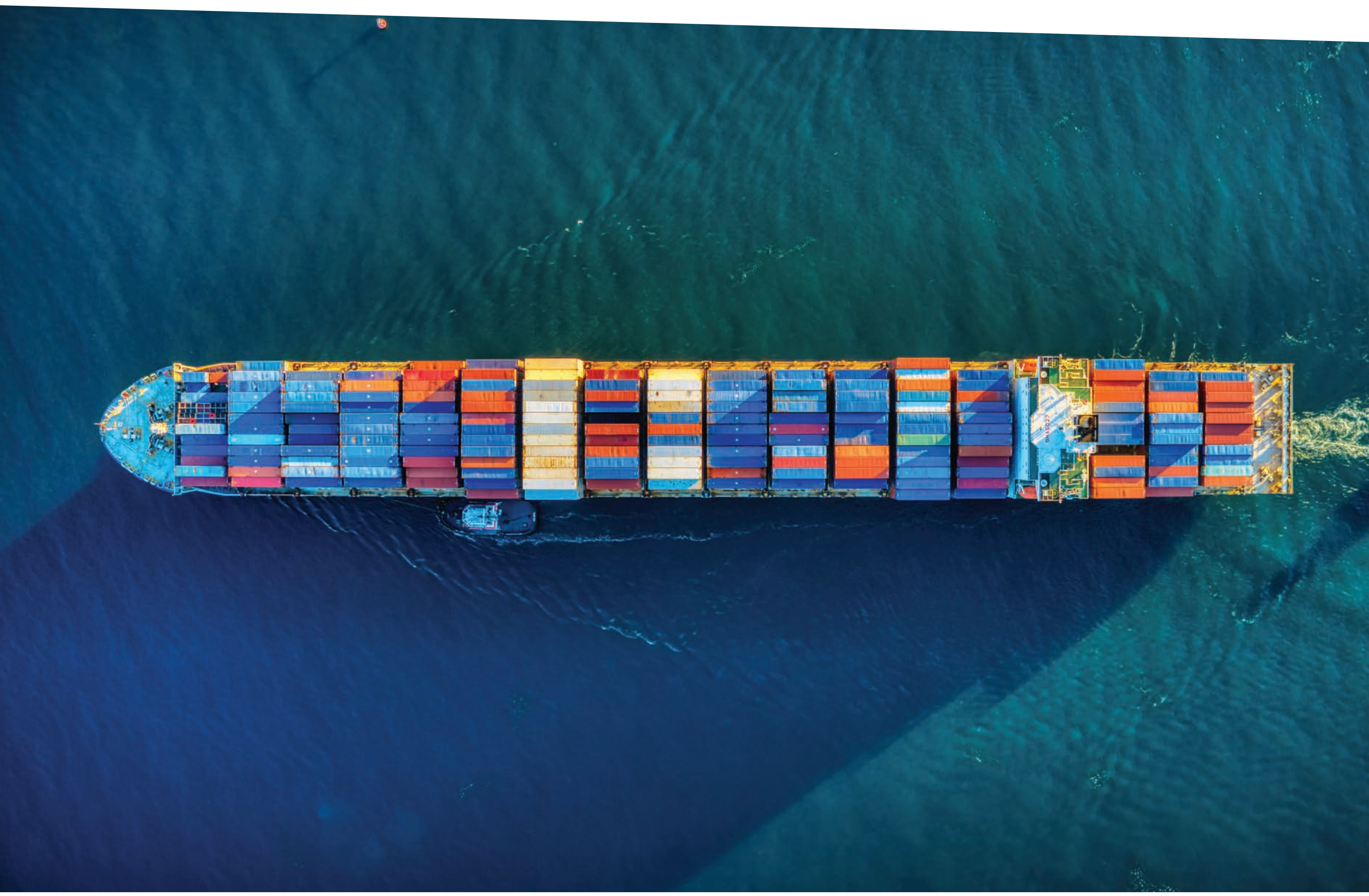
In a world moving more towards "as a service", we may not even think about energy at all when we order a driverless car to bring us to our rental house that produces and consumes energy from the grid. What is Tesla? A car company or an energy company? Either way, its market capitalisation at the beginning of 2022, represented roughly the equivalent of the 10 largest car companies in the world combined. Clearly, the market does not see Tesla as a pure car company.

Hard to abate sectors

Certain sectors are hard to decarbonize. This includes the following: heavy industry, and long-distance transport on land, at sea and in the air where battery technologies do not provide sufficient ratio of energy density to be feasible. Likely fuel alternatives are clean hydrogen (e.g., ammonia and methanol), and biofuels. Clean hydrogen will typically be either green or blue. Green hydrogen is produced via electrolysis based on electricity from renewable sources. Blue hydrogen is produced from natural gas combined with carbon capture and storage. There are several issues with hydrogen. Technically transport is an issue given the small molecules and high energy density of hydrogen. The current cost to produce hydrogen is very high

and the efficiency loss is significant. Why produce blue hydrogen if you can sell natural gas for a higher price? Even if hydrogen was available at a competitive cost today, it would take time to build demand as fuel cells, infrastructure and other prerequisites are not in place. Hence, the development of a market for hydrogen will take time even though there is a limited market for refineries already. Technological development, incentives and regulation are probably all need to speed up demand as well as supply. A well-functioning carbon market would be helpful in this regard to build demand to enable scale and lower cost curves. Falling electricity prices will also help. Even though hydrogen is a long-term growth area, it is still likely that the production of it will be commoditised in a similar fashion to renewables. Hence, a similar argument to use scale as a competitive advantage might be valid in this context as well.

What other business opportunities may present themselves in this growth area? Blue hydrogen might be a front runner to green hydrogen. One is the cost level, and



the other is reuse of gas infrastructure into hydrogen. This means that early mover advantage may provide scale and the control of infrastructure such as pipelines. Indeed, a part of the EUs response to the current energy crisis has been to scale up natural gas to phase out Russian gas, and at the same time making new infrastructure investments more hydrogen enabled to avoid stranded assets. Whilst it may not be a high margin business, the utility position of providing hydrogen infrastructure transport, is at least likely to provide predictability for returns.

The main problem though is likely to be build-up of demand for hydrogen. The following example may illustrate the complexity of the issue. If we assume that a consumer goods company, mainly transporting goods by sea containers will be able to meet its net zero targets, then the potential implications are:

- The global container shipping fleet will switch to hydrogen-based fuels
- Ports will have hydrogen infrastructure available
- Energy companies can produce hydrogen at a competitive price, in practice meaning that the local grid has renewable energy surplus

Taking a customer centric view, maybe there are some significant opportunities to start find lasting competitive advantage along such a value chain? Energy production at least quickly becomes a question of "where to play" at lower cost, whilst "how to win" will be the sources of lasting competitive advantage.

Looking at this particular value chain, new alliances between players can shape new business models, and early mover advantage can be gained through clever collaboration shaping "green corridors" to cover the green transport needs for the end customer. A significant uncertainty is related to whether hydrogen will be centrally produced or decentralised. In the first instance, it will require transport infrastructure and additional business opportunities.

During the transition, many players will struggle with how to transition from carbon fuel to a cleaner fuel, such as biofuel and hydrogen variants, etc. A challenge for many industries that cannot electrify, is to place their bets and experiment as they have little room for hedging. This is indeed a business opportunity for trading organisations that can provide this at scale, potentially also as advisors. They will thereby also get early insights into market developments that can provide scale in other parts of the business to gain cost competitiveness. It is indeed a good example of how to earn a premium while accelerating energy transition.

We can probably find similar ways of shaping business opportunities in other value chains for all types of transport as well as for heavy industry.

A negative emissions system

It is hard to transition all demand to clean energy. In addition, economic growth has always been fuelled by energy. This creates the dilemma, in particular in the global south to balance clean energy versus affordability to lift people out of poverty. These factors means that it is hard to find a credible way to net zero by 2050 without negative emissions.
Current carbon capture, utilization, and storage (CCUS) is rather expensive and

therefore limited. Nature based solutions are less expensive, but there is a lack of viable projects, land, regulation, and incentives. Both have an interesting element in common if technology can bring down the cost curve for carbon capture, and that is availability of reservoirs to store carbon or land to use nature-based solutions. They are both potentially scarce resources that may provide higher margins.

Either way, negative emissions can only be made possible though a well-functioning, transparent, and liquid carbon-credit markets at scale, and this will take time to develop politically. Theoretically, such a market combined with massive volumes of carbon capture and storage, will in practice create a circular economy for carbon. There are probably also significant opportunities in recycling carbon products too.

Who will be the winner?

Given the examples of potential changes to business models in the energy system, what are the potential implications for current large players in the energy ecosystem?

Asking the right question, is sometimes half the answer. International oil and gas companies, especially European ones are diversifying into renewables and new energy solutions. How can they establish a defendable competitive advantage in lower margin businesses given their high margin operating models? Will they be able to become more customer centric? Hydrogen might be close to their current core capability, but will that also turn into a low margin business? Will they eventually turn into a pure CCUS business using existing reservoirs to store carbon as the only defendable limited resource? Perhaps utility companies have a better position to get predictable returns on infrastructure or use and existing local customer base though customer centricity? Will tech companies or new start-ups establish platforms for offering services for smart energy management, smart mobility, carbon markets, completely disrupt the energy markets as we gradually become carbon neutral and we enter an age of energy abundance? Will established players try to do the same? Will we see new alliances?

First and foremost, no specific outcome can be predicted correctly, and indeed many of the business models and ways of gaining competitive advantage may turn out to be exactly wrong. However, they do indicate that the transition we are now going through is potentially as fundamental as the industrial revolution and its impact on society. What can companies do then to become winners? From a strategic point of view, scenario-based strategies that are robust under different scenarios will enable companies to be more resilient and adaptable to unforeseen changes in underlying drivers. It can also enable capture of value and learning during the transition as well.

Secondly, placing the right bet is probably quite a challenge. Some models will work, and others don't. A balanced portfolio approach might be useful. However, large corporations typically struggle building up new business models within existing corporate environments. Existing business models have often been highly streamlined and geared towards efficiency for such a long time that "everything" in their operating model is geared towards this. Oil and gas is a brilliant example where a litre of petrol might turn out to be less expensive than a bottle of water, and this is rather impressive when one considers the complexity behind one versus the other.

The problem that occurs for new businesses is that the existing "immune system" of the dominating legacy business will quickly attack any new comer through culture, procedures, tax systems, ways of thinking, commercial mind set etc. The list is endless, and it is hard to survive as a new business in such an environment. Deloitte's think tank "Centre for the Edge" has through its research found a few clever ways to address this issue such as shield a potential new business by ring fencing it to protect it, giving it extensive autonomy to experiment finding the right business model that actually works, establish clear sponsorship from the executive level to solve issues quickly, starve funding so that the new business is not living off subsidies but rather focus on finding the best commercial model, and last but not least, do not have too many such initiatives as this will turn to lack of focus. Ørsted's journey from oil and gas into wind might serve as a good illustration of such an approach, AWS in Amazon is another.

We cannot predict the future, but we can shape it. Capitalism has reinvented itself and solved fundamental problems for centuries. With the right enablers including regulation, new technology, right financial incentives, there is a significant opportunity to turn a societal problem like climate change into the business opportunity of a life time. Can future generations trust our generation will succeed?

> " Can future generations trust the current generation will succeed?"

Norway

CAN NORWAY MAINTAIN ITS STATUS AS EUROPE'S OIL AND GAS SUPPLIER OF CHOICE?

As of now Norway is a stable supplier of energy to Europe, but will it last? Are there enough discoveries and projects to be developed, and what about the varying degree of success in the Barents Sea? Neivan Boroujerdi, Research Director North Sea Upstream and Fraser McKay, Head of Upstream Analysis in Wood Mackenzie gives the outside look of Norway as an energy major. They urge Norway to explore its potential as an energy super basin.

By Neivan Boroujerdi, Research Director North Sea Upstream and Fraser McKay, Head of Upstream Analysis in Wood Mackenzie

The range of outcomes for oil and gas demand through the energy transition remains wide. But in our base case, demand in the EU is likely to keep growing until the mid-2030s. Russia's invasion of Ukraine has pushed energy security to the top of the EU's agenda, and its desire to curtail imports from Russia has exacerbated the pressure on already tight markets.

Norway, Europe's biggest oil and gas provider, has responded to calls to raise short-term output and cemented its place as a supplier of choice. At a time when politicians are calling for extra taxes to be levied on producers' windfall profits, Norway's stable fiscal regime is appealing, and the country is also leading the way on decarbonisation. But can it seize this opportunity and maintain or even grow supply further?

There are headwinds. An unprecedented level of activity – driven by the temporary tax package introduced in 2020 – is placing pressure on the supply chain. Raw materials inflation is being compounded by service sector capacity and hotspots are emerging. Norway is one of them. While the fiscal terms provide flexibility to absorb cost overruns, long lead-times and execution risk remain big issues for industry safety records, project economics and near-term supply.

Of longer-term concern is a thinning pipeline of development opportunities. While current levels of production are likely to be maintained to the late 2020s, underwhelming frontier exploration results – particularly disappointments in the Barents Sea – have taken their toll.

Fundamentally, exploration – and new developments – are needed. We believe there is a lot to play for. Norway is still a top-10 global regime in prospective resource terms but just under half the potential resides beneath the Barents Sea. While the Barents offers significant resource potential, it carries many risks.

Waning interest in the basin has been exacerbated by the shift in the corporate landscape. Consolidation has halved the number of active producers in recent years and there are big question marks on whether the current crop of players has the appetite – or expertise – to unlock the complex developments required to maintain sector momentum.

Longer-term, the world's growing need for sustainable energy will change the geography of oil and gas. Its future will be ever more entwined with renewables. For the upstream industry to become more sustainable, it must focus on resources co-located with both plentiful clean electricity and scalable CCS potential. Norway already has an electrification advantage and an early-mover foot on the offshore wind and CCS ladder. In addressing the challenges of meeting Europe's call for reliable energy supplies, the Norwegian sector's attention should also focus on consolidating its energy super basin status.

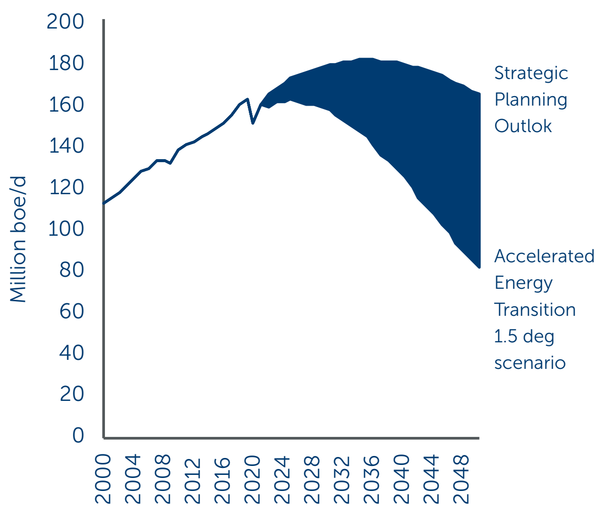
THE OPPORTUNITY: THE CALL ON NORWEGIAN SUPPLY
(SECTION 1)

The range of outcomes for demand through the energy transition remains wide. But in our base case, oil and gas demand in the EU is likely to keep growing until the mid-2030s. Russia's invasion of Ukraine has pushed energy security to the top of the EU's agenda, and its desire to curtail imports from Russia has exacerbated the pressure on already tight markets. Simply put, there's a lot to play for.

Norway, Europe's biggest oil and gas provider, has cemented its place as a supplier of choice in 2022. Having been called on to increase output, it responded by lifting production caps at flexible fields, redirecting gas from reinjection, and accelerating infill drilling and debottlenecking. It is set to produce a record amount of gas in 2022.

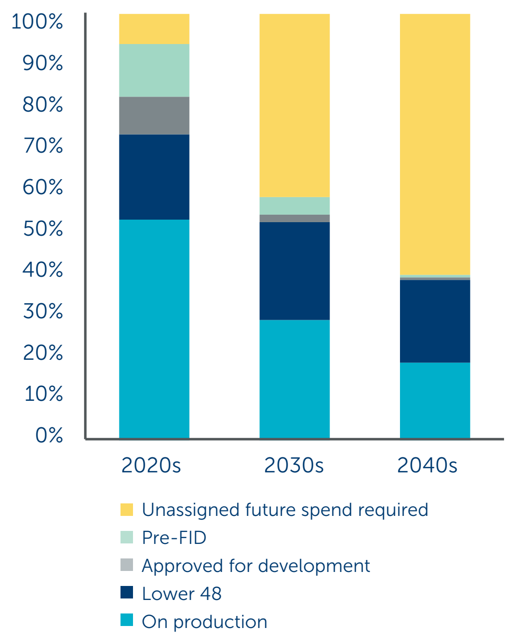
But can Norway's upstream industry seize this opportunity and grow supply even further? Can it even maintain current levels?

RANGE OF GLOBAL OIL AND GAS DEMAND*



Source: Wood Mackenzie,
*Based on "Wood Mackenzie's Energy Transition Scenarios"

UPSTREAM CAPEX SPLIT BY DECADE



Source: Wood Mackenzie, Lens Upstream, SPO scenario

NORWAY IS A SUPPLIER OF CHOICE: POSITIVE SENTIMENT AND FISCAL NEUTRALITY

(SECTION 2)

While global oil and gas producers are realising record free cash flow, consumers are facing equally huge increases in their heating and fuel bills. Politicians in several countries are calling for extra taxes to be levied on producers' windfall profits, which they can then use to assist low-income households. The introduction of a windfall tax in the UK is the most high-profile change to be announced so far, consistent with its policy of adjusting the marginal tax rate in response to price over the last 50 years.

But investors abhor uncertainty. Norway's commitment to maintaining a stable investment environment through previous cycles has not gone unnoticed. With tax neutrality at the core of its strategy – the concept that resources that are profitable to develop before tax, should be profitable for companies after tax – Norway's petroleum tax system includes deductions and incentives that mitigate the deterrent of a high marginal tax rate.

The broad public and political support for the oil and gas sector was evident during the downturn in 2020. Attractive fiscal incentives were introduced to protect ongoing and incentivise new investments. These allowed accelerated depreciation and a higher uplift of development spend on projects sanctioned by the end of 2022.

It worked. Operators have rushed to take advantage, committing to new projects and ensuring investment momentum until the late 2020s. Some developments undoubtedly crept up the pecking order, such as NOAKA and Wisting, and all could potentially come onstream to receive prices far higher than those prevailing at the time the tax breaks were introduced.

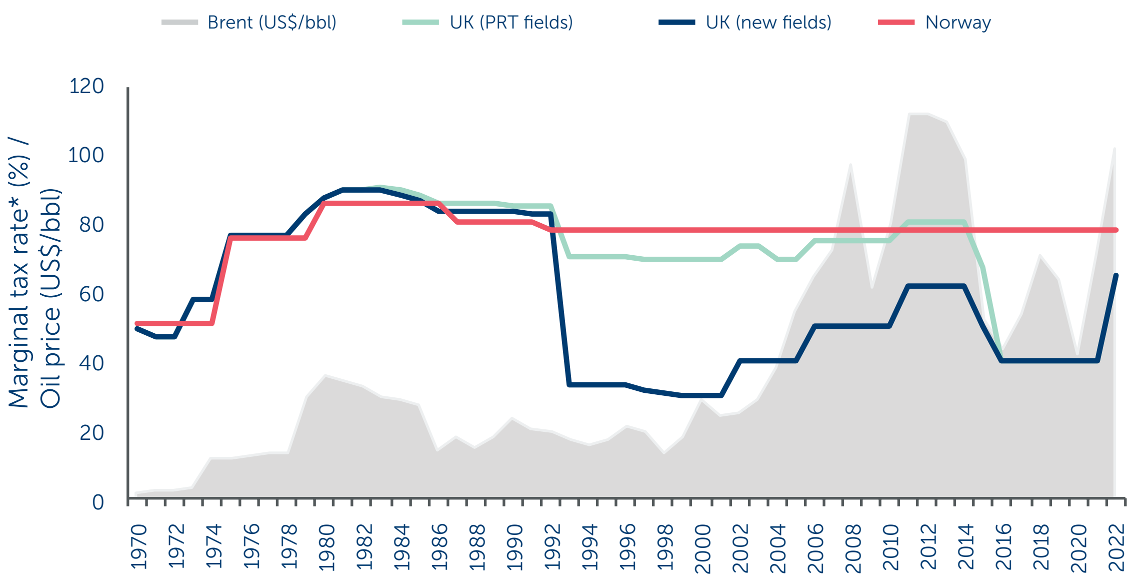
The future of its industry was a key topic of debate in the run up to the 2021 parliamentary election. Norway's politicians and public grappled with the juxtaposition of being Europe's largest oil and gas producer, the importance of hydrocarbons to the economy and ambitions to meet decarbonisation targets in line with the Paris Agreement.

In the end, Norway's incoming Labour party – which had outlined a commitment to the industry in its election campaign – approved the tax proposals first proposed by the outgoing Conservatives in a show of bipartisan industry support.

The changes keep the total marginal tax rate at 78%, and even though the headline exploration refund has been removed, 71,8% of losses will be recovered (or offset for taxpayers) through the special tax. This - and other capital allowance changes - has created one of the most neutral tax systems in the world, where ongoing investors will essentially get the same rate of return on their investment as if the government wasn't there.

The outliers to this win-win outcome are companies which are not investing and are therefore subject to the full marginal tax rate. The government will always be the primary beneficiary of any resource harvesting, but it could go some steps further. Future considerations should focus on how to create a holistic energy and emissions taxation regime which allows all spend on non-upstream CCUS and renewables development to be included within the petroleum fiscal ring fence.

MARGINAL NORTH SEA TAX RATES VERSUS OIL PRICE



Source: Wood Mackenzie, Fiscal Service *allowances have also changed over time that significantly impact the effective tax rates

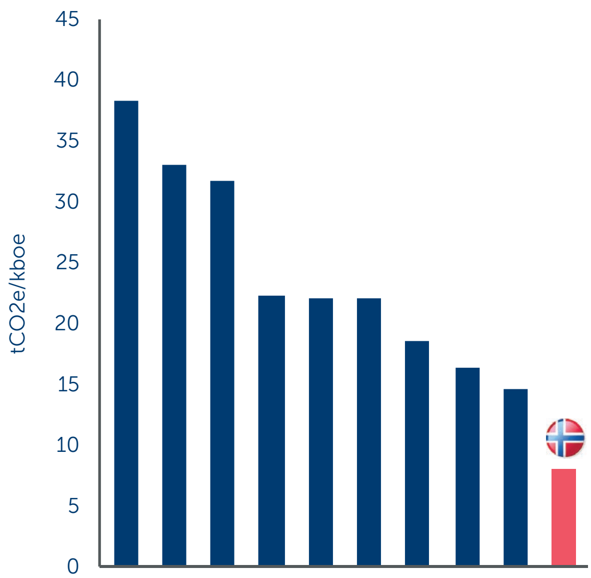
Decarbonisation leader

Norway is a global leader in upstream decarbonisation. It has the lowest Scope 1 and 2 emissions intensity of the most prolific oil and gas producing countries by some margin. At just 7 ktCO2e/boe, its aggregate upstream emissions intensity over the next decade is less than one third of the global average.

With the highest proportion of electricity produced from renewables in Europe, Norway is a net electricity exporter, and it has been electrifying platforms for nearly 30 years. By 2023, nearly 60% of Norway's production will be either partially or fully electrified with power from shore or from floating offshore wind.

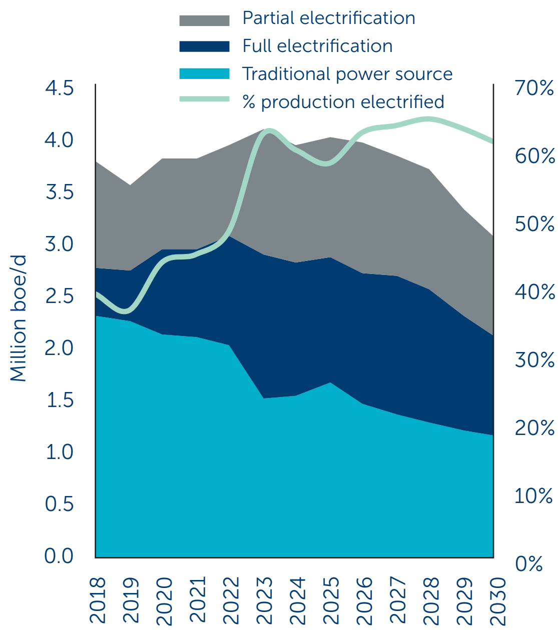
Norwegian emission taxes are also leading the industry. Already the highest in the world, the carbon tax on oil and gas producers is set to exceed US$260/tonne by 2030, following a government initiative in January 2021. But that's not the whole story. These taxes are deductible for tax purposes, which softens the blow, as does inherently low emissions, necessitating high tax rates to have any impact.

EMISSIONS INTENSITY* OF TOP 10 PRODUCERS



Source: Wood Mackenzie Emissions Benchmaking Tool, *includes scope 1 and scope 2 emissions

NCS PRODUCTION BY POWER SOURCE



Source: Wood Mackenzie, Lens Uptream

CAN CURRENT LEVELS OF OUTPUT BE MAINTAINED?

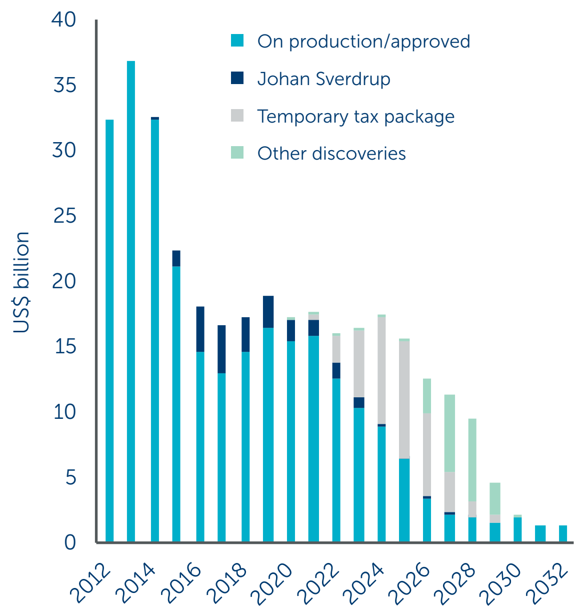
(SECTION 3)

Investment in the Norwegian sector has fallen from its peak in 2013 but spend has been maintained at around US$15 billion per annum, largely underpinned by the giant Johan Sverdrup development.

The 2010 discovery of Johan Sverdrup precipitated a period of high exploration activity. But results have largely underwhelmed, and in the absence of a pipeline of greenfield projects, investment levels were expected to fall this decade.

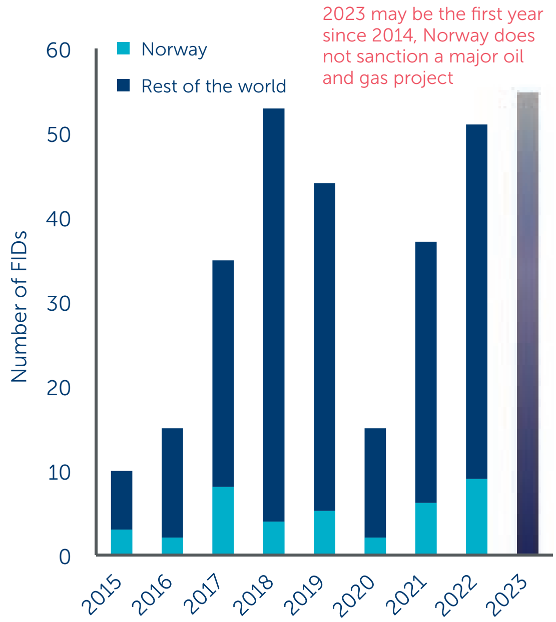
However, the temporary tax package gave the industry a shot in the arm. Projects – some marginal – have been revived and accelerated, resulting in up to 50 developments sanctioned between 2020 and 2022, 17 of which are over 50 million boe. This means Norway continues to stand out on a global scale even if the pipeline of opportunities beyond 2022 suggest this will be hard to maintain.

CAPEX BY DEVELOPMENT STATUS



Source: Wood Mackenzie, Lens Uptream

NUMBER OF PROJECT SANCTIONS



Source: Wood Mackenzie, Lens Upstream, *only projects above 50 mmboe included

Short-term risks – cost inflation

There are short-term risks to this unprecedented level of activity. Global upstream cost inflation is intensifying. Like-for-like project costs are sharply up in 2022. First driven by raw materials inflation, cost inflation is now being compounded by service sector capacity and supply chain constraints. The net result will be global aggregate offshore inflation of 10-18% in 2022. Many of the constraints will not be alleviated by 2023 and double-digit cost inflation is likely to persist.

Russia's invasion of Ukraine has impacted the cost and availability of some goods and services and has increased demand for non-Russian commodities. In addition to market factors, the global oil and gas service sector is fast becoming resource constrained.

General inflationary factors have now been joined by margin expansion as suppliers look to exert pricing power in a tight market, where operators are still keen to maintain capital discipline. Suppliers remain cautious about adding capacity and utilisation has exceeded 80% in some sectors.

Capacity is not the same as it used to be. There has been a 30+% reduction in major category capacity across the industry over the past eight years. Despite the slow uptick in activity levels, global service sector capacity is a concern. Hotspots are emerging and Norway is one of them.

Being so reliant on its indigenous supply chain is creating pinch points as activity flows through from the wave of project sanctions. Increasing demand for harsh environment rigs will push utilisation rates over 90%, driving up rig rates.

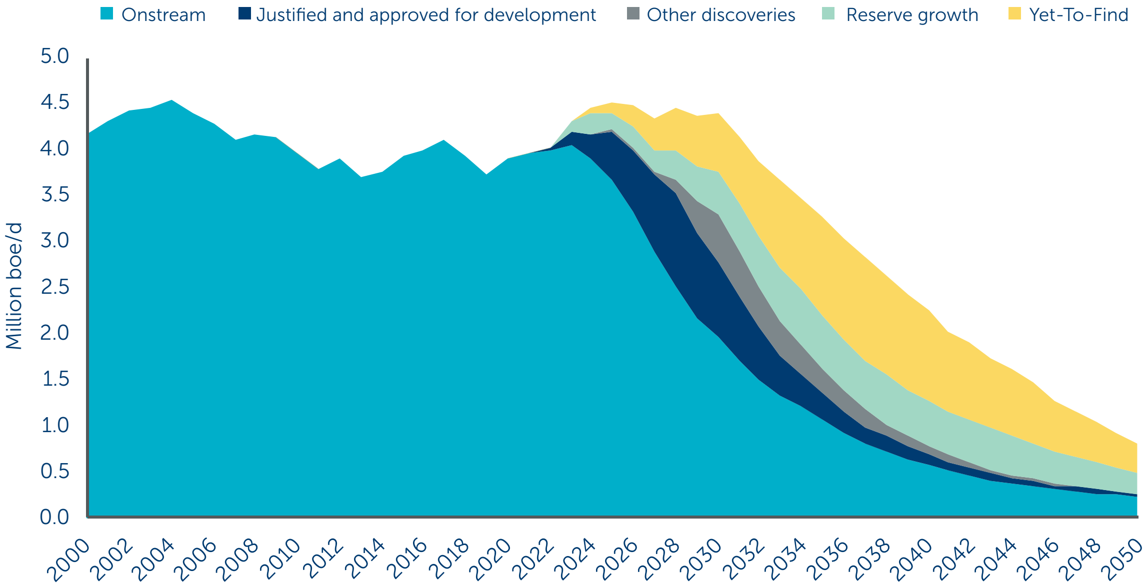
Norway, along with Latin America, is driving the global recovery in subsea kit demand. But regional capacity has been cut. Aker ceased subsea tree production in Norway in 2020, meaning operators are increasingly reliant on what is a global market. Most Norwegian projects have experienced around a 20% increase in cost estimates from FEED through to FID.

While the fiscal terms provide flexibility to absorb cost overruns, long lead-times and execution risk arguably remains a bigger issue to both industry safety records and project economics. Getting access to the right talent and equipment at the right time and in the right order will be difficult. Ensuring and maintaining successful working partnerships between producers and the supply chain is crucial.

Medium-term risks – thinning pipeline of opportunities and company appetite

Of longer-term concern is a thinning pipeline of development opportunities. While current levels of production are likely to be maintained to the late 2020s, underwhelming frontier exploration results – particularly disappointments in the Barents Sea – have taken their toll. Beyond 2022, there are very few projects in the pipeline.

NORWAY PRODUCTION OUTLOOK BY DEVELOPMENT STATUS



Source: Wood Mackenzie, Marco Oil, Global gas and Lens Upstream

Maintaining output above four million barrels of oil equivalent per day beyond 2030 will be a challenge. The pace of longer-term declines will partly depend on the effectiveness of reserve growth at producing fields. With the application of leading-edge technology commonplace in Norway, further increases in the recovery level from existing fields are inevitable.

But fundamentally, exploration – and new developments – are needed to support mid-and long-term production. The Norwegian Petroleum Directorate estimates there are 25 billion boe of Yet-to-Find volumes across the NCS, 9 billion of which sit in closed off areas that are unlikely to be opened up for exploration activity anytime soon.

We are less bullish on Norway's resource potential than these aggressive estimates, but we believe there is a lot to play for. By our estimates, Norway is still a top-10 global regime in prospective resource terms. Just under half the potential resides beneath the Barents Sea, which remains the area most likely to yield the largest discoveries.

But while the Barents offers significant resource potential, it carries many risks. Lying above the Arctic circle, the region is environmentally sensitive and high cost. Existing infrastructure is currently limited to the southern part of the basin near the coast. And while oil projects such as Goliat and Johan Castberg have progressed in recent times, the development of gas has been limited to the Snøhvit LNG facility.

Construction of a new gas pipeline to the shore and expansion of the existing Snøhvit LNG facility have been under consideration for years. With Europe scrambling around for gas, they are likely to be on policymaker and industry agendas again.

We think there is a role for Barents Sea gas in the supply mix but further exploration in the area is required and it is a tough sell. Concerningly, exploration in the past 10 years has failed to create value despite discovering almost two billion boe of resource.

The much-touted Southeast Barents play has failed to deliver anything of note and as a result, interest in recent frontier licensing rounds has waned. Only six companies applied for Barents Sea acreage in the 25th licensing round last year, compared to 36 in the 22nd round in 2014. Last year, Aker BP – the second biggest producer on the shelf – announced it was walking away from the Barents.

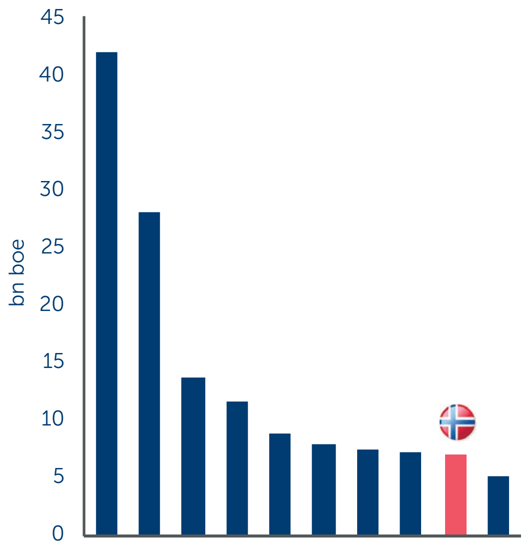
The waning interest also reflects what has been a shift in the corporate landscape. The sector continues to be dominated by Equinor – which is celebrating its 50th anniversary this year – and the State Direct Financial Interest (State DFI); combined they hold over 50% of Norway's upstream commercial value and reserves.

But the Majors and IOCs, for so long key players on the shelf, have vacated in recent years due to a perceived lack of materiality and competition with lower costs of supply. A wave of NCS midcaps has entered this space, including independents and private equity-backed companies who have grown and been able to invest where previously the Majors were unable to attract capital.

While this has been broadly positive, we've also seen an unprecedented level of consolidation. The number of active producers has nearly halved in recent years from 55 in 2013 to less than 30 today.

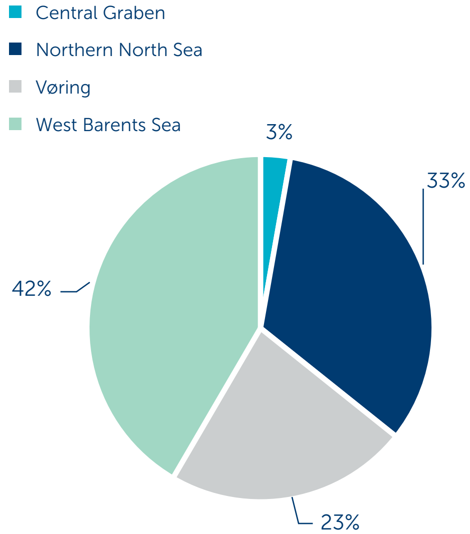
Last year's mega tie-up of Aker BP and Lundin was the most high-profile of a long line of mergers, largely eradicating niche E&Ps. There are big question marks on whether the current crop of players – Equinor aside – has the appetite (or expertise) to unlock the complex developments required to maintain sector momentum. It may fall to Equinor to bear the greatest burden if Norway's full potential is to be realised.

PROSPECT RESOURCES BY COUNTRY (TOP 10)



Source: Wood Mackenzie, Exploration Service

NCS PROSPECT RESOURCES BY BASIN



Source: Wood Mackenzie, Exploration Service

Norway's place among the Energy Super Basins of the future

The world's growing need for sustainable energy will change the geography of oil and gas. Its future will be ever more entwined with renewables. The upstream industry of the 2030s and beyond must focus where its synergies with new energies are strongest.

Advantaged resources – low cost and low carbon – must become the future of oil and gas. For the upstream industry to become more sustainable, it must focus on resources co-located with both plentiful clean electricity and scalable CCS potential.

On this basis, some traditional hydrocarbon super basins will evolve into the energy super basins of the future. Other traditional hydrocarbon basins, which are disadvantaged in any of those areas will be harder to decarbonise and face being left behind.

Ranking basins by availability of clean electricity and CCS potential reveals clear winners. Good examples among the largest basins in the world include the Permian Basin and the Gulf Coast in the US, Australia's North Carnarvon and the Rub al Khali in the Middle East.

Norway already has an electrification advantage, and an early-mover foot on the offshore wind and CCS ladder. In addressing the challenges of meeting Europe's call for reliable energy supplies, the Norwegian sector's attention should also focus on consolidating its energy super basin status. Please look out for an upcoming Wood Mackenzie Horizon report on Energy Super Basins.

The next big change

HOW WE MADE IT – LOOKING BACK FROM 2060

Let’s say we made it. We reached net-zero by the 2050s. But how? Peter Littlewood, Founding Chair of The Faraday Institute and Professor of Physics at the University of Chicago will bring us through the technology and cost perspective on how history unfolded bringing us to the middle of this century.

By Peter Littlewood, Founding Chair of The Faraday Institution and Professor of Physics at the University of Chicago

Many governments have committed to net-zero-carbon emissions by mid-century. There is an emerging societal consensus on this goal, which matches the scientific consensus that net-zero as soon as possible is imperative. In many quarters these promises have been met with incredulity, either because the commitments are lightly given or because they seem thoughtless in the face of the scale of the change needed. There are several aspects to this renewable transition, which I will cast into four segments:

- Technological and scientific feasibility
- Affording the financial investments
- How we tackle the disruption
- The geopolitical will

This article will try to assess the prospects for the first two legs of this stool; science and technology; and cost.

Even though one should be wary of making specific predictions, science, technology, and cost at least move in a predictable direction. As long as society does not collapse, science will discover, technology will improve, and costs will reduce. The only question is how quickly and how much and in what areas; and about the only lever we have for this is investment, both in R&D and in scale-up. The direction for business and the economy is an exercise in comparative investment and adds friction and hysteresis even to change that is inevitable over the long term; historical investments can extend the life of inferior technologies such as the internal combustion engine over naturally superior but less-developed competitors like batteries and electric motors. In this arena it is the role of policy to mitigate the evils, buffer the consequences, and expedite the changes. I'm going to take the somewhat pollyannish view that the stars align in the last two categories (business and policy), because they need to. Should they fail we are doomed. We are searching for a virtuous circle where technology change creates enough value that the economy follows, policy aligns.

So let us look back from the sunny uplands of 2060 or so, to assume those commitments are realized, and ask how we achieved Earth4.0.

Solar, wind and nuclear

At the macro level one can find a great deal of comfort. In terms of energy supply, the total power from our Sun that reaches the upper atmosphere is 1.7×10^{17} Watts, which is around four orders of magnitude larger than total human energy consumption, and five orders of magnitude larger than the energy in human food consumption. So to power ourselves, we need to harvest sunlight with an overall 0.01 % efficiency, which seems not insurmountable. The solar energy input is converted to energy in wind, waves, biomass, and hydropower, all of which can be separately harvested – though with decreasing levels of efficiency because they are farther down the chain from the primary source. While there are huge geographic variations, only solar and wind are generally abundant and cheap, hydropower is already saturated (though important in mountainous places with high precipitation and low population – Norway being the poster child), and biomass is a dangerous distraction unless something changes (plants are only about 1% efficient in converting solar energy to biomass - also we need to eat them). The power delivery (measured in Watts per square meter of land, on average) of the best technologies in the best places is 50-100 Wm^{-2} for solar, 10-20 Wm^{-2} for wind, 1-3 Wm^{-2} for biomass, and less than 1 for hydro. In contrast a conventional fossil or nuclear power plant is of order 1 GW per square kilometer, about 100 times larger than the best solar. These numbers fit the physics rule of thumb that nuclear energy density (energy per unit mass) is much much larger than that for chemical energy (solar and solar fuels) which is in turn greater than kinetic energy (wind and wave), and gravitational energy (hydro) brings up the rear. So yes, it would be irresponsible to ignore nuclear – not officially a renewable resource (except for fusion) – but in principle carbon neutral.

Renewable energy sources are doing well. The progress in wind and solar is such that for new construction strike prices are already around one dollar per Watt. (Nuclear costs a lot more (in the west) for reasons that have little to do with its intrinsic costs). So our needed 20

TeraWatts global energy capacity should cost about 20 Trillion dollars in investment, which is about 1 annual GDP of the United States. (Currently the global capacity of modern renewables is about 2 TW). There will be more infrastructure needed to deal with the electrical distribution and back-up, so maybe double or triple that. But for the world to invest, say 100Tera$ over 30 years doesn't seem implausible. Wind and solar are variable depending on weather and will need to be supported by baseload capacity (i.e. nuclear, hydro) and by electrical grid storage (batteries or renewable fuels). Note that to back up 1 TW for half a day requires an energy storage equal to about 200 M electric vehicles so batteries will usually not be adequate. A strong focus should be on nuclear power and green fuels, and they are well paired. Next generation nuclear reactors could be rolled out in volume after 2030.

Minerals

The other basic resource is minerals. Our planet is extraordinarily well endowed with elements, courtesy of being recycled since the big bang through stars and supernovae that create all the elements heavier than hydrogen and helium. When the earth was created, these elements were heavily mixed. But the 4 billion years of geochemical evolution of the Earth has processed these elements into ores of varying grades. There is plenty of lithium/cobalt/nickel/manganese/lanthanide/name your element – but there are indeed some places where it is cheaper to extract elements than others. [Slight qualification is that what we call 'precious' metals tend to segregate in the earth's core. This is a problem for catalysts we need like platinum, palladium, and iridium.] Note however, that just for battery tech alone we will need to extract several orders of magnitude more Mn/Co/Ni/Li than we do presently, and this will place them alongside silicon (Si) and aluminum (Al) in terms of mining products, below only iron (Fe) and hydrocarbons. Are these numbers plausible? Obviously they are, just by comparison to hydrocarbons: the mineral extraction in coal and oil and gas vastly exceeds in volume and global distribution what our renewable world will require. In 2017 we extracted 8 thousand million metric tons of coal alone and made 2 thousand million metric tons of steel; the next largest elements are aluminium (60 million metric tons), manganese (18 million), lead (10 million) and silicon (8 million). We will need a lot more lithium, cobalt, nickel, and copper than we produce now, but in aggregate terms extractive and mining industries will shrink by volume but not by value.

A little bit lower in the hierarchy one needs to focus on where the energy is used. I've implicitly assumed that our economy will be electrified (this is the most efficient conversion from solar and wind) and the liquid fuels we will need will be electrochemically created (powered by renewable or nuclear energy). Energy use in an advanced economy is divided into three roughly equal segments: transport; residential and light commercial; heavy industry. To go beyond 'energy' per se we must include food, and the environment more broadly.

> To go beyond 'energy' per se we must include food, and the environment more broadly.

Transport: For road vehicles there is now a path to battery electrification. Rail is largely a matter of the electrification of supply. Light aircraft and marine may become battery-powered using the next generation of battery technology beyond lithium-ion, and in the longer term perhaps powered by fuel cells. Large marine and mid-range aircraft could run on renewable hydrogen, ammonia, methane using fuel cells; longer range aircraft on combustion of such fuels. The large amount of capital being deployed for battery technology shows how a policy commitment {for electric vehicles) combined with a predictable R&D landscape (the competing technology options are generally known in principle though there is a lot of work to do) supports a vigorous business climate. Spillover between this sector and the electricity grid can be expected to produce positive feedback because of 'dual-use'. Note that historically the development of rechargeable batteries was made possible by the high-cost and low-physical-volume consumer electronics industry beginning in the 1990's. By about 2015 the cost reduction and volume growth in that industry almost accidentally made a much higher-volume EV market viable, and EV's now drive the market for Li-ion batteries. One might hope that innovations in the EV market (now underwritten by government commitments) will propel the even higher volume requirements for grid storage. Underway here is a virtuous circle.

Residential/commercial: Almost all of this can be fixed by electrification of supply using renewables, mitigated by improved energy efficiency. The 'last mile' of electrification is an issue, not because it's intrinsically costly at the micro-level but because digging up roads and refitting houses in urban environments is not easy and the incentives are confused. Note that the decentralization of electricity generation with solar and wind could offer developing and rural economies a 'leapfrog' opportunity, akin to that of cell-phones over landlines. This third of the economy is highly dependent on policy. Lurking in this sector is energy use in information technology which is increasingly problematic and needs to be addressed separately.

> Why should a farmer by nitrogenous fertilizer from a petrochemical company if she could make it locally from solar energy and electrolysis?

Heavy industry: This includes steel production, aluminum, plastics and petrochemicals, ammonia, mining, and minerals refining. Almost all (aluminum is an exception) are currently refined using energetically- and carbon-intensive thermal processes powered by fossil fuels. The chemical processes exist in principle to do this, but few have been scaled to volume, and none are yet competitive financially. To which we will add in the future the large-scale generation of green hydrogen. This third needs massive investment in R&D, because we need better and cheaper catalysts, better materials and processes and a path to scale them up. This may not happen without the incentive of proper accounting for the cost of carbon. However, if the cost of carbon were a constraint the very centralization of these industrial processes could rapidly tilt investment in favor of new tech. This area is ready for a virtuous circle to develop. When gasoline hits 5$/gallon all kinds of things move into the money. Why should a farmer buy nitrogenous fertilizer from a petrochemical company if she could make it locally from solar energy and electrolysis?

Food: I dismissed biomass above based on its energy (in)efficiency but also because we are already heavily reliant on land for crops. About 50% of our planet's habitable land is farmed, and around ¾ of that is devoted (directly or indirectly) to animals – though they provide less than 1/5 of the calories and about 1/3 of the protein. The energy we eat is an order of magnitude less than the total energy we use in total, but plants extract only about 1% of solar energy input so we currently need most of the surface of the planet to feed ourselves. This will change; vertical farming will increase the solar efficiency (and reduce land, water, and nitrogen use); fake and lab-based meat will reduce the need for pasture and feed crops; genetic engineering could make nitrogen fixation ubiquitous; and just possibly engineered algae and grasses could make biofuels something other than a distraction especially if food production

has its footprint reduced. We know so little about the oceanic ecosystem that any understanding there would be productive. Marine phytoplankton are responsible for fixing about half the atmospheric CO2. Our poor understanding of their role as a planetary thermostat is scary.

Let's try not to create new problems. Every human technology revolution has solved one issue only to create others. There have been three technology revolutions in our history so far: weapons, beginning with the spear, gave us access to animal protein but was so successful we killed off the large fauna and then used those weapons to kill each other (Earth1.0); agriculture rescued us and provided a controlled source of energy but led us to domesticate the whole planet and led to a consequent devastating loss of diversity (Earth2.0); what we call the industrial revolution freed us temporarily from Malthusian energy constraints but led to climate change, pollution and resource destruction (Earth3.0). Of course, those revolutions each produced other things that are generally regarded as good: language, cities, literature, science, so in no sense were they entirely retrograde.

The fourth renewable revolution must aim for stasis. There are several areas where we need to be paying attention in order not to exacerbate or create new problems.

Mining and materials: It has been estimated that a 1kWh battery takes of order 50kWh of energy to build: so the payback occurs after only 50 charge/discharge cycles on a product that may have a theoretical lifetime of 1000 cycles but a practical lifetime of much less. This is profligate. It occurs because of processes that begin with mining, refining, and materials engineering, that also involve global transport. The materials in a typical EV battery may have travelled more than once around the world before turning up in a finished product. There are well-discussed issues about sourcing cobalt. The sheer volume of new materials that will be required for energy technologies at scale mean that big pressures will turn up on staid industries. But as mentioned above we have global supply chains for hydrocarbons and iron that are considerably larger in volume.

Information technology: Information is not free. The brain of a large animal runs on the power of a few tens of Watts, but information processing is now a disproportionate consumer of energy. At the top end, the highest performance computers require tens of MW of power (enough to run a small town) and the power consumption for an AI task that is trivial for a mouse to perform can consume many orders of magnitude more energy on a computer than does a small rodent. The growth of data storage and global information transfer has its own Moore's law of exponential growth, and already accounts for around 10% of energy consumption in advanced economies (Bitcoin, much maligned as perhaps it should be, remains a blip in comparison). Silicon information technology benefits from enormous historical investment and in terms of performance has probably a few more decades of growth. There is essentially nothing on the horizon to challenge Si for raw computing and while our appetite for data grows as it does this mountain will never end. The much more interesting future of computing is on the "edge" particularly when combined with physically active devices. Animals need brains because they need to move, and the embedding of computing with physical hardware will drive integrated devices and lower power consumption. Watch this space.

Recycling: The universe (on average) is at a temperature of 3 degrees above absolute zero and contains (again on average) a few atoms per cubic meter. Earth is (fortunately for us) only in temporary and dynamical equilibrium with this cold and unforgiving space. We take in high-quality energy from the Sun and export an equal amount of low-quality energy to the universe. That transfer circumvents the second law of thermodynamics (which says that disorder inexorably grows) so that we can locally cheat on this rule by exporting our entropy to the distant parts of the galaxy. As the earth cooled over the last 4 billion years, elements got concentrated by geochemistry into

> There is plenty of lithium in the sea, but it's a lot cheaper to extract Li from a concentrated brine in Chile or an ore in Australia,[...]

high quality ores, which we exploit. Trees turned into coal as nearly pure carbon. Biology preserves complexity against the ravages of the second law. The fundamental role of biology is recycling. Concentrated carbon and nitrogen (in particular) are too valuable to waste, and there is a whole recycling industry in biology (bacteria, fungi, algae) that keeps higher organisms functioning. In our industrial lives we have nothing comparable. We make our living using complex arrangements of elements in plastics, silicon chips, batteries, metal alloys and numerous others. The (thermodynamic) energy embedded in these materials includes the cost of extracting them atom by atom from some primordial soup, and that is too precious to waste. There is plenty of lithium in the sea, but it's a lot cheaper to extract Li from a concentrated brine in Chile or an ore in Australia, but these sources are finite. As we scale up the production of new minerals, we must also pay attention to the entropic and economic penalty of throwing them out at end of life. We need to learn from biology and create an ecosystem to recycle our materials.

Looking back from our 2060 success, we might find the following. We will have decarbonized primary electricity generation, using wind, solar, nuclear and perhaps wave power. We will be managing a power surplus from renewables, which we will use to generate liquid and gas fuels, probably hydrogen, ammonia, methane, methanol, and possibly heavier hydrocarbons – and allow some of the more energy intensive industries to remain in advanced economies.

Transport will run on a variety of fuels: light vehicles will mostly be battery powered, though fuel cells will have a place, certainly for heavier and long-distance transport. Light aero will be electric and ubiquitous and at least as energy efficient as a large car, though long-haul flight will still require liquid fuels. Residential and commercial heating will shift more electric, but in certain places we may re-use legacy gas distribution systems with renewably generated fuels. Many petrochemical inputs and the materials and chemistries that they produce will be served by electrochemically derived resources.

We will have replaced large thermal industrial plants with distributed electrical ones. We will be using carbon capture and storage to draw down CO2 and reverse the damage of fossil fuels. Carbon negative buildings will be enabled by new materials and technologies. Information technology will not have run away in energy consumption as current trends would predict, both because of better algorithms than modern AI and because of smarts embedded directly in the relevant hardware technologies (so-called neuromorphic computing). We will have improved our land-management practices and most of our food will come from vegetables and grasses. We will have learned to embed recycling into product design, and the recycling industry will be as central to the economy as mining is now. Much has been discovered and invented. Our social, economic, and business environment will have changed in ways we cannot predict, except that there will be vast new economic opportunities that emerged in the transition.

The big uncertainty is not so much science, technology, and business, but geopolitical will.

If one must name a single big economic thing that will have happened, it is local empowerment and local self-sufficiency. Energy (from the sun, wind, and rain) is everywhere abundant. With a superfluity of energy, materials are available everywhere and manufacturing is distributed and local. Decentralization enhances self-sufficiency. Global supply chains are no longer a stranglehold of the resource rich.

This is of course a challenge for the 2020's geoeconomic order. The big uncertainty is not so much science, technology, and business, but geopolitical will.

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