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White Paper

The Speed of the Energy Transition

Gradual or Rapid Change?

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91-93 route de la Capite
CH-1223 Cologny/Geneva
Switzerland
Tel.: +41 (0)22 869 1212
Fax: +41 (0)22 786 2744
Email: contact@weforum.org
www.weforum.org

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Foreword

Christina Lampe-Onnerud, Founder and Chief Executive Officer, Cadenza Innovation, USA; Co-Chair of the Global Future Council on Energy

Jules Kortenhorst, Chief Executive Officer, Rocky Mountain Institute, USA; Co-Chair of the Global Future Council on Energy

Will the global energy transition from fossil fuels to sustainable energy be gradual or rapid? This key issue for the 2020s has profound implications for governments, energy producers, technology providers as well as industrial and private consumers. But, more importantly, the difference between a gradual and rapid transition will determine the climate future of humanity. A gradual transition will mean that the goals of the Paris Agreement will be badly missed. A rapid transition will give humanity a chance to meet the goals of the Paris Agreement and keep temperature well below 2 degrees Celsius.

Intending to both inform and spark further debate, this White Paper compares the two transition scenarios for our energy future, setting out two clearly different narratives.

The Gradual narrative is that the energy world of tomorrow will look roughly the same as that of today – implying that the global energy system has an inertia incompatible with the Paris Agreement.

The Rapid narrative is that current and new clean energy technologies are rapidly supplying all the growth in energy demand and together with new policies will reshape markets, business models and patterns of consumption leading to a peak in fossil fuel demand in the course of the 2020s.

Whether the world will follow a path of a gradual or rapid transition will also make a significant difference to business across the energy spectrum. The rapid transition will bring new opportunities but the need to adapt to faster change will be greater.

While the global energy system and the factors that impact it are more complex than any scenario or narrative can capture, this paper builds on different existing scenarios and summarizes the main ways in which they differ. It also highlights what to look for over the course of the next decade to see which narrative plays out.

The Global Future Council on Energy 2018-2020 strives to inform the debate and decisions for the near- and long-term energy future.

While acknowledging lead authors Kingsmill Bond, New Energy Strategist, Carbon Tracker Initiative; Angus McCrone, Chief Editor, BloombergNEF; and Jules Kortenhorst, Chief Executive Officer, Rocky Mountain Institute, this White Paper includes significant input and insights from our Council (see the list of members at the end of the paper). The findings, interpretations and conclusions expressed herein are the result of a collaborative process facilitated by the World Economic Forum, but they do not necessarily represent the views of the Forum, nor the entirety of its Members, Partners or other stakeholders, nor the individual Global Future Council members listed as contributors, or their organizations.

1. Executive summary

The great energy debate. The energy industry is complex, and understanding the major trends changing the industry can be challenging. Investors, policy-makers, business people and other interested stakeholders require clear information about the evolution of the energy system to inform present decisions, which can have long-lasting effects. This White Paper provides a framework for navigating the mosaic of often conflicting narratives for how the energy system is evolving. The two very different narratives about the energy transition are: Gradual and Rapid. This paper summarizes the main ways in which they differ and what to look for over the course of the next decade to see which narrative is playing out.

The Gradual narrative is that the energy world of tomorrow will look roughly the same as that of today. Gradual scenarios extrapolate current patterns of policy, industry, consumption and investment, thus supporting planned carbon-intensive investment decisions and implying that the global energy system has an inertia incompatible with the Paris Agreement.

The Rapid narrative is that new energy technologies are rapidly supplying all the growth in energy demand, leading to peak fossil fuel demand in the course of the 2020s. Rapid scenarios suggest that current technologies and new policies will reshape markets, business models and patterns of consumption, challenging planned carbon-intensive investment and leading to a low-carbon global economy while creating considerable economic and social benefits.

The narrative can become self-fulfilling. Energy systems have considerable inertia. If investors and policy-makers believe that future energy demand and supply structures will be broadly the same as today, they will invest accordingly, helping to lock in the current system. If they believe that change is likely, they will invest in and legislate for new opportunities, speeding up the transition.

The road to Paris. Gradual scenarios recognize with regret that carbon emissions will continue to rise, making compliance with the Paris Agreement ever more difficult to achieve. Rapid scenarios provide a framework under which global emissions can reach the goals of the Paris Agreement.

Implications for the fossil fuel sectors. Gradual scenarios imply that peak fossil fuel demand is at least a generation away, that growing economies and populations will drive continued growth in demand for natural gas, oil and, to a lesser extent, coal and that the impact of the transition on these sectors will be muted with a gradual shift towards natural gas within the fossil fuel mix. Rapid scenarios imply that the demand for fossil fuels will peak in the 2020s and the same technology, policy, consumer and financial pressures that are being felt across the energy system at present will have an effect on all fossil fuel sectors. And as technology improves, the fungibility between fossil fuels and renewables will further increase. The implications for the world's fossil fuel sectors are significant: either they will thrive for years to come, or they are about to be disrupted and need radical change.

What determines the difference. The two narratives are distinguished by four main features: what matters, technology growth, policy and emerging market energy pathways. Views on these issues largely determine conclusions on where the energy markets are heading.

1. **What matters – stock or flow**. Gradual advocates and scenarios focus on total demand (stock) and argue that new energy technologies are relatively small and will take decades to overtake fossil fuels. Rapid advocates focus on change (flow) and argue that new energy technologies will soon make up all the growth in energy supply.

2. **Technology growth – linear or exponential.** Gradual advocates argue that new energy technologies are expensive and face insoluble economic or technical impediments to growth, meaning that growth rates will only be linear. Rapid advocates argue that solar and wind are already cheaper than fossil fuels for the generation of electricity and that electric vehicles (EVs) are about to challenge internal combustion engines (ICEs) on price, that the barriers to growth are soluble for the foreseeable future, and that these disruptive new energy technologies will continue to enjoy exponential growth. They anticipate the rise of new technologies, such as green hydrogen, to lead to further waves of change.

3. **Policy – static or dynamic.** Gradual advocates argue that it is necessary only to model policies that are certain to happen, that the forces of inertia are very powerful and that policy-makers will remain cautious and slow-moving. Rapid advocates argue that the forces for change are considerably greater than those for inertia, and that technology opens up the opportunity for policy-makers and regulators to design markets to better provide for all consumers' needs. As the necessity for action becomes clear, there will be an Inevitable Policy Response.[1] Modelling only the existing policy environment understates trends in policy-making.

4. **Emerging market energy pathways – copy or leapfrog**. Gradual advocates argue that the emerging markets (including China and India) will broadly follow the path taken by developed markets and use more fossil fuels as they get richer and energy demand rises. Recent years' investments in infrastructure, such as coal-fired plants, are seen to lock in consumption for years to come and increase the costs of transition, thereby slowing down its pace. Rapid advocates argue that the emerging markets will enjoy an energy leapfrog to new energy technologies and significantly less energy-intensive forms of economic development, while providing critical improvements in the quality of life.

Is the energy transition just about solar and wind? Gradual advocates argue that solar and wind are too small to drive an energy transition. Rapid advocates argue that technology disruption started with solar and wind, has since spread to renewable integration technologies, is now moving into transport, and will shift into other areas of energy. As in any transition, the low-hanging fruit of change is plucked first, leaving the more problematic areas for later.

How important are different fossil fuels? Gradual advocates note that coal, oil and natural gas and every fossil fuel sector in every country are different, and highlight the areas that appear to have few renewable energy alternatives. Rapid advocates argue that the energy transition will drive peaks in one fossil fuel sector after another. First coal, then oil, then gas will be impacted, in one country after another, in a pattern whose shape and trajectory will become increasingly familiar.

What is the role of finance in the energy transition? Gradual advocates argue that the capital invested in the fossil fuel sectors and the market need for fossil fuels are so considerable that investors in aggregate will not speed up the transition but will be a neutral force investing across the energy spectrum where they see the best opportunities for returns on capital. Rapid advocates argue that the financial sector as a whole will act to increase the speed of change as it searches for new growth opportunities, becomes more environmentally sustainable and restricts the flows of capital to declining industries.

What about countries that resist the energy transition? Gradual advocates note that many fossil fuel exporters and the current US administration are resistant to an energy transition, and large emerging economies like China and India will continue to fuel demand growth for all energy sources. Rapid advocates note that four out of five people live in countries that import fossil fuels, meaning that they would stand to benefit from a transition to local renewable energy sources. In particular, China and India are the largest and third largest fossil fuel importers and are strongly committed to a transition.

Can technology solve everything? While technology is increasingly devising cost-effective solutions that will drive an energy transition, the forces of inertia are very powerful. Therefore, policy-makers will need to play an active role for the goals of the Paris Agreement to be achieved in time.

Don't shoot the messenger. In an increasingly fraught world, it is important to note that some organizations whose data is referred to in this paper are providers of scenarios, not necessarily advocates of one narrative or the other.

Recent developments. Gradual advocates point to a rapidly rising energy demand, the roll-back of environmental protection in the US and the fact that renewable energy capacity growth in 2018 was similar to that in 2017. Rapid advocates point to the continued and unexpected fall in renewable costs, the continued S curves of new energy technology growth, and the rising pressure from financial markets and society for policy-makers to take more assertive action. They note that disruption is already happening in a series of energy and related sectors, from coal to electricity, turbines to cars.

What to watch out for. The key issues to watch over the course of the next decade have been laid out to see which narrative will prevail. In technology, the focus is on the cost and growth rates of the key disruptive technologies – solar, wind, batteries, EVs and green hydrogen. In policy, the focus is on whether politicians implement more rigorous actions to make fossil fuel users pay for their greenhouse gas externalities. In the emerging markets, the question is whether China and India will be able to continue to implement new clean energy and energy efficiency technologies at scale and whether the path they are setting will be followed by South-East Asia and Africa.

Signposts. A series of signposts are presented. Pass these and the Rapid narrative is on track. Fail to pass them and the Gradual narrative is playing out. Three targets have been set for 2030: solar electricity at $20-30 per megawatt hour (MWh); advanced lithium-ion batteries at $50-100 per kilowatt hour (kWh); and carbon taxes implemented on around half of emissions at $20 per tonne, with three peaks to take place in the 2020s in the event of Rapid transition: peak demand for new ICE cars; peak demand for fossil fuels in electricity; and peak demand for all fossil fuels.

2. Energy transition narratives

There are as many scenarios for the future of energy as there are forecasters, and it is of course not possible to know in advance which one is optimal. Paul Warde, the Cambridge energy historian, notes[2] that most long-term energy projections have been consistently wrong,[3] that projections have tended to have a significant bias in favour of the person asking the question, and that most projections have overestimated future demand.

Nevertheless, scenarios can be grouped into two primary narratives about the speed of the energy transition:[4] a gradual transition (Gradual); and a rapid transition (Rapid). In discussions about the future of energy, advocates of both sides will tend to select those scenarios and models that fit with their narrative. It is important to note that some organizations do not publish forecasts but scenarios; these scenarios can be used by advocates on both sides of the debate.

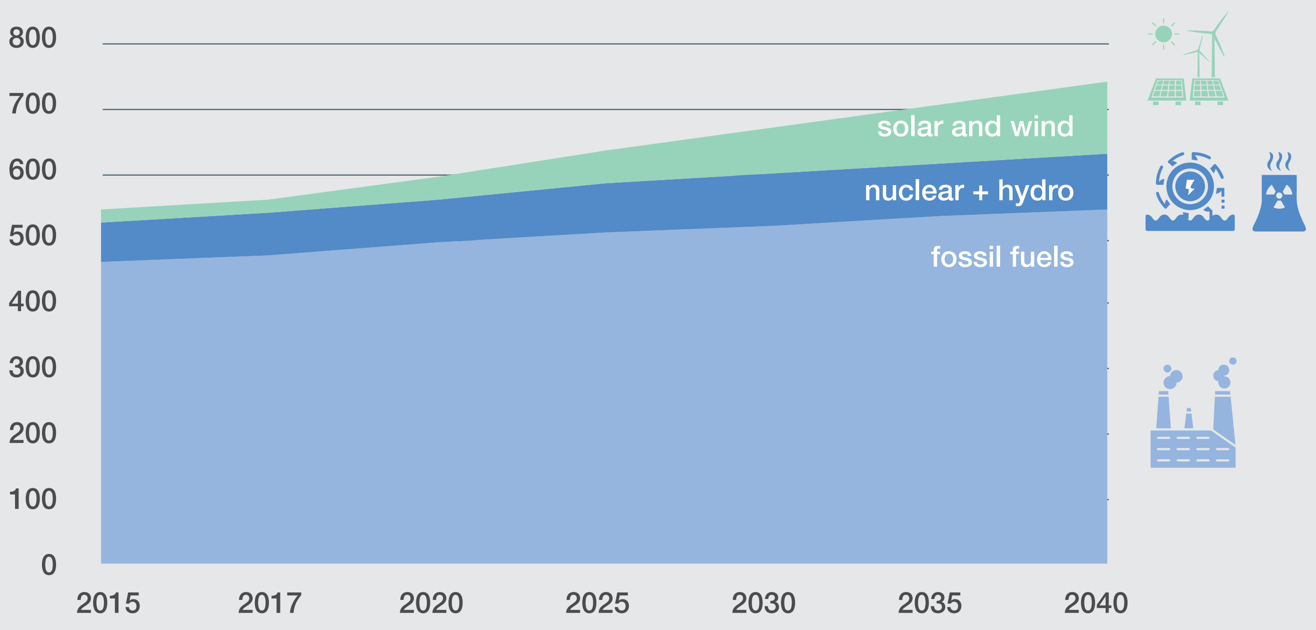
It is the narrative that sets expectations for the future, and this in itself is important because it determines how governments, companies and individuals allocate their resources.[5]

2.1 Gradual

Gradual scenarios include those from Exxon,[6] the Organization of the Petroleum Exporting Countries (OPEC),[7] the World Energy Council[8] and the Energy Information Administration,[9] as well as the IEA New Policies Scenario (NPS),[10] and the BP Evolving Transition Scenario (ETS).[11]

These scenarios imply that the energy world of tomorrow will look roughly the same as that of today. Fossil fuel demand will rise for the foreseeable future and, when it does start to decline, the decline will be gradual. Regrettably, this means that the goals of the Paris Agreement will become increasingly unachievable. Figure 1 shows an example from BP's ETS.

Figure 1: Energy supply (EJ), Gradual narrative, 2015-2040



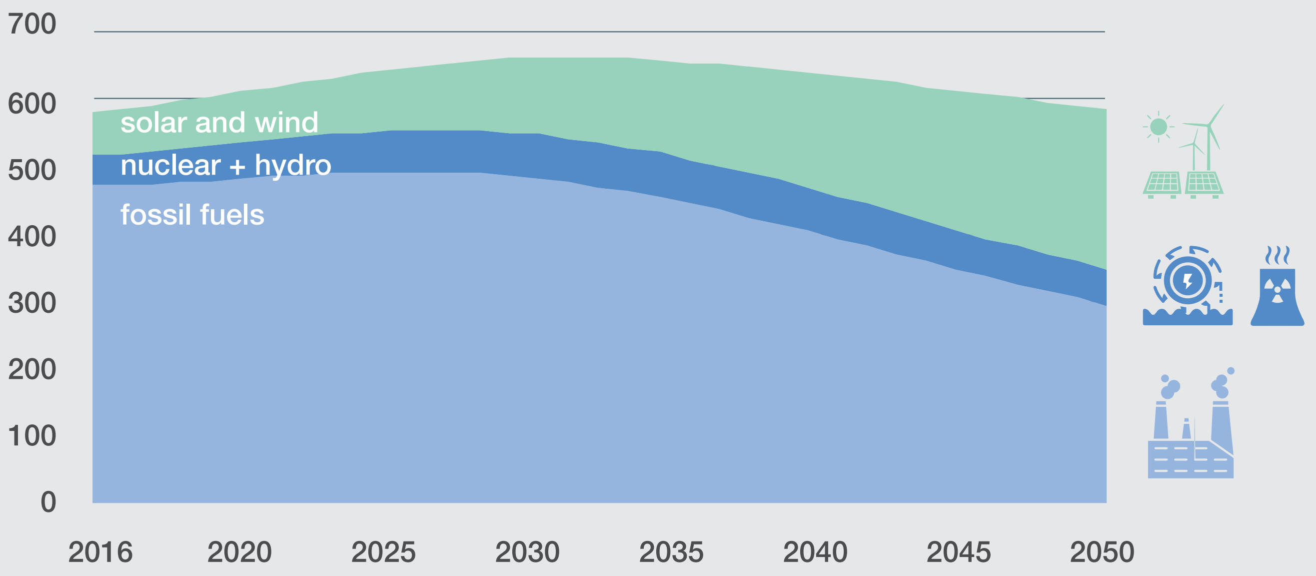
Source: Authors, based on data from BP, *BP Energy Outlook: 2019 edition,* Evolving Transition Scenario.

2.2 Rapid

Rapid scenarios include normative scenarios,[12] such as the IEA Sustainable Development Scenario (SDS),[13] the International Renewable Energy Agency (IRENA) REMap,[14] the Intergovernmental Panel on Climate Change (IPCC) less than two-degree models,[15] the BP Rapid Transition Scenario,[16] the International Institute for Applied Systems Analysis (IIASA) Low Energy Demand Scenario[17] and the Shell Sky Scenario,[18] as well as the primary scenarios of organizations such as Bloomberg New Energy Finance (BloombergNEF),[19] DNV GL,[20] McKinsey[21] and the Energy Transitions Commission.[22]

As a rule, these scenarios seek to achieve the goals of the Paris Agreement,[23] and imply that the energy sector is about to be disrupted. They forecast rapid growth in solar and wind electricity, the gradual electrification of transport, industry and heat, greater efficiency, policy action to tax fossil fuel users for their environmental externalities, and the development of new technologies like green hydrogen. They imply that demand for fossil fuels will soon peak and then enter a long period of decline. Figure 2 shows the example of the DNV GL energy forecast.

Figure 2: Energy supply (EJ), Rapid narrative, 2016-2050



Source: Authors, based on data from DNV GL, *Energy Transition Outlook 2018*.

It is important to emphasize that the Rapid path is the more difficult of the two. It will require a major coordinated effort of policy, technology development and behaviour from all sections of society to drive change across the whole of the economy on the timescale needed to achieve the goals of the Paris Agreement.

3. Differences between the two narratives

The differences between the two narratives can be summarized with regard to four key features: what matters, technology growth, policy and emerging market energy pathways. Of course, many other important drivers of the energy transition exist, such as efficiency or digitization, but these tend to be a feature of both narratives and are not the focus of this paper.

The energy sector is highly complex and the large number of variables in any scenario makes them hard to compare; as a result, examples seek to illustrate rather than to be comprehensive in this analysis. Not all scenarios fit neatly into the divisions describe below and each needs to be judged on its own merits. Moreover, some scenarios will of course be more extreme than others. Nevertheless, the chasm between the two narratives is sufficiently wide to merit some analysis.

3.1 What matters

At the start of this review, the assumption was that it would be possible to have a common starting point based on the facts for 2018. However, the facts can be interpreted very differently depending on the narrative. The focus is on four main points of difference: what matters for the energy transition; the importance of electricity; the importance of solar and wind; and the importance of distinguishing between the fossil fuels.

3.1.1 Total supply or change in supply?

What is the issue?

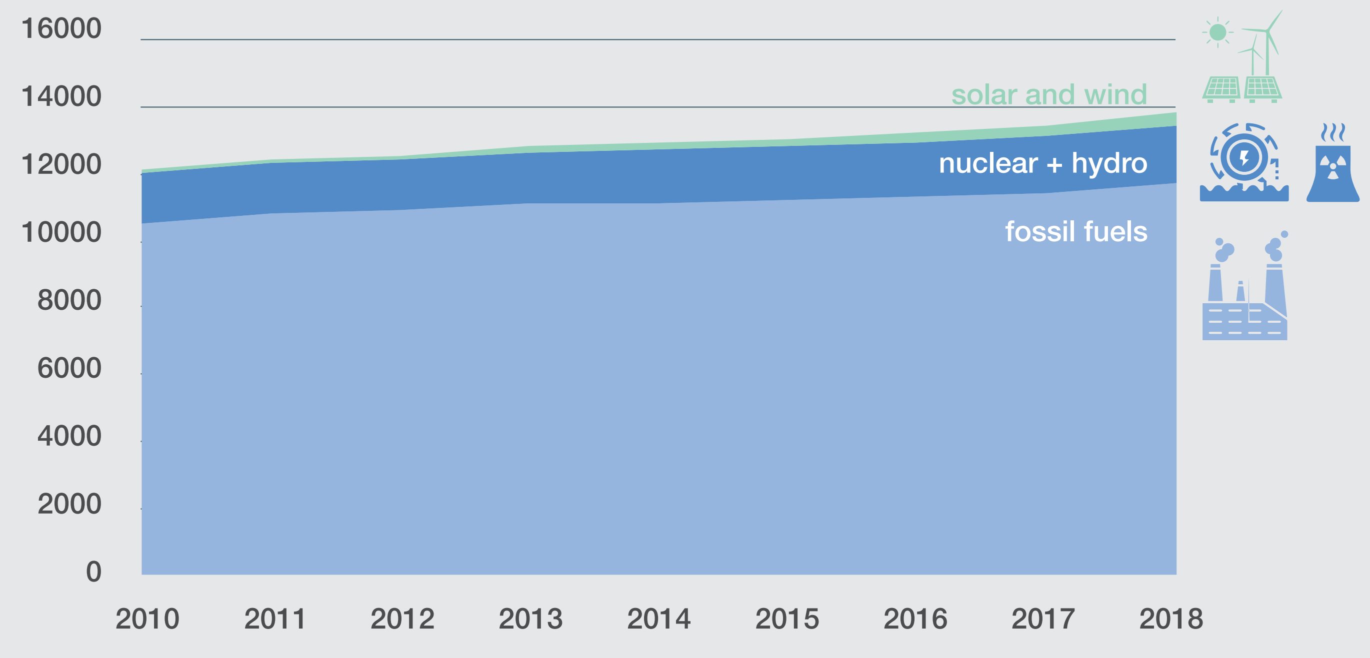
Should analysts focus on total supply or change in supply? For example, total supply of a product may be 100 units, projected to fall to 90 units in a decade. The analyst looking at total supply will argue that supply is still high, at 90 units. The analyst looking at change will say that supply has peaked and fallen by 10 units.

Total energy supply growth is usually 1-2% per annum, so the difference between total supply and the change in supply is enormous – nearly two orders of magnitude. In 2017, for example, total primary energy supply was 13,475 million tonnes of oil equivalent (Mtoe) and the change in supply was 246 Mtoe, according to BP.[24]

Gradual approach

The Gradual approach focuses on total supply and notes that, even with relatively high renewable growth, total supply for fossil fuels will remain high with a gradual shift towards natural gas within the mix of fossil fuels as a cleaner option to coal.[25] The energy historian Vaclav Smil comments that it will take many decades for renewable energy to overtake fossil fuels in terms of market share, and he argues that the move away from fossil fuels will be a protracted affair.[26] In Figure 3 from BP showing total energy supply over the last decade, it is very hard to see any impact from solar and wind, for example.

Figure 3: Total energy supply (Mtoe), 2010-2018



Source: Authors, based on data from BP, *BP Statistical Review of World Energy 2019*, 68th edition.

Rapid approach

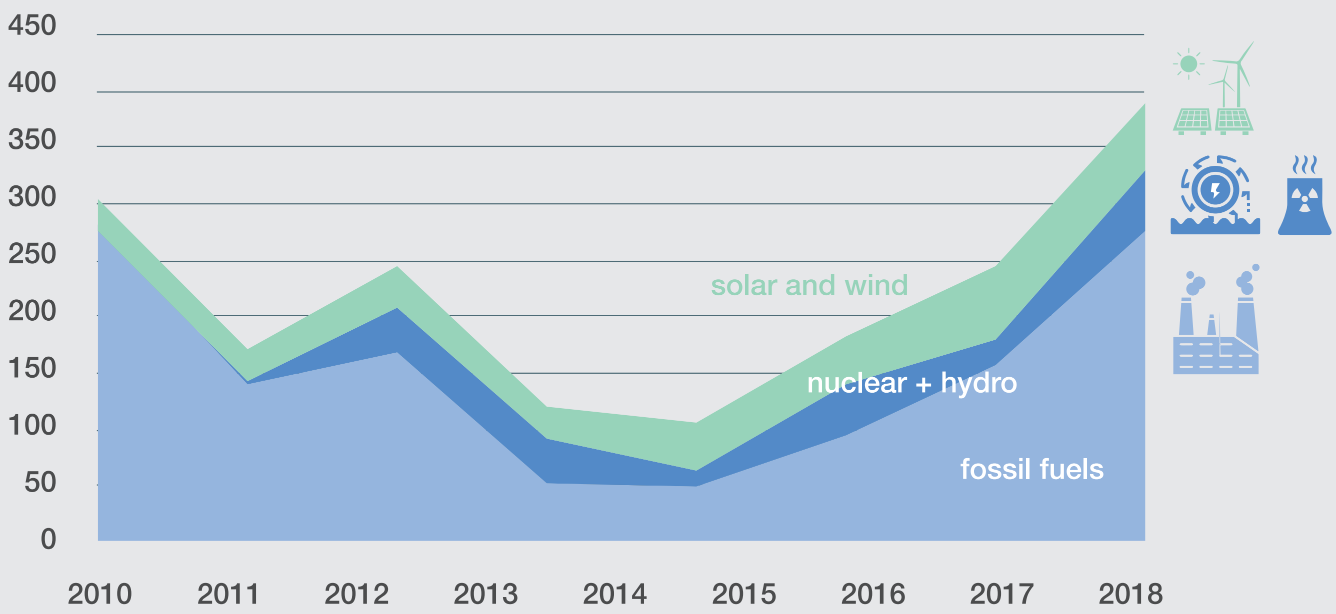
The Rapid approach does not deny that fossil fuels will continue to play a major role in energy markets for decades to come. The difference lies in the fact that the Rapid approach focuses on the change in supply and notes that the effects of change are felt by companies in these sectors as growth in their core markets turns to decline,[27] and are priced by financial markets even before supply peaks. Moreover, once a tipping point is reached, financial markets will tend to speed up the pace of change by constraining capital to declining industries and reallocating it to those that are growing.

The four most well-known examples of this process in recent years are electricity in Europe, coal, fossil fuel turbines and the car sector. In each case, incumbents were disrupted and stock prices impacted at around the time that demand for their product peaked. Advocates therefore focus on how long it will take for new energy technologies to supply all the growth.

If total supply growth is 246 Mtoe and non-fossil supply growth is 90 Mtoe, there will be many countries and sectors where fossil fuel supply has already peaked and is falling. To take three examples from the BP statistical review: European oil demand peaked in 2007 and has since fallen by 14%; Chinese coal demand peaked in 2013 and has fallen by 3%; and Japanese gas demand peaked in 2013 and is since down by 6%.

Taking exactly the same data as that set out above, but for the change in energy supply, a very different picture emerges (Figure 4). Non-fossil sources made up nearly one-third of the growth in energy supply in 2018 and the amount of energy they produce continues to grow rapidly. Energy demand growth in 2018 was unusually high; if it had been the same level as in 2015 for example, then non-fossil sources would already be supplying all the growth in energy demand.

Figure 4: Change in energy supply (Mtoe), 2010-2018



Source: Authors, based on data from BP, *BP Statistical Review of World Energy 2019*, 68th edition.

3.1.2 How important is electricity?

What is the issue?

Final energy consumption includes both electricity (a high-quality energy carrier) and other energy sources, such as coal, oil and gas. However, electricity can be used with minimal losses for energy services (like turning on a light), while fossil fuels lose about two-thirds of their energy in thermodynamic losses when they are converted into most forms of useful energy. The question then is how to compare the two.[28]

In 2017, electricity was 19% of total final energy consumption and 38% of total primary energy demand, according to the IEA.[29] Because of the continued electrification of a range of sectors, electricity was 56% of the increase in total primary energy demand. The question is: which of these numbers is more relevant?

Gradual approach

The Gradual approach compares electricity with fossil fuels as if they were equivalent and notes that a deep restructuring of the entire energy system is needed. Advocates argue that electricity is a small share of total final consumption, so growth in that area is likely to be offset by continued fossil demand growth in other areas.

Rapid approach

The Rapid approach seeks to adjust for the thermodynamic losses of fossil fuels by looking at total primary energy demand. From that perspective, electricity used 38% of all primary energy in 2017. Moreover, they look at the change in demand, where electricity was 56% in 2017 and is likely to increase to two-thirds as a result of rising electrification of end-use sectors, such as transport and heat.

Electricity therefore assumes a much more important role in the discussion. And a transition of the electricity sector alone will be sufficient to drive peak demand for fossil fuels (but not the Paris Agreement). The math is not complex. Falling fossil fuel demand in electricity generation (two-thirds of the growth in demand) needs to be higher than rising fossil fuel demand in all the other sectors (one-third of the growth in demand).

3.1.3 How important are solar and wind?

What is the issue?

The issue is how to count solar and wind electricity (a high-quality energy carrier) as a share of global energy supply.[30] Because of thermodynamic losses, this is a real issue – the introduction of 100 MWh of solar will replace primary energy supply of 200-300 MWh of coal.

Gradual approach

The Gradual approach counts solar electricity in the same way it counts coal, without any adjustment. As a result, the new energy technologies of solar and wind appear relatively small. For example, the IEA implies that solar and wind electricity were just over 1% of global primary energy supply in 2017.[31]

Rapid approach

The Rapid approach seeks to adjust for the gap by multiplying solar and wind by a factor of 2-3 times when converting them into primary energy equivalents. For example, BP multiplies solar and wind electricity by 2.6 when converting them into Mtoe, and calculates that the share of solar and wind electricity in global primary energy supply is more than twice as large as the IEA estimates, at 2.6%.[32]

The gap between the two does not appear to be very material until the argument shifts to the change in supply rather than simply the total supply. BP data show that solar and wind made up 27% of the change in total energy supply in 2017. If current solar and wind growth rates of 15-20% are maintained, Carbon Tracker calculates that they will supply all incremental energy (not just electricity) in the early 2020s.[33] This makes them extremely material as agents of change.

3.1.4 Differences between the fossil fuels

What is the issue?

The three main fossil fuels of course are coal, oil and gas. Each is used in different applications in each of the world's countries, in a bewildering amount of complexity. The question is whether it makes any sense to talk about fossil fuels as a whole or whether it is necessary to look at each fossil fuel in each country separately.

Gradual approach

The Gradual approach is built upon highly complex models and seeks to model each end sector and each fuel in each country. The advantage of this method is that it enables forecasters to understand the impact of detailed changes, such as the removal of a refinery or a country from the global oil supply mix. Moreover, the argument is often made that the disruption striking the energy sector applies much more to coal than it does to oil and gas. Therefore, a coal transition rather than an energy transition affecting all fossil fuel sectors is being witnessed.

Rapid approach

The Rapid approach argues that it is necessary to take a simpler modelling approach at times of disruption. The technology and policy pressures that are being felt across the energy complex at present will have an effect on all fossil fuels. And as technology improves, the fungibility between fossil fuels is also increasing (for instance cheap batteries make solar more fungible with oil to power vehicles at scale). Therefore, the peak in coal demand is likely to be the first of these peaks, to be followed by a peak in oil demand and eventually by a peak in gas demand. And as companies and financial investors see the pattern of these peaks, they will invest accordingly, which will in turn speed up the transition.

3.1.5 The starting point of the two narratives

These four issues mean that there are major differences in the way the energy environment is perceived today, before the discussion on the future even starts.

Gradual approach

Gradual advocates argue that the forces of disruption are small and therefore unlikely to have much of an impact. They concede that changes are taking place in the electricity sector, but note that electricity is only 19% of total final energy consumption. Meanwhile, they argue that solar and wind are only 1% of total energy supply and electric cars are only 0.5% of the global car fleet. They focus on the difficulty of providing renewable energy solutions in sectors like heat and petrochemicals, and argue that developments in electricity are necessary but not sufficient. They note that in 2017, fossil fuels provided 81% of primary energy supply, and coal provided 38% of electricity, about the same as 30 years ago. It will take decades for renewable energy sources to become dominant in energy supply.

Rapid approach

Rapid advocates note that non-fossils provided 51% of the growth in global electricity supply in 2018[34] and 28% of the growth in global energy supply, and that solar and wind are still growing very rapidly. Electricity is 38% of primary energy demand and will be two-thirds of the growth in primary energy demand as the world continues to electrify. As a result, the disruption that is taking place in the electricity sector will be sufficient to drive a peak in demand for all fossil fuels because declining demand in fossil fuels for electricity generation will outweigh rising demand for fossil fuels elsewhere in the energy complex.

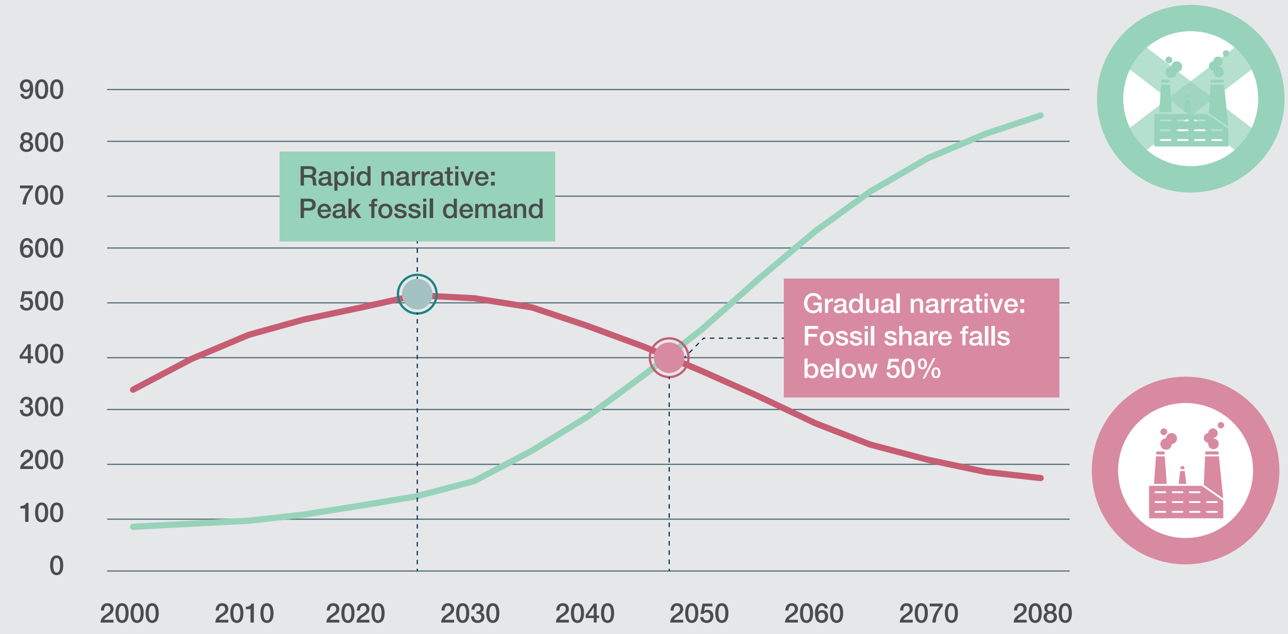
The gap

It is instructive to consider the gap between the two narratives with regard to the importance and timing of the moment when the transition is felt. To illustrate this, Figure 5 shows energy supply in the Shell Sky Scenario split into fossil fuels and non-fossils.

The Gradual narrative focuses on the point where non-fossils make up half of all supply. This, even under the Shell Sky Scenario, is not until 2050. Furthermore, advocates point out that even in 2100, the demand for fossil fuels is still quite high.

The Rapid narrative focuses on the point where non-fossils make up all incremental supply. This is in 2025, which is a generation earlier, and when non-fossils are just a quarter of total energy supply. Advocates argue that the remaining amount of demand for fossil fuels in 2100 is both hard to forecast with any certainty and is part of the "endgame", the final areas of fossil fuel demand that may survive and will need to be replaced, but which are not enough to sustain the industry at its current size.

Figure 5: Global energy demand (EJ), 2000-2080



Source: Authors, based on data from Shell International, *Shell Sky Scenario,* 2018.

3.2 Technology growth

Technology differences between the two narratives include the cost of existing new energy technologies, expectations for future technologies, the impediments to change and expected future growth rates.

3.2.1 Cost of variable renewables in electricity

The reason why variable renewable costs are so important is because costs are the agents of disruption in this as in so many other technology transitions. In the discussion below, the focus is on the cost of electricity from solar, although the story is similar for other disruptive technologies, such as wind, batteries and smart demand-side technologies.

What is the issue?

The question relates to what the costs of variable renewables are today and in the future. It might seem strange that there is dispute even over facts that are known, but this is indeed the case.

Gradual approach

The Gradual approach tends to be relatively conservative.[35] It takes peer-reviewed data (which is by definition backward-looking) and is cautious about future changes in costs. For example, the IEA NPS argues that the levelized cost of energy (LCOE) of solar in 2017 in the United States was $105 per MWh,[36] and that it would fall to $50 per MWh by

2040. Furthermore, the NPS argues that there are additional expenses for the deployment of solar (because of connection costs and intermittency costs), known as system costs, which make the real cost even higher. The total US cost of solar with system costs is calculated as $105 per MWh in 2017 (the same as without system costs) and $55 per MWh in 2040 (so 10% higher than without system costs).

Rapid approach

The Rapid approach tends to take forward-looking costs, to use actual projects[37] and to be more optimistic about future cost falls. It is accepted that solar electricity costs have been falling at over 15% a year since 2009, and that solar modules have enjoyed a learning rate of 28% for every doubling in capacity.[38] Advocates argue that it therefore makes sense to look forward because of the speed of change, and that costs are likely to continue to fall in line with the learning rate. They argue that the costs used by the Gradual approach are demonstrably incorrect, and that the Gradual approach fails to incorporate the cost of externalities.

Moreover, they note that a number of renewable technologies have enjoyed rapid cost falls thanks to learning by doing, the scale effect and the virtuous learning circle. As costs have fallen, consumers have embraced the new technologies and governments have encouraged them, leading to lower costs and a new round of adoption. Hence, they argue that the growth should be modelled in a dynamic manner not a static one.[39]

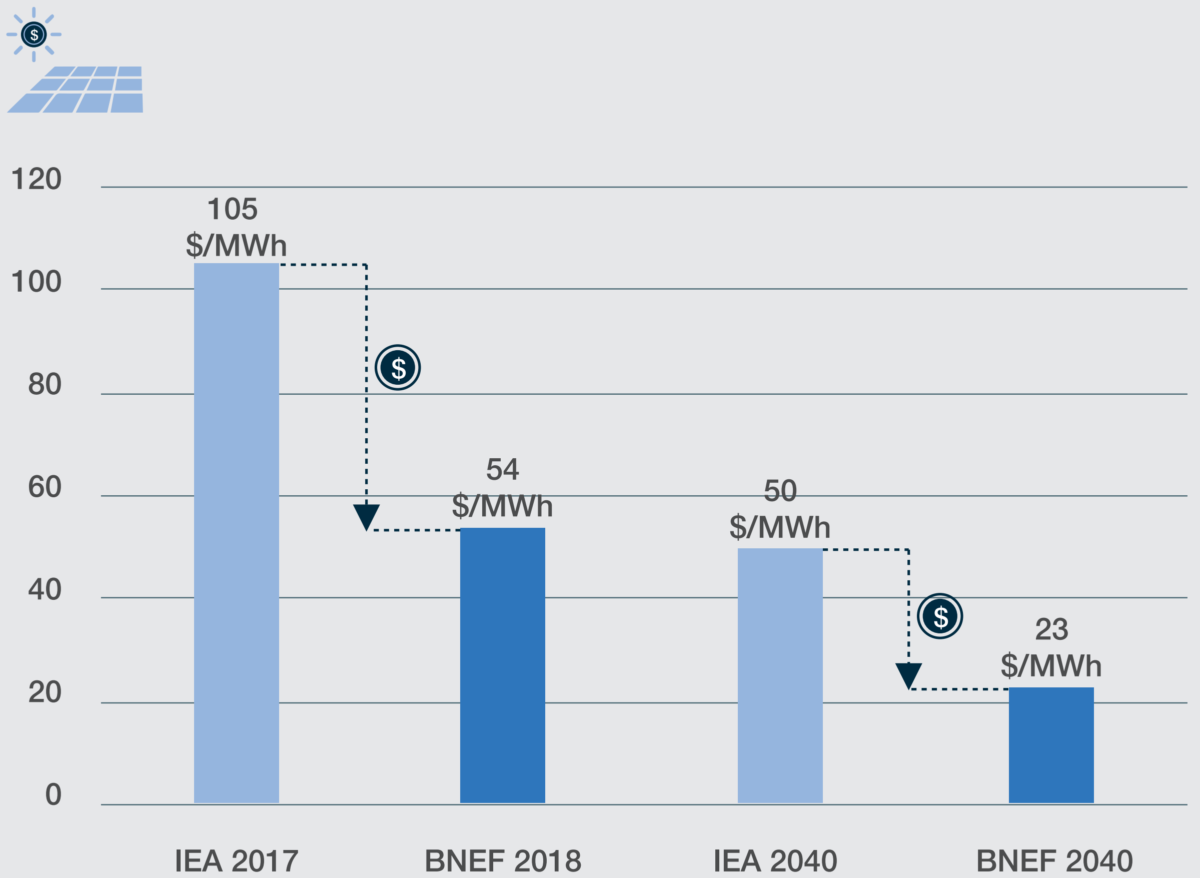
The upshot is that Rapid models have very different costs even for today. For example, BloombergNEF argues that the 2018 LCOE of solar in the United States was $42-65 per MWh, and it expects this to fall to $20-25 per MWh by 2040.[40]

Rapid advocates note that system costs vary with the level of penetration of variable renewables and argue that they are unlikely to impose a major burden on the cost structure for the foreseeable future. Even as penetration rises, technologies such as storage and demand response are likely to make higher levels of penetration cheaper. It is notable, for example, that solar plus storage projects are already starting to compete with fossil fuels in the United States.[41]

The gap

The gap between the two approaches is captured nicely by the actual and forecast US LCOE, according to the IEA NPS and BloombergNEF. The forecast IEA NPS 2040 solar costs are almost the same as the actual average BloombergNEF 2018 cost (Figure 6).

Figure 6: US solar (LCOE, US$/MWh)



Sources: Authors, based on data from International Energy Agency, *World Energy Outlook 2018*, New Policies Scenario, and BloombergNEF, *New Energy Outlook 2018*.

3.2.2 New technologies

What is the issue?

The Energy Transitions Commission points out that existing new energy technologies will be able to accomplish much of the energy transition. However, improved technologies will be required to replace fossil fuels in hard-to-solve sectors, such as petrochemicals, airlines, winter heating or cement.[42] It is clear that investment is needed today for costs to fall so these technologies are ready by the time they are required. The question is whether it is feasible and reasonable to forecast technology evolution.

Gradual approach

The Gradual approach is relatively conservative on the development of new technologies, preferring to focus on what is known rather than what may happen.[43] Advocates point out that the evolution of technologies is a complex and slow-moving process, requiring long lead times and significant amounts of capital. The implication is that these hard-to-solve areas not merely remain insoluble but will also grow. For example, most Gradual scenarios see rising demand for trucks and petrochemicals as the primary driver of rising oil demand over the next 20 years.

Rapid approach

Advocates note that energy technology developments over the last decade have already been rapid as technologies progressed on learning curves. In 2009, lithium-ion batteries cost over $1,000 per kWh and solar cost over $350 per MWh; by 2019, the cost of lithium-ion batteries had fallen to $160 per kWh and solar to $50 per MWh. Clearly change has indeed been possible. The advocates use this to make three key arguments:

– Current disruptive technologies, such as solar and batteries, continue on their learning curves. This will enable them to penetrate into ever more sectors.

– Technologies will continue to evolve to enable deeper penetration of existing disruptive technologies. For example, variable renewable energy will be able to increase its share of total electricity supply. Or electricity will be able to increase its share in the transport, heat and industry sectors. The speed with which companies are developing etrucks, and the many new solutions being put forward to reduce the demand for plastics are examples.

– New technologies will be developed to address the more intractable hard-to-solve sectors, such as petrochemicals or airlines. A series of solutions was put forward in the Energy Transitions Commission's *Mission Possible* publication. Meanwhile, the IEA notes that cheap solar can be used to create green hydrogen through electrolysis, and that hydrogen can substitute for gas or oil in many areas of the energy system.[44]

This is not to say that a shift will be easy. Success will be the result of a combination of good policies and technologies following learning curves. Not all renewable technologies have succeeded, and not all apparently promising technologies will succeed.

3.2.3 Impediments to growth

What is the issue?

The impediments to the implementation of the new energy technologies are the issue: at what point will technologies be unable to grow any further because of some insurmountable technological, economic or physical barrier? Social and political barriers are dealt with in the next section.[45]

Gradual approach

Gradual scenarios tend to be relatively cautious regarding the difficulty of implementing new energy technologies. They have a wide range of concerns, including the lack of space for renewable energy technologies to be deployed; the difficulties inherent in reaching 100% carbon-free energy; the problems of setting up EV infrastructure; or the lack of supply of various minerals, from cobalt to nickel to rare earths.

Moreover, in many cases, the widespread adoption of new technologies proves prohibitively difficult to model with existing modelling practices. Existing models are built to balance supply and demand in fossil-fuel-based markets, which are fundamentally distinct from emerging renewables and high asset-utilization service-based markets.

Rapid approach

Rapid models do not deny that impediments exist in most countries to implement 100% carbon-free energy. However, they make two observations: most countries are well below the feasibility ceiling; and the ceiling of feasibility keeps rising as the result of the continued improvements in technology and emerging business models.

This can be illustrated with regard to wind and solar. In 2018, solar and wind provided 7% of the supply of electricity globally, ranging from many countries with very small amounts (in 27% of global electricity supply, solar and wind country penetration is under 5% and, in 94% of the total, country penetration is under 15%) to a number of countries with more than 25% solar and wind, and some regions with more than 50%. Clearly, then, the feasibility ceiling is above 25%, and the IEA notes that there are phases in the process.[46]

Many examples of the rising feasibility ceiling exist. Innovations in electricity distribution systems have dramatically increased the feasible levels for the implementation of solar and wind, from under 5% some 20 years ago to over 50% today, and these systems continue to evolve.[47]

Outside the electricity sector, the picture differs, but the approach assumes that solutions will be found. In light transport, for example, there seemed to be many impediments to the growth of the EV. But as battery costs fall and expertise increases, range anxiety is diminishing as an issue. Meanwhile, it has become more likely that EV infrastructure will be rolled out as EV sales rise; some companies are now offering free home charger installation in return for access to the battery as a storage device.

Meanwhile, economic impediments reduce as costs fall. It is possible to build marginal abatement cost curves to calculate the cost per tonne of reducing carbon dioxide emissions, and the Global Commission on the Economy and Climate argues that, when the co-benefits of an energy transition are taken into account, two-thirds of greenhouse gas emissions (25 gigatonnes (Gt) per year) can be eliminated at zero cost by 2030.[48] Even without co-benefits, its analysis suggests that half the emissions can be eliminated at zero cost.

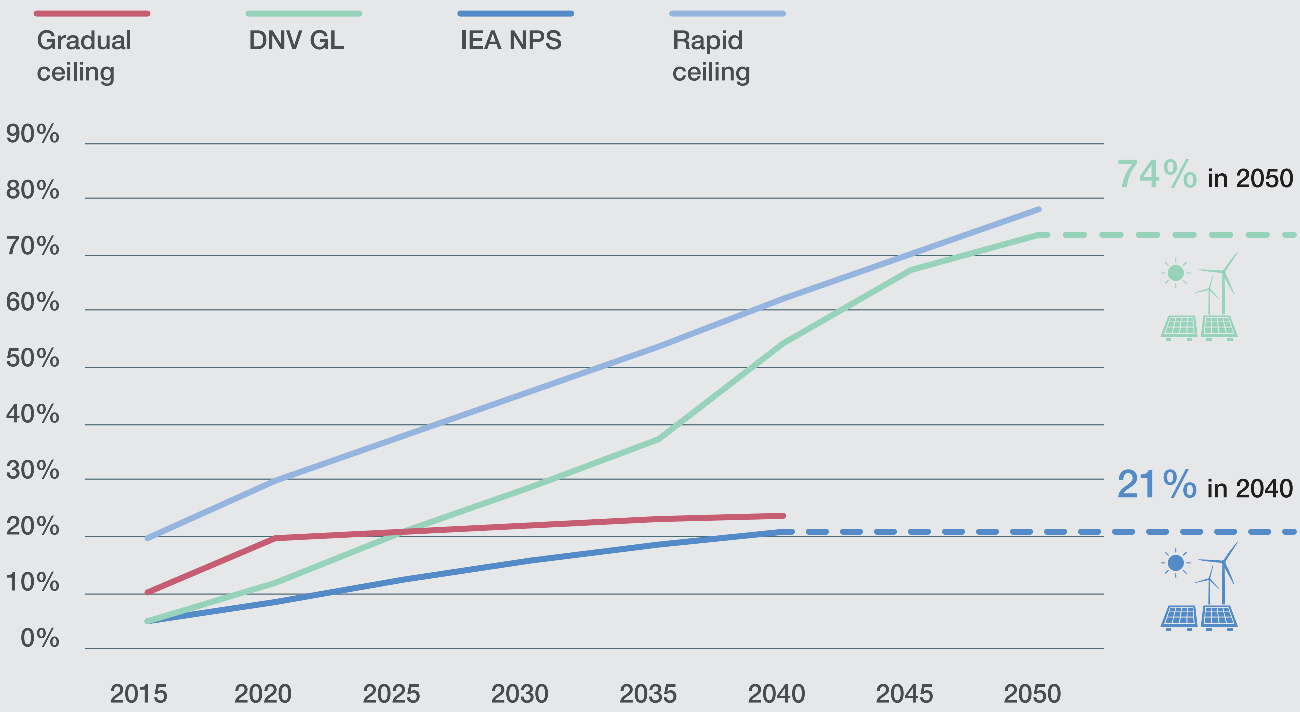
As a result, advocates argue that the technological and economic impediments to the growth of renewables can be solved for the foreseeable future. No change is easy, nothing can be accomplished without effort, but that does not mean it is unachievable.

The gap

For each perspective, it is possible to show the ceiling of technological possibility graphed against today's levels of penetration. Neither perspective argues that the ceiling has been hit today. The Gradual narrative argues that we will shortly bump up against it; the transition will peter out as the low-hanging fruits are plucked. The Rapid narrative argues that the ceiling is high above our heads and will continue to rise as the result of technological improvements.

The argument is illustrated in Figure 7 with regard to solar and wind as a share of electricity generation with an illustrative depiction of the ceiling, but it could apply to many other sectors as well.

Figure 7: Solar and wind as a share of electricity generation and the ceiling level, 2015-2050



Sources: Authors, based on data from International Energy Agency, *World Energy Outlook 2018*, New Policies Scenario, and DNV GL, *Energy Transition Outlook 2018*; Carbon Tracker Initiative estimates for the "ceiling" level.

Growth rate of existing new energy technologies

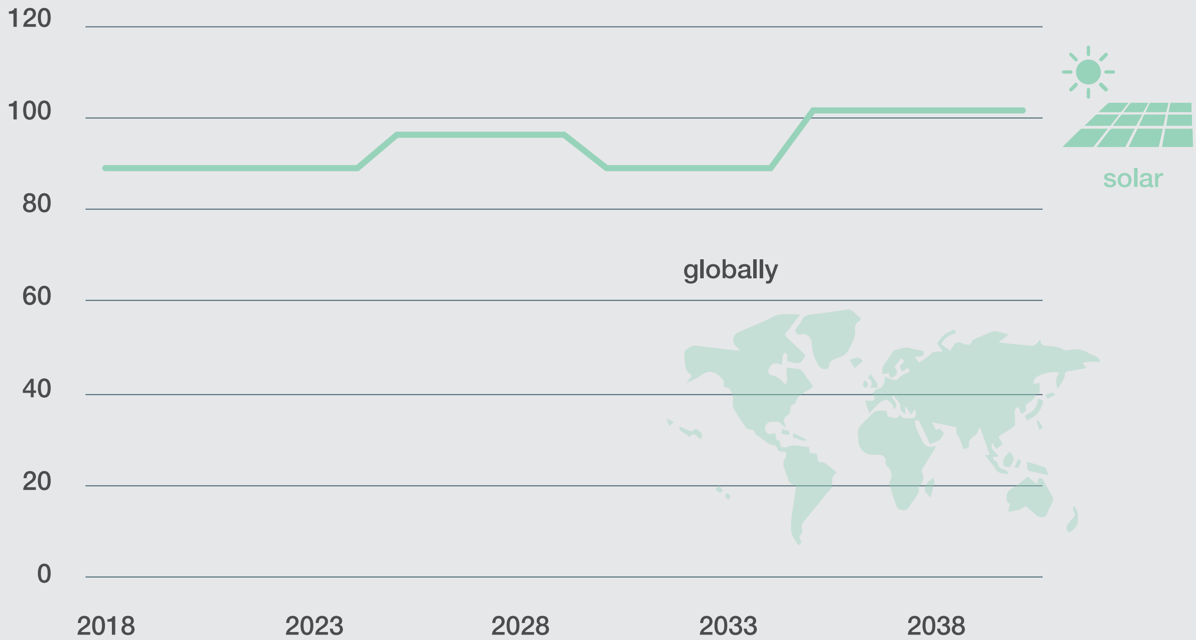
What is the issue?

Different assumptions regarding costs, barriers to growth and technology evolution drive very different projections of the growth rate of renewables. Will the growth rate of new technologies be linear or exponential?

Gradual approach

Gradual models assume that the renewable energy growth rate is linear. An example is the projection of annual installations of solar capacity in the IEA NPS. In the 2018 forecast, for example, it is assumed that solar panel installations will remain at around 100 gigawatt (GW) per annum until 2040 (Figure 8).

Figure 8: New solar capacity (GW), 2018-2040



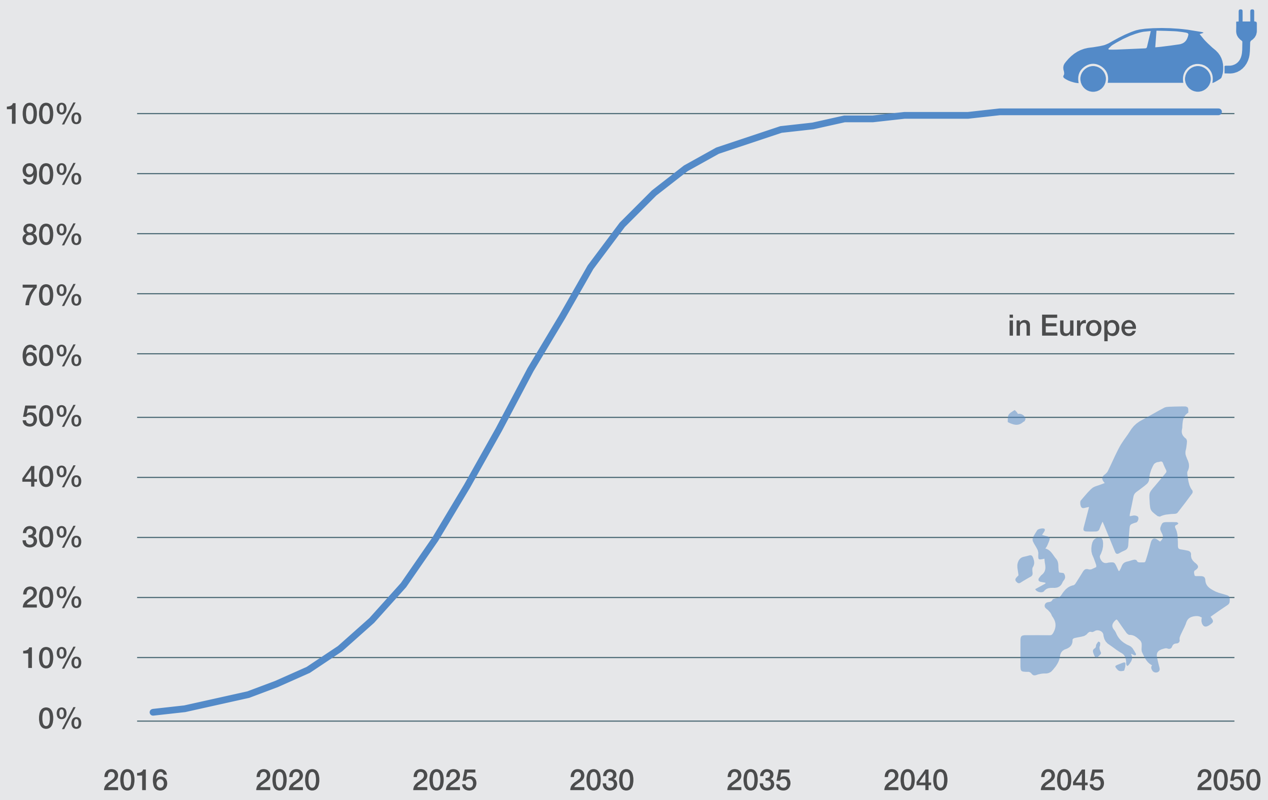
Source: Authors, based on data from International Energy Agency, *World Economic Outlook 2018*, New Policies Scenario.

Rapid approach

Rapid models assume that renewable supply continues to rise on exponential S curves of growth. In an S curve, the market share of the new technology moves very rapidly from 5% to around 90%, before slowing down. This is a phenomenon that has been seen in technology diffusion many times in the last century, from cars, radios and televisions to the mobile phone and internet in recent years. Advocates note that Gradual models failed to forecast the rapid growth of solar and wind for many years, and that it is necessary therefore to adopt a different approach.[49] They point out that, even in 2018, the installation of solar panels (96 GW, according to BP) was much higher than the forecasts of standard Gradual models for 2018.

DNV GL, for example, forecasts the rapid growth of solar, wind and EVs along S curves. Sector specialists, such as IDTechEx, have a similar perspective.[50] This is illustrated in Figure 9 with the DNV GL forecast for the market share of EVs in Europe.

Figure 9: Market share of electric vehicles in Europe, 2016-2050

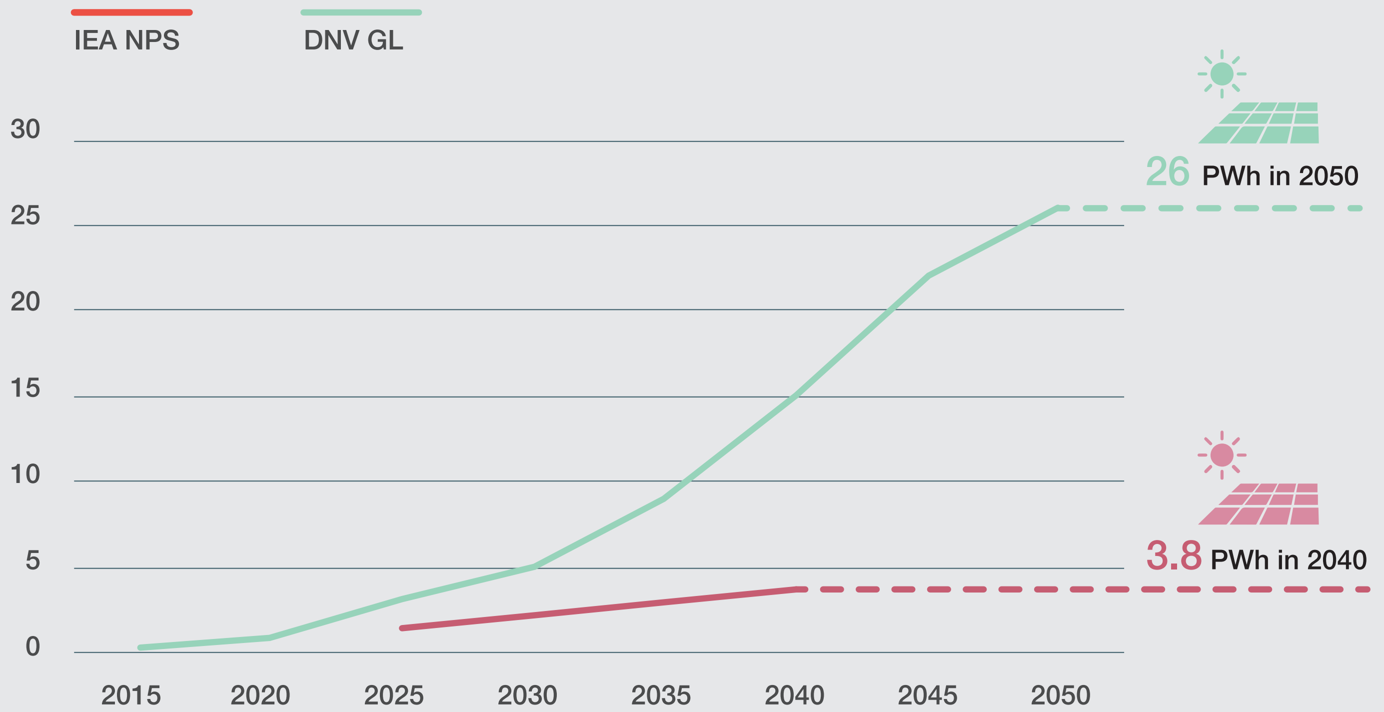


Source: Authors, based on data from DNV GL, *Energy Transition Outlook 2018*.

The gap

Different assumptions about the nature of growth lead to a huge gap between the two narratives. This is illustrated with the forecasts for electricity generation from solar photovoltaics (Figure 10). The IEA NPS forecast assumes slow linear growth, while the DNV GL forecast assumes exponential growth rates.

Figure 10: Solar electricity generation (PWh), 2015-2050



Sources: Authors, based on data from International Energy Agency, *World Energy Outlook 2018*, New Policies Scenario, and DNV GL, *Energy Transition Outlook 2018*.

3.3 Policy

Developments in technology are only one part of the energy transition. For change to happen rapidly, policies will need to better align the incentives of investors, businesses and individuals with the interests of society. And here again, a major gap exists between the two narratives in terms of what can be expected from policy. Gradual models expect limited policy action, while Rapid models expect significant policy action, encapsulated in the idea of an Inevitable Policy Response.[51] The two perspectives with regard to the global balance of forces are summarized, followed by the country balance of forces.

3.3.1 The global balance of forces

What is the issue?

First, a look at the global balance of forces. Many forces impact policy-makers. These include considerations on costs, jobs, health, global warming, geopolitics, pressures from civil society and the lobbying power of incumbents and beneficiaries of the fossil fuel system.

The IEA and IRENA have shown that the capital cost of an energy transition is similar to the cost of maintaining the current fossil fuel system.[52] Moreover, IRENA has shown that more jobs are required in a renewable system than a fossil fuel system.[53] However, a shift from one energy source to another would reduce rents flowing to the owners of fossil fuel assets (estimated by the World Bank to be around 3% of global GDP)[54] and could lead to stranded assets and communities if not handled in a sensitive manner. If these were the only considerations, then the power of inertia and lobbying would likely be able to maintain the status quo.

However, a number of further considerations are starting to impact decision-making.

– The cost of global warming, estimated by the Stern report[55] at 5% of global GDP with large tail risks from feedback loops, and by Burke, Davis and Diffenbaugh at 15-25% of global GDP[56]

– The dramatic human costs of heat stress, disease and migration that are hard to quantify in GDP terms

– The impact on health of outdoor air pollution (mainly from fossil fuels), estimated by the World Health Organization as killing 4.2 million people a year[57] and likely to double by 2060[58]

– The 1 million species at risk of extinction.[59]

When these are factored in, IRENA calculates that the benefits of an energy transition will outnumber the costs by 3-7 times.[60]

Gradual approach

The Gradual approach argues that policies that have yet to be approved should not be forecast, and points to the repeal of the Clean Power Plan (CPP) in the United States.[61] Moreover, the prospect of a rapid transition will create losers who want to maintain the status quo and feel relatively passionate about it. In certain countries, they are able to capture the government and use it to resist change.

Advocates note that even after a decade of pronouncements about the need to tax fossil fuels, the average global carbon tax per tonne is under $2.[62] Even if policy-makers ought to act, reality suggests that they will not.

Rapid approach

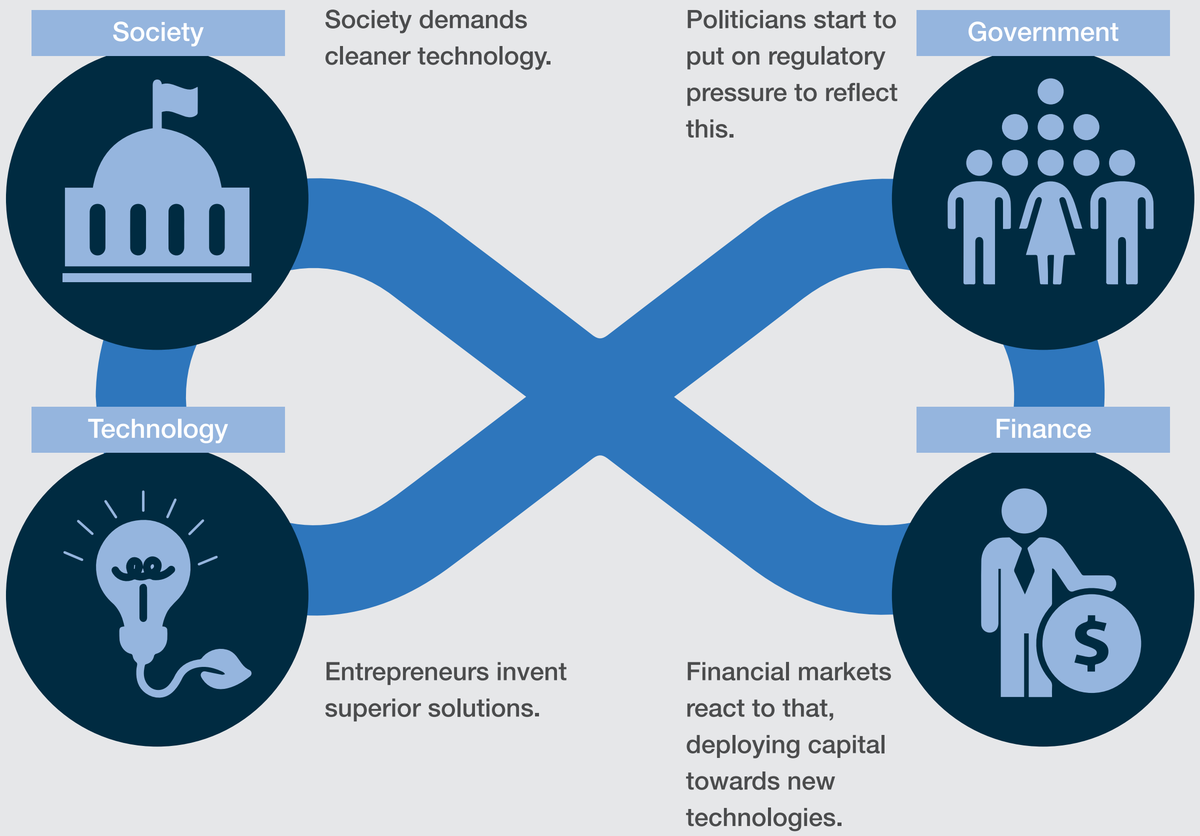
The Rapid approach notes that societal and financial forces for change are building, as seen in the rise of civil society pressure movements, such as Extinction Rebellion, and financial pressure groups, such as Climate Action 100+. Coal plants are still closing down in the United States because of economic pressures, in spite of support from the Federal government.

Advocates for this approach assume that policy will take advantage of new technological innovations in order to meet the aspirations of society. The falling costs of renewables have opened a window of opportunity for politicians to pursue green policies without imposing major costs on society, while garnering significant public support.[63] The rising popularity of the Green New Deal is an example of such a political shift.

To quote the Committee on Climate Change: "Once a technology becomes sufficiently competitive, it starts to change the entire environment in which it operates and interacts. New supply lines are formed, behaviours change, and new business lobbies push for more supportive policies. New institutions are created, and old ones repurposed. As costs fall … the political and commercial barriers to a transition begin to drop away. A tipping point is eventually reached where incumbent technologies, products and networks become redundant."[64] That is to say, as the costs of renewables continue to fall, policy-makers will be able to react to the desire of voters to take action, and start to make fossil fuel users pay for their externalities.

Moreover, Rapid advocates argue that there is a positive feedback loop between government, technology, finance and society (Figure 11). Society demands cleaner technology and politicians start to put on regulatory pressure to reflect this. Financial markets react to that, deploying capital towards new technologies,[65] and entrepreneurs invent superior solutions. As these achieve greater scale, costs fall, society is able to afford more, politicians can legislate and investors allocate more capital. Electric vehicles provide an excellent example of this positive feedback loop. They started as expensive toys for the rich, but rising sales are driving much lower battery costs and more aggressive policy action, and they are now becoming a mass-market product.

Figure 11: The positive feedback loop



Source: Authors, based on data from Carbon Tracker Initiative.

As a result, Rapid scenarios assume rising costs of carbon and falling subsidies for fossil fuel usage. Even if policy cannot be forecast in detail, they argue it is reasonable to assume that policy will evolve, encapsulated in the idea of an Inevitable Policy Response. This is the moment when governments will be forced by the deteriorating environmental position to take more drastic action to curtail fossil fuel demand. They point to the increasing number of countries that target 100% renewable electricity by 2050,[66] and to individual states in the United States, such as California or Hawaii, which plan to move to 100% renewables.

3.3.2 The country balance of forces

What is the issue?

Even if the global balance of forces may favour a transition, the picture can be very different at a country level. Although the situation is more complex, the first distinction to be made is between fossil fuel exporters (which may well resist a transition) and importers (who as a rule would benefit from it). There are of course exceptions to this framework. Japan is the world's second largest fossil fuel importer but has so far been relatively supportive of the coal sector, and Norway is one of the world's larger oil exporters but has embraced a transport transition.

Gradual approach

The Gradual approach points to recent developments in the United States and in Australia as examples of countries where fossil fuel supporters have been able to take control of the political process and use it to hold back change.

Rapid approach

Advocates note that around 20% of the world lives in counties that are net exporters of fossil fuels, and 80% of the world lives in countries that are fossil fuel importers, so the geopolitical and societal advantage is aligned with reducing fossil fuel usage.[67] While incumbents may find it easier to prevent change in the energy exporters (such as Australia), they are likely to find it more difficult to do this in the importers of energy. And in the world's two largest countries of China and India, the imperative is clearly to reduce fossil fuel imports.

3.4 Emerging market energy pathways

The emerging market energy story is singled out for special treatment because it is key to any transition. In 2018, the average US citizen used 295 gigajoules (GJ) of energy, while the average Indian used just 25 GJ.

3.4.1 What is the issue

It is generally accepted that energy demand in the OECD has been falling and is likely to continue to fall. Almost all growth in energy demand is likely therefore to come from the emerging markets. The implication is that developments in China and India are therefore more pertinent to the question of the change in energy demand than those in the United States and Europe. The question is whether these countries will follow the Western path of fossil-fuel-based development or take their own energy path. Will countries like India or Viet Nam build their growing electricity systems on coal or on solar? Will they drive in ICE cars or in EVs?

3.4.2 Gradual approach

Gradual advocates assume that emerging market demand will largely follow the pattern set by developed markets – the demand growth for fossil fuels will increase as GDP rises and people become richer.[68] These models are able to point to the fact that energy demand clearly rises with GDP, which in the past has meant more demand for fossil fuels.

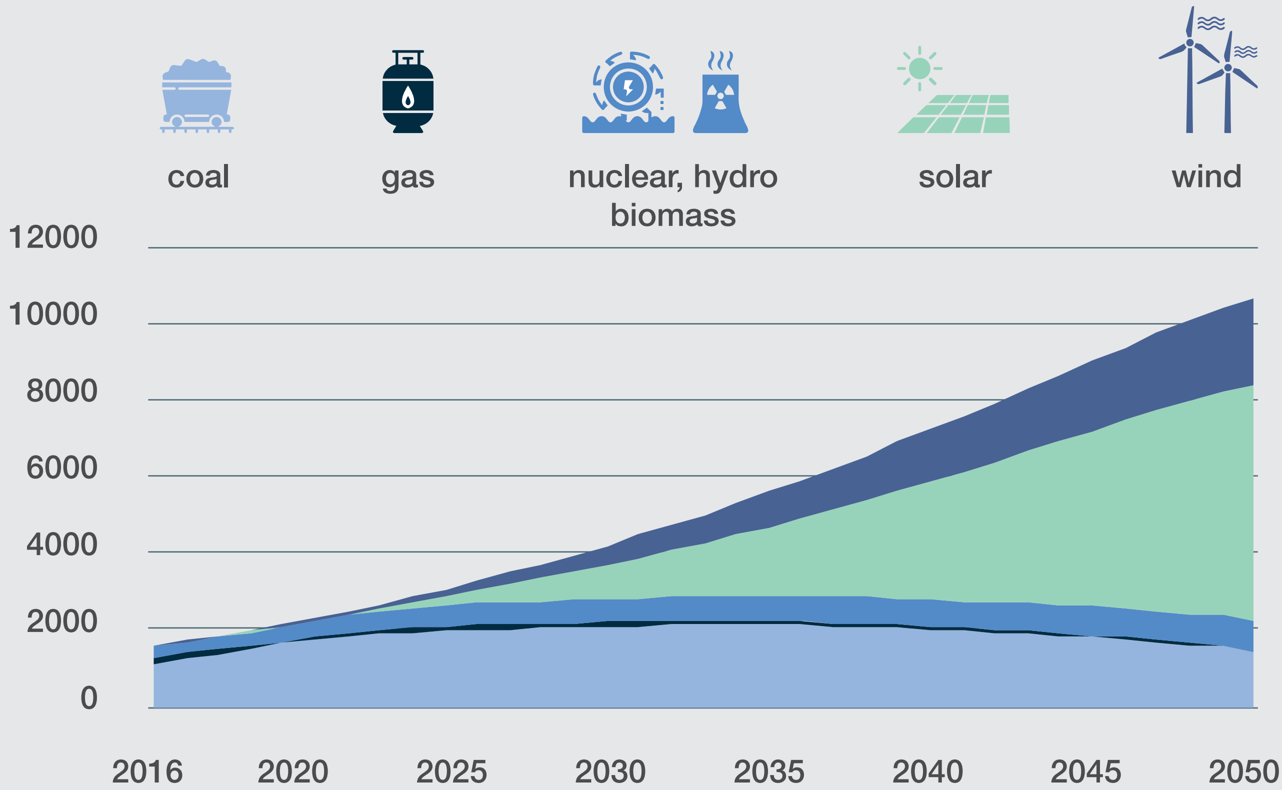
3.4.3 Rapid approach

Rapid advocates do not deny the legitimate aspiration of the world's energy poor to enjoy the benefits of more energy. They simply argue that this energy will be supplied by renewable technologies because they are cheaper, faster to implement, less polluting and use domestic fuel sources rather than imports. Moreover, they take into account the high level of pollution faced by countries, such as India where 140 million people already breathe air that is 10 times more toxic than the level considered safe by the World Health Organization, and polluted air is responsible for the deaths of over 1 million people a year.[69] This provides extra incentive to the emerging markets to embrace energy technologies that cause less pollution.

These advocates argue that there will be an energy leapfrog, similar to that observed in mobile phones or banking services. They also argue, to a greater extent than the Gradual advocates, that energy demand growth will be limited by the introduction of energy-efficient technologies.

Rapid advocates focus on developments in China and India, which between them are forecast to account for over half of the growth in global energy demand. In both China and India, solar electricity is now cheaper than that from fossil fuels, when comparing new projects in both.[70] Indian policy-makers, who only recently were mocked for having a renewable capacity target of 175 GW, recently raised it to 500 GW. As a result, models forecast that the share of electricity supply from renewables will grow rapidly, as in Figure 12 from DNV GL for the Indian subcontinent.

Figure 12: Electricity supply (TWh), Indian subcontinent, 2016-2050



Source: Authors, based on data from DNV GL, *Energy Transition Outlook 2018*.

A similar story can be told in transport. Higher domestic petrol prices and lower driving distances (hence smaller battery requirements) than in the United States meant that EVs in China have already crossed the key 5% market-share penetration level (next stop on an S curve is 90%), and the demand for ICE cars is already falling.

4. Implications of the two narratives

With different modelling assumptions come different conclusions. This focus is on three: the likelihood of achieving the goals of the Paris Agreement; the timing of peak fossil fuel demand; and the significance of peaking demand.

4.1 The road to Paris

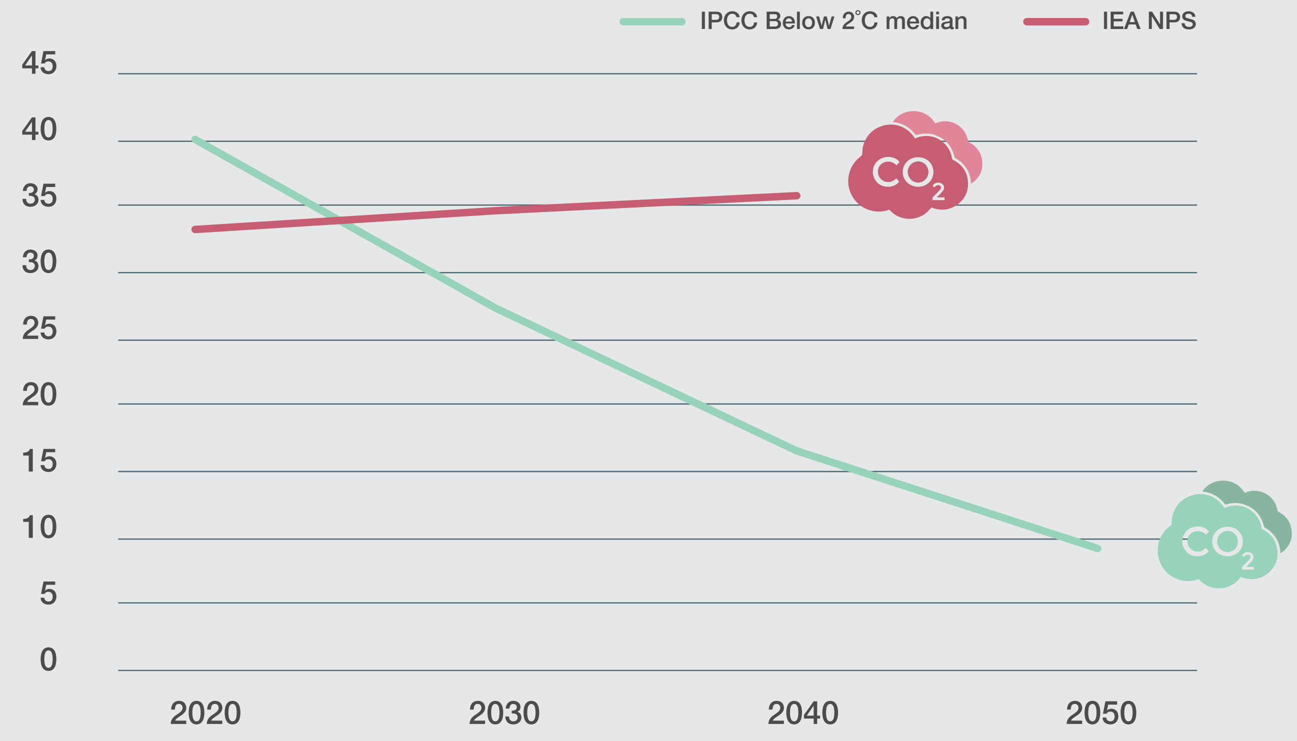
The central aims of the Paris Agreement are to strengthen the global response to the threat of climate change by keeping the global temperature rise this century well below 2 degrees Celsius compared to pre-industrial levels, and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius.

Gradual scenarios have rising emissions, implying that they will be unable to achieve the goals of the Paris Agreement.

Rapid scenarios have a peak in emissions in the 2020s. This means that they provide a foundation to achieve the goals of the Paris Agreement.

The gap between the two narratives is captured by the expected carbon emissions under the IEA NPS and those required to reach 2 degrees, as summarized by the IPCC (Figure 13).[71]

Figure 13: CO_2 emissions (Gt), 2020-2050



Sources: Authors, based on data from International Energy Agency, *World Energy Outlook 2018*, New Policies Scenario (fossil fuel sector only), and Intergovernmental Panel on Climate Change (total emissions for median below 2 degrees Celsius scenario).

4.2 When is peak fossil fuel demand?

The difference between the two narratives on the timing of peak fossil fuel demand is profound.

Gradual scenarios do not foresee peak fossil fuel demand for another generation. Peak demand for fossil fuels is out of the forecast range of models such as the IEA NPS, the BP ETS and those of Exxon, and is not expected until after 2040.

Rapid scenarios foresee peak fossil fuel demand in the 2020s. DNV GL and McKinsey, for example, expect a peak by 2028, and the Shell Sky Scenario by 2025.

4.3 How significant is peak demand?

Narratives differ dramatically on the significance of peak demand.

Gradual scenarios imply no major threat to fossil fuel sector incumbents from peak demand. This is in part because they do not see a peak for many years, and in part because they argue the decline will be slow after the peak. After all, the market will still require fossil fuels for many years.

Rapid scenarios, in contrast, imply that the fossil fuel sectors will be disrupted by the transition from growth to decline if they do not adapt quickly. They point to the experience of the European electricity sector, the global coal sector, the gas turbine sector and the auto sector. All in recent years have faced disruption, when challenging technologies have had a small market share but have captured the growth in the market. For example:

- The European electricity sector lost over half of its capitalization in the decade after demand for fossil fuels stopped growing.

- Half the US coal sector went bust when global coal demand fell just 4% from its all-time high.

- GE lost two-thirds of its capitalization in 2018 after it had to take a major write-down on its turbines division.

- The global auto manufacturers have been underperforming as they struggle to come to terms with a new environment.

And as a result, they expect a major impact on incumbents in the fossil fuel sectors from peaking demand in their core markets if they do not adapt quickly.

However, recent history has also shown that many incumbents, especially in the electricity sector, have been able to change business models and investment strategies to take advantage of new opportunities centred more around energy services to customer, renewables and the digitalization of energy.

5. Conclusion: What to watch out for

At the time of writing in 2019, it is not yet clear which narrative is likely to prevail. It is difficult for complex models to forecast systemic change because developments beyond 10 years are very hard to predict with any accuracy in three areas in particular: technology, policy and society. These are the three areas at the heart of the energy transition.

Indisputably, growth occurs in some areas and decline happens in others; the question is how they balance. Ultimately, the path to be taken will depend on a complex series of growth and decline rates. Outlined below are recent developments that are used by advocates on the two sides of the debate as well as some of the key factors to help establish which path the world is following.

5.1 Recent developments

5.1.1 Gradual approach

Gradual advocates point to a number of recent factual developments to support their narrative:

– **Energy demand growth**. High energy demand growth occurred in 2018 (2.3%), significantly higher than in the previous few years.

– **Growth of the hard-to-solve sectors**. Demand is rising from petrochemicals and airlines. These sectors appear to have few renewable alternatives.

– **Peaking renewable supply**. Data suggests that solar and wind capacity installations in 2018 were similar to those in 2017, implying that growth rates may have peaked.

– **Insufficient renewable investment**. Investment in renewable capacity is not growing as rapidly as is necessary to achieve the goals of the Paris Agreement.[72]

– **Policy rollback**. Environmental protections in the US under the Trump administration have decreased and US energy demand has increased.

– **More coal**. Coal-fired power stations are still being built and coal demand rose in 2018.

– **Not enough success.** The IEA tracks progress across 45 clean energy technologies, highlighting that progress is only on track in 7 of the 45 areas to hit the targets of the Paris Agreement.[73]

5.1.2 Rapid approach

Rapid advocates point to a competing set of facts:

– **Peaks have begun**. Disruption is already happening, but not widely distributed. Each year sees peaking demand for fossil fuels in some applications within countries. For example, ICE demand may have peaked in 2018 in China, and the automotive sector has transformed its strategy accordingly, pledging $300 billion to EV strategies.

– **Cost falls continue**. The cost of new energy technologies (especially solar and batteries) has continued to fall rapidly to levels below the price of fossil fuel technologies.

– **Rapid renewable growth continues**. EVs, batteries, solar and wind energy continue to exhibit exponential growth. This is in spite of the slowdown in investment, because costs are still falling.

– **Some policy-makers are acting**. Global carbon taxes increased by one-third in 2018 to $44 billion,[74] and state and city action has shifted to 100% renewable energy and enacted bans on certain types of ICE cars. This is happening from California to Hawaii, from Paris to Berlin.

– **Fossil fuel capex is low**. Final Investment Decisions (FID) on coal-fired power stations are down by 75% in the last five years and are tracking seven years ahead of the expected levels in the IEA NPS. Meanwhile, oil and gas capex is in line with the IEA SDS.

– **Societal pressure is rising**. Public concerns about the impact of global warming and pollution are rising, as manifested by Greta Thunberg and the rise of Extinction Rebellion.

– **Finance is mobilizing for change**. This is manifested by the success of the CA100+ movement and the growing calls for disclosure from the Task Force on Climate-related Financial Disclosures (TCFD).

5.2 Technology

Issues to focus on to determine if a Gradual or Rapid narrative is playing out in coming years include:

- **Cost of solar, wind and batteries**. These technologies are key because they are large enough to have a material impact, they are already challenging fossil technologies on price and they are on well-established learning curves. Will costs continue to fall at learning rates of around 20%? If so, generation costs from solar by the end of the decade will be so low that it will be possible to use solar electricity to make hydrogen economically via electrolysis in some countries. And battery costs will be so low that it will be possible to reduce the variability of solar and wind dramatically and increase still higher their ceiling of penetration. The key numbers to focus on for 2030 would be solar and wind costs of $20-30 per MWh and battery costs of $50-100 per kWh.

- **Growth rate of solar, wind and EVs**. Will these technologies remain on their S curves of growth? If so, they will start to supply all net new generation capacity by the early 2020s and will start to replace existing fossil fuel plants later in the same decade. By 2030, Rapid models expect to see over 300 GW a year of solar and wind installations and global EV market share of at least 30%.

- **Electrification**. Will electricity continue its march into other sectors? A Rapid transition would need growth in the share of electricity to be at least 3-4 percentage points per decade.

- **New renewable technologies**. Will other new technologies arise that can change the story dramatically? Those to watch include green hydrogen, pyrolysis and next generation biofuels.

- **Other energy technologies**. Of course, the potential exists for major cost falls in carbon capture and storage, which is technically available and has a number of leading pilot applications at scale. With the right policy support, the technology may also enjoy learning curves. Separate to this, a perennial hope is nuclear fusion, and breakthroughs may occur in other areas. These could also alter the energy mix dramatically.

5.3 Policy

Areas to focus on include:

- **Efficiency**. Governments have a key role to play in the promotion of efficiency,[75] through regulation on building codes, cars, appliances and so on. Efficiency levels rose to over 2% in the years before 2017, before falling back to 1.3% in 2018, according to the IEA. Rapid change would be much easier if efficiency were to rise to over 2%, driving down global energy demand growth to around 1%.

- **Carbon taxation**. Will policy-makers seize the opportunity of falling new energy technology costs to implement much more aggressive regulatory regimes so as to tax fossil fuel users for their externality? The two key metrics to focus on are the phasing out of support for fossil fuels and the widespread imposition of carbon taxes. IEA and IRENA have shown that even a relatively low carbon tax would be sufficient to make around half the world's emissions uneconomic.[76]

- **Electrification**. Support for the electrification of the rest of the energy complex is needed, including heat, transport and industry.

- **The emerging market energy leapfrog**. Attention must be paid above all on the policy direction being set by the world's largest growth markets, such as China, India and South-East Asia and, within these markets, whether coal is being substituted by solar and whether EV sales are moving up an S curve of change. Recent examples of this include the growing number of cancellations of coal-fired power stations across Asia as well as the breakthrough of EV sales through the key 5% market-share penetration level in China.

- **The just transition**. Can governments devise ways to mitigate the pain of the energy transition for those individuals and communities most impacted?

- **The policy ratchet**. The Intended Nationally Determined Contributions submitted to Paris imply global warming of 2.7 degrees Celsius, and a number of countries are already failing to hit their Paris commitments. By 2030, commitments would need to be ratcheted much closer to 2 degrees Celsius.

5.4 Milestones for 2030

The intention is not to be drawn into a scenario debate, but nevertheless it is useful to give a sense of the gap between the two narratives. Therefore, some pointers are summarized below that help to indicate the current path; clearly not all targets will be reached, but it is likely that a dominant narrative will emerge over the course of the decade. The focus is on the year 2030 to give a sense of what needs to happen over the course of the next decade for the Rapid narrative to be credible. Concentration is on a limited number of factors that are easy to monitor.

5.4.1 The price of solar electricity in 2030

Under the Gradual scenario, solar prices are likely to stop falling rapidly and average global prices will be at $50-70 per MWh in 2030. Under the Rapid scenario, they would fall to the $20-30 level, at which point they start to impact many other sectors.

5.4.2 Solar capacity installations in 2030

Under the Gradual scenario, solar capacity installations would stay at levels similar to today, around 100 GW per annum. Under the Rapid scenario, solar installations would rise to well over 200 GW per year.

5.4.3 EV market share in 2030

Under the Gradual scenario, EVs would increase their market share to around 5-10% of sales by 2030. The Rapid scenario would see them taking a market share of over 30%.

5.4.4 Carbon taxes

In 2018, the World Bank calculated total global carbon taxes to be $44 billion,[77] so under $2 per tonne for the 37 Gt of carbon dioxide emissions in that year. Only 20% of emissions are priced at all, and only 5% are priced at a level consistent with the Paris Agreement.

Under the Gradual scenario, taxation would increase a little, but the difference would not be dramatic. Under the Rapid scenario, the policy response would be much more aggressive, which would see a dramatic increase in the share of emissions subject to carbon pricing, and a major increase in the level of taxation. It is hard to put a number on this, but the level of action that would be needed is around half of emissions being taxed at average tax rates of around $20 per tonne taxed.

5.4.5 Peak demand

There are then three specific peaks that distinguish the two narratives. The Rapid narrative would see peaks in these areas in the 2020s; the Gradual narrative would not.

- Peak demand for new ICE cars
- Peak demand for fossil fuels in electricity
- Peak demand for fossil fuels in total.

6. Members of the World Economic Forum Global Future Council on Energy

The findings, interpretations and conclusions expressed herein are the result of a collaborative process within the Global Future Council on Energy facilitated by the World Economic Forum, but they do not necessarily represent the views of the individual Global Future Council members listed as contributors or their organizations, or those of the Forum and its partners.

Jeremy Bentham, Vice-President, Global Business Environment, Royal Dutch Shell, Netherlands

Kingsmill Bond, New Energy Strategist, Carbon Tracker Initiative, United Kingdom

Scott Burger, Research Associate and MIT Energy Fellow, Massachusetts Institute of Technology (MIT), USA

Jane Burston, Managing Director, Clean Air Fund, United Kingdom

Hela Cheikhrouhou, Chairman and Chief Executive Officer, Nithio, USA

Brian Dames, Chief Executive Officer, African Rainbow Energy and Power, South Africa

David Giordano, Managing Director, BlackRock Alternative Investors (BAI), BlackRock, USA

Andrew Herscowitz, Coordinator, Power Africa, South Africa

Amadou Hott, Minister of Economy, Planning and Cooperation of Senegal

Zoe Knight, Group Head, Centre of Sustainable Finance; Managing Director, HSBC Holdings, United Kingdom

Jules Kortenhorst, Chief Executive Officer, Rocky Mountain Institute, USA

Christina Lampe-Onnerud, Founder and Chief Executive Officer, Cadenza Innovation, USA

Lourdes Melgar Palacios, Research Affiliate, Massachusetts Institute of Technology (MIT), USA

Jon Moore, Chief Executive Officer, BloombergNEF, United Kingdom

Matar Hamed Al Neyadi, Undersecretary, Ministry of Energy of the United Arab Emirates

Maximo Pacheco Matte, Member of the Executive Board, Engineering School (DUOC), Pontificia Universidad Catolica de Chile, Chile

Nandita Parshad, Managing Director, Sustainable Infrastructure Group, European Bank for Reconstruction and Development (EBRD), United Kingdom

Milagros Rivas Saiz, Global Head, Cross Industry Advisory, International Finance Corporation, Washington DC

Joisa Saraiva, Professor, Fundação Getulio Vargas, Brazil

Samah El-Shahat, Vice-President, China-I, People's Republic of China

Nidhi Tanti, Vice-President; Head, Business Review Committee and New Business, Suzlon Energy Group, India

Sanjayan Velautham, Chief Executive Officer, Sustainable Energy Development Authority (SEDA), Malaysia

David G. Victor, Professor, University of California, San Diego (UCSD), USA

Wang Zhen, Deputy Director-General, China National Petroleum Corporation (CNPC), People's Republic of China

World Economic Forum

Espen Mehlum, Head of Knowledge Management and Integration, Shaping the Future of Energy; Global Future Council on Energy Manager

Emma Skov Christiansen, Specialist, Shaping the Future of Energy

Endnotes

1 Principles for Responsible Investment (PRI), "Inevitable Policy Response", 2018; see https://www.unpri.org/news-and-press/take-action-on-climate-now-or-risk-disruptive-policies-in-future/3625.article.

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3 There are of course some exceptions. For example, the growth of renewable energy has been within the framework of Shell's published scenarios.

4 A distinction is made between narratives, scenarios and models. The narrative is the high-level conclusion shared by a group of scenarios. A model is a building block that makes specific assumptions. A scenario is the outcome of a selected suite of models.

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9 US Energy Information Administration, *International Energy Outlook 2018*, 2018.

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12 Normative scenarios start with a goal, such as a specific level of global warming, and then work backwards to calculate the levels of fossil fuel production allowable to meet that goal.

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18 Shell International BV, *Shell Sky Scenario: Meeting the Goals of the Paris Agreement*, 2018.

19 BloombergNEF, *New Energy Outlook 2019*, 2019.

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22 Energy Transitions Commission (ETC), *Mission Possible*, 2019.

23 Not all scenarios hit all these targets. The DNV GL scenario, for example, implies global warming of 2.6 degrees Celsius.

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25 In further work, it would be important to delineate between developed markets that have substantial infrastructure lock-in to overcome, and emerging markets, especially Sub-Saharan Africa, where technology leapfrogging, similar to what happened with mobile phones, is a distinct possibility.

26 Smil, Vaclav, *Energy Transitions: History, Requirements, Prospects*, Praeger, 2010.

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28 DNV GL examines this issue in depth in the *Energy Transition Outlook* where the authors distinguish between a number of counting methods, including the “physical energy content method” favoured by the IEA and the “substitution method” favoured by BP.

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30 See the comment by Erik Sauar, “IEA counts fossil fuels threefold versus wind and solar”, *Energi og Klima*, 28 August 2017, https://energiogklima.no/kommentar/iea-counts-fossil-fuels-threefold-versus-wind-and-solar.

31 IEA, *World Energy Outlook 2018*, op. cit.

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35 For the sake of clarity, this observation is not a criticism. Under most circumstances, this approach is necessary and provides more accurate results. The problem for such an approach comes at times of disruptive change, when it struggles to keep up with the speed of change.

36 It is important to note that the observed prices in the market are already substantially below those used in the cost forecasts for Gradual approach narratives. This trend is likely to accelerate.

37 The IEA NPS takes a standard cost of capital and a model-based approach to the calculation of LCOE. BloombergNEF and IRENA take data from contracted solar projects.

38 BloombergNEF, *New Energy Outlook 2019*, op. cit.

39 Ekins, Paul, *Report to the Committee on Climate Change of the Advisory Group on Costs and Benefits of Net Zero*, op. cit.

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43 The forecasts for the Gradual approach in oil demand do not appear to take disruptive events into account, such as the plastics crisis or the potential for electrification of road haulage. If these are borne out in the marketplace, the drivers for continued rises in oil demand would be removed.

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World Economic Forum
91–93 route de la Capite
CH-1223 Cologny/Geneva
Switzerland

Tel.: +41 (0) 22 869 1212
Fax: +41 (0) 22 786 2744

contact@weforum.org
www.weforum.org