Carbon Tracker Initiative

INEVITABLE POLICY RESPONSE

The trillion dollar energy windfall

Falling renewable costs and intermittency solutions drive a tipping point for the Inevitable Policy Response

Analyst Note

September, 2019

About Carbon Tracker

The Carbon Tracker Initiative is a team of financial specialists making climate risk real in today's capital markets. Our research to date on unburnable carbon and stranded assets has started a new debate on how to align the financial system in the transition to a low carbon economy.

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About the Inevitable Policy Response

The Inevitable Policy Response (IPR) is a landmark project to prepare financial markets for a wave of policy moves as governments worldwide are forced to address climate change. A collaboration between PRI, Vivid Economics and Energy Transition Advisors.

About the Authors

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Kingsmill has worked as a sell-side City equity analyst and strategist for 25 years, including for Deutsche Bank, Sberbank and Citibank in London, Hong Kong and Moscow. He has written strategy on emerging markets and global themes, including the wider significance of the shale revolution. He worked for many years in Russia, which is the world's largest exporter of fossil fuels, and deeply impacted by the transition. He has an MA in history from Cambridge University, trained as an accountant (CIMA), and is a Chartered Financial Analyst (CFA).

Mark Fulton – Chair of the Carbon Tracker Research Council, Adviser to PRI

Mark Fulton has had 35 years experience in financial markets spanning three continents in London, New York and Sydney. As a recognised economist and market strategist at leading financial institutions including Citigroup, Salomon Bros and County NatWest, he has researched international economies, currencies, fixed income and equity markets. Mark has also held corporate strategy, finance and management roles.

Having a strong interest in the environment and sustainability, starting with a report on climate change and markets in 1991, Mark was Head of research at DB Climate Change Advisors at Deutsche Bank from 2007 to 2012, where he produced thought leadership papers for investors on climate, cleaner energy and sustainability topics and advised investment teams in asset management. From 2010 to 2012 he was Co-chair of the UNEP FI Climate Change Working Group and in 2011 and 2012 was part of the technical committee of the UN Secretary General's Sustainable Energy for All.

Currently, Mark is Chair of the Research Council at the Carbon Tracker Initiative; a Senior Fellow at CERES; and Special Advisor to IGCC. He is also a member of the Capital Markets Climate Initiative; UK Department of Energy and Climate Change; Advisor to the Carbon Disclosure Project; and the Climate Bond Initiative. Mark has a BA in Philosophy & Economics from Oxford University.

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1 The Context for the Inevitable Policy Response (IPR)

The Inevitable Policy Response (IPR) is a landmark project which aims to prepare financial markets for climate-related policy risks. What is "Inevitable" is some further policy response as the realities of climate change become increasingly apparent. The key questions are when this response will come, what policies will be used, and where the impact will be felt. IPR forecasts a response by 2025 that will be forceful, abrupt, and disorderly because of the delay. It quantifies the impact of this response on the real economy and financial markets. The project is a collaboration between PRI, Vivid Economics, Energy Transition Advisers, and Carbon Tracker.

IPR is based on setting the context – the ingredients of the climate and energy transition are centered around:

- Technology as a driver.
- Policy as an enabler and forcer.
- Temperature targets for the climate which act as a constraint and require swift action which policy can force.
- Changes in consumer preferences towards sustainability.
- Action by financial markets to support the transition.

What is the IPR?

- Within this context of technology trends and consumer preferences, and the need to act swiftly, the IPR forecasts realistic policy action to force the climate transition which will affect the real and financial economy.
- As such it prepares participants in financial markets for what is policy and regulatory risk.
- Companies will need to respond.
- Investor portfolios will be affected. And action from investors will help shape the transition in conjunction with policy action, supplying capital to green energy investments and encouraging a switch from high carbon activities.
- Regulators will test resilience of the financial system and focus on disclosure.

This work focussing on renewable energy costs makes a compelling case for policy makers to enable and force the energy transition.

Mark Fulton

Chair of the Carbon Tracker Research Council, Adviser to PRI

2 Key Findings

Time to reap the harvest. Renewable electricity from solar and wind costs less than electricity from gas and coal, and can be implemented everywhere at huge scale, giving rise to a trillion dollar energy windfall. The challenge for policymakers is to reap this harvest.

Renewable costs are below those of fossil fuels. Five years ago, fossil fuels were the cheapest baseload. The collapse in renewable costs means that for two thirds of the world, renewable electricity is the cheapest source of new baseload. By the early 2020s it will be every major country.

The business case keeps getting stronger. As costs fall, so new cost tipping points will be crossed over the next decade. The cost of new renewables will become cheaper than fossil operating costs during the 2020s, and the cost of dispatchable renewables (with a battery) will fall below the cost of new fossils.

The intermittency ceiling is high and rising. New technologies and tools keep raising the intermittency ceiling, as countries like Germany and the UK move over 25% variable renewables and regions like South Australia and Northern Ireland aspire to 50% and more. Meanwhile, 97% of the world's population is below the intermittency ceiling, and can copy the leaders.

The imperative to act is still there. Renewables provide a way to reach the goals of the Paris Agreement, cut deaths from air pollution, and enhance energy independence. They produce more local jobs, increase social justice and are extremely popular.

The harvest is huge. The world can now enjoy a renewable energy windfall – a Gigafall. 6 PWh of renewable energy can be produced before even today's intermittency ceiling is reached. Ascribe that a value of $10 per MWh and capitalise, and you have a trillion dollar windfall. Add in the value of renewables in cutting the externality costs of fossil fuels, and you rapidly get to a much larger number.

The transition will be sequenced. Countries with large domestic coal and gas extraction and electricity generation will face more powerful impediments to change. However, countries with rising demand and pollution issues and those with significant fossil fuel imports will drive the transition. A quarter of global coal and gas is imported, and 65% of people live in countries that have rising energy demand and import coal and gas.

Why will policymakers act. The reward to successful policymakers will be greater wealth, cleaner air, reduced global warming, energy independence and electoral success. This drives the Inevitable Policy Response.

What will policymakers do. There are four key areas of action: provide enabling regulatory regimes; tax the fossil fuel externality; force the pace of change, and retrain fossil fuel workers for the new world.

3 The business case for renewables

In this note we focus on the growth in the supply of electricity from solar and wind (renewables) in a system dominated by electricity from coal and gas (fossils).[1] As renewable costs fall, so it becomes economically rational to deploy renewable energy in more and more areas. This is a remarkable change from only a few years ago, when idealistic governments were investing heavily to get the industry started. Instead of being driven by subsidy this is now an industry driven by economic gain.

We set out below the tipping points that are reached by area and by country. We believe that this provides a framework which helps to explain the many confusing signals in this area of tremendous complexity.

3.1 Cost tipping points

The fall in solar and wind electricity costs over the last five years has been remarkable. In 2014, variable renewables were the cheapest source of new electricity in around 1% of the world. In 2019 they are the cheapest source in two thirds of the world,[2] and by the early 2020s, they will be cheapest source in all major markets.

Renewable electricity costs have been on technology learning curves of around 20% for every doubling of capacity for decades,[3] and there is every reason to believe that these technology learning curves will continue. Wind turbines continue to get taller, installation costs get standardised, and material efficiency increases. Meanwhile, solar panel costs continue to fall, new technologies like perovskites increase yields, and developers globalise cost structures. Battery costs are falling even more rapidly, thanks to new technologies, the scaling up of production and lower material costs, opening up the opportunity for dispatchable renewables.

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[1] *Nuclear, hydro and biomass are mature technologies which are assumed to continue on their longstanding path of low growth. As such they are neither the drivers nor the victims of change and we do not focus on them in this report.*

[2] *The best sources for this data are organisations which use real-world numbers from actual developers and coal plants. For example, Carbon Tracker, BloombergNEF and IRENA have similar conclusions that the first tipping point is largely crossed.*

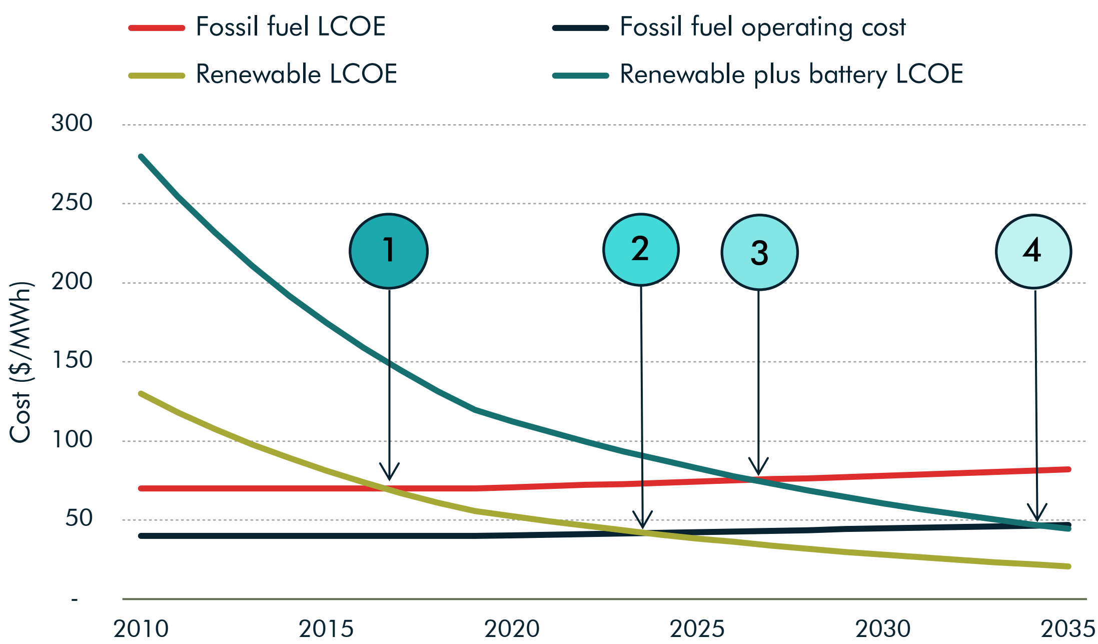
[3] *IRENA and BNEF calculate the data in detail. See for example* IRENA, *Renewable Power Generation Costs,* 2018, Lazard, *Lazard's Levelised Cost of Energy Analysis,* 2018, or BloombergNEF, *New Energy Outlook,* 2019.

The fall in costs drives four main tipping points for renewable energy:

1. New renewables are cheaper than new fossils. As noted above, this has largely happened.
2. New renewables are cheaper than the operating cost of existing fossil plants. The point where the full cost of renewables is cheaper than the cost of the raw materials used for fossil fuel generation.[4] This is happening in renewable leaders across the world (e.g. Indian solar or German wind) and will be a feature of the 2020s.
3. New dispatchable renewables are cheaper than new fossils. Renewables are of course hampered by their intermittency. But this is increasingly being addressed as developers add batteries to their operations, giving them flexibility. The tipping point is starting to occur (e.g. US solar with four hour batteries), and will be a feature of the second half of the 2020s.
4. New dispatchable renewables are cheaper than the operating cost of fossils. The final tipping point. This will be a feature of the 2030s.

The chart below illustrates this framework.

FIGURE 1 - THE COST PER MWH AND THE RENEWABLE TIPPING POINTS



Source: Carbon Tracker

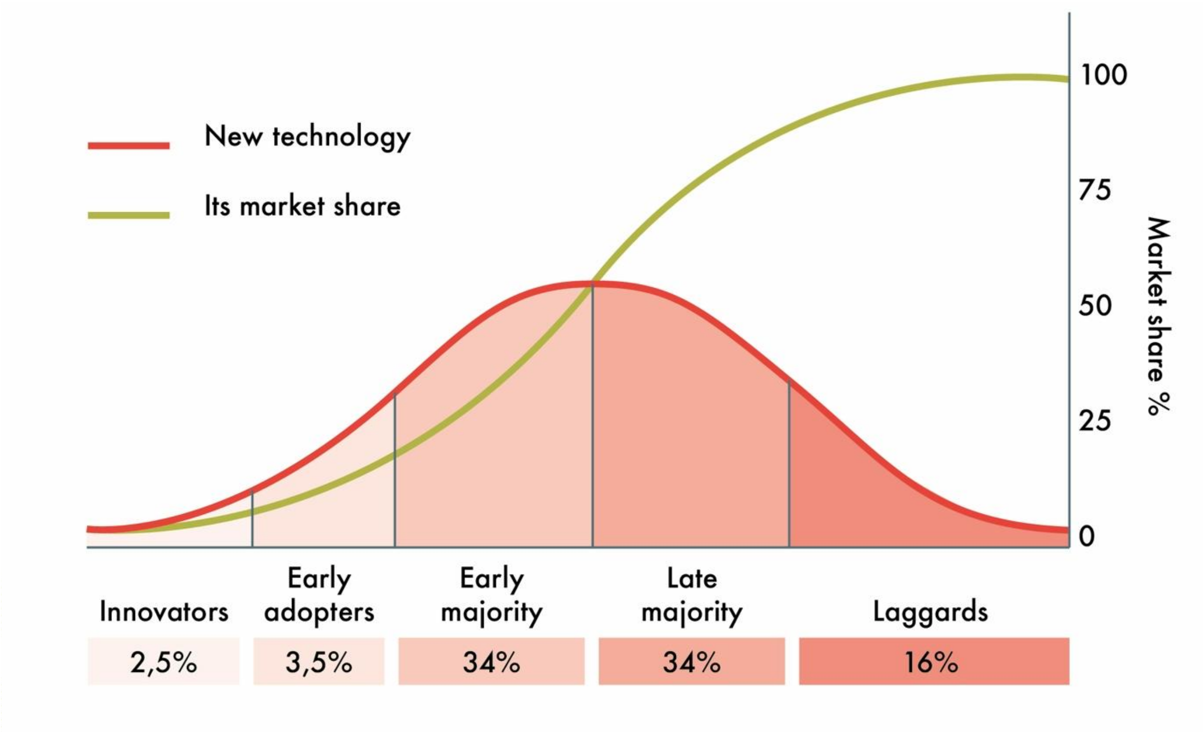
3.2 Country tipping points

The chart above is a broad global framework and each country is of course different. Solar and wind battle with coal and gas, and the winner depends on the cost of each energy source. As a rule of thumb, tipping points happen sooner in countries which import their fossil fuels than those which have cheap domestic sources. In most countries the main battle is between cheap domestic coal and onshore wind.

As so often, Rogers' theory of innovation framework provides the theoretical background to understand this sequencing of the change. You start with innovators, move on to early adopters and finish with laggards.

[4] See Carbon Tracker Initative, *Powering Down Coal,* 2018.

FIGURE 2 - DIFFUSION OF INNOVATION THEORY



Source: Rogers

Innovators were places like Denmark, with excellent domestic wind resources and high fossil fuel import costs. Early adopters were found in Texas, with excellent domestic wind resources, low financing costs, and large amounts of free space. The early majority includes India, which benefits from low labour costs and struggles under the necessity to import most of its fossil fuels. The cost of wind has only just fallen below the cost of coal in China, making that country a part of the late majority.

Countries which are yet to reach the tipping point include Japan, which has high labour and land costs, as well as parts of South East Asia, which have low domestic coal costs and have not yet reached sufficient scale to drive down the cost of renewables.

The process whereby the late majority and laggards finally cross the tipping point is worth consideration as it should give hope to those which have yet to see the benefits of low renewable energy costs. Most countries have a decent amount of low cost solar or wind resources. So the availability of the raw material of renewables is not usually the issue. The main reason why the laggards are behind is because they have failed to build up enough scale for the technology to enjoy learning curves and drive down the costs. If you install wind turbines for example you need skilled local labour, they need to learn how to implement at scale, and specialist equipment has to be made. This takes time and money initially.

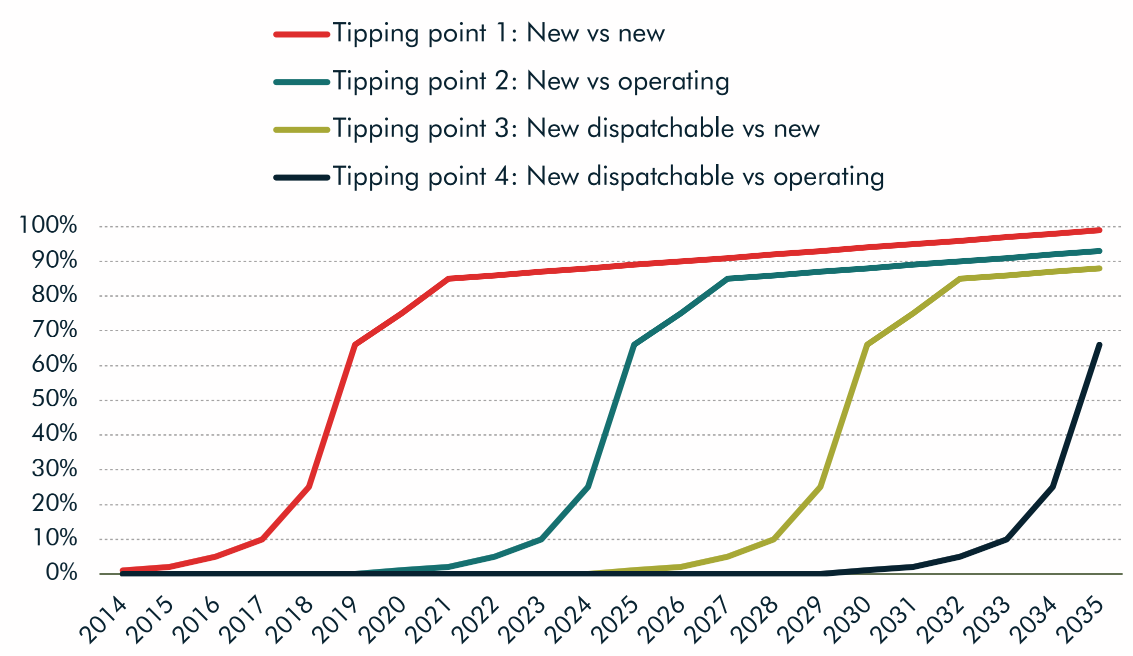
And the main reason why scale is not built up is usually because policymakers do not create a legislative environment in which the new technology can be implemented. When they do, renewables technologies costs can fall very rapidly as some of the many global developers bring their experience to bear. The classic example of this is Argentina. Sebastian Kind, the undersecretary of renewable energy, introduced an enabling framework for renewable energy, and brought costs down to below those of the fossil fuel alternatives within a year, by the end of 2016.

Whilst the laggards are only today starting to cross the first tipping point, the early adopters are already crossing the second tipping point and innovators are crossing the third. The variable cost of electricity from coal usually falls into the $30-40 range and from gas it is around $10 per MWh higher. Solar and wind costs in leaders such as India, Texas or Saud Arabia are now at $20-30 per MWh. Quinbrook Infrastructure Partners plans a solar plus battery plant in the US at a price of under $40 per MWh in 2022.

And as countries cross the tipping points at different dates, so energy intensive sectors will migrate to those countries with lower costs, enhancing the speed of change.

The chart below presents in a schematic fashion the share of the global population that passes each tipping point. We deliberately slow the pace of adoption after 85% global penetration to reflect those countries which lack the political or administrative framework to implement the necessary change.

Figure 3 - Share of the global population at the tipping point



Source: Carbon Tracker

4 The intermittency ceiling is high

The second major development over the last decade has been the lifting of the intermittency ceiling. The intermittency ceiling is the maximum economical level of deployment of solar and wind in an electricity system. Twenty years ago, this was thought to be less than 2%, but it has risen consistently over time thanks to the evolution of new techniques and technologies.

4.1.1 How to raise the intermittency ceiling

Renewable intermittency is an issue on the level of hours, weeks or seasons, and as so often the easiest problems are solved first. The IEA talks about the six phases of renewable energy integration, with each one being more complex than the last. There is a large body of literature on how to solve intermittency problems, most notably by the IEA and IRENA, and we seek merely to summarise some of the points made.[5]

There have been five main ways to solve the problem of renewable intermittency in the first instance:

- Flexible demand. This can either being demand side response or load shifting.
- Flexible supply. Existing fossil fuel generation is used as backup.
- Bigger grids. Renewables are by their very nature local, and this can help to reduce the need for transmission. On top of this, countries have been increasing the number of interconnectors that they deploy.
- Batteries. Batteries are starting to be deployed in order to enable renewables to be dispatchable. They are typically deployed for one to four hours of storage.
- System changes. Codes and systems need changing in order to accommodate variable renewable generation.

At higher levels of renewable penetration, new technologies come into play: superior forecasting and system integration with heat and transport are amongst these.

These techniques have been enough for variable renewables to provide more than half of electricity in Denmark, a third in Uruguay and a quarter in Germany.

4.1.2 How high can the ceiling be

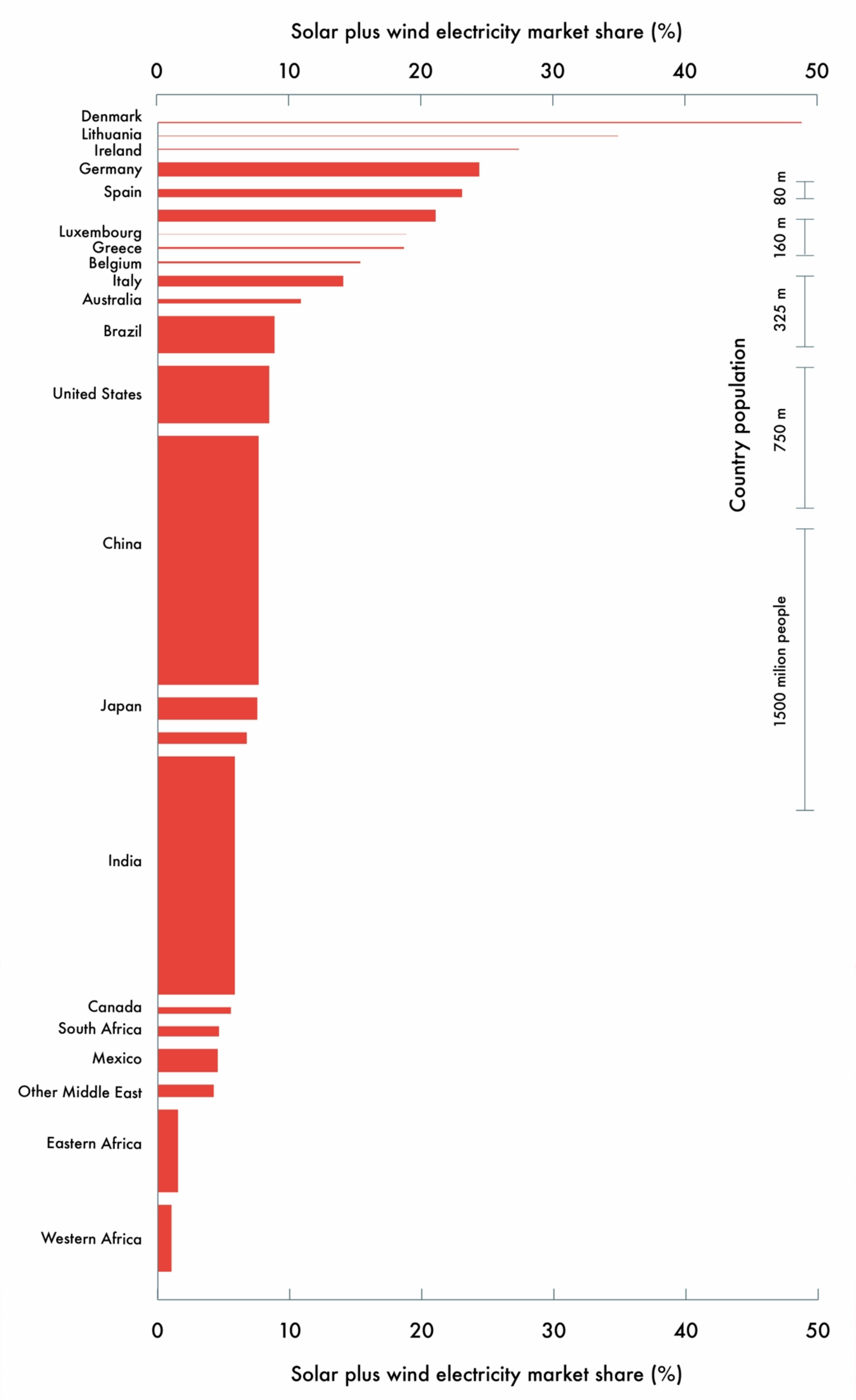
There are now plenty of regions which aspire to 100% renewable electricity. From South Australia to California, the UK to Denmark. As the Committee on Climate Change notes in its latest report on getting to 100% renewables, the challenges increase after penetration levels of around 80%. However, as we see below, this is a rather academic issue given that the world today gets only 7% of its electricity from solar and wind.

4.1.3 Most countries are far below the ceiling

The difficulty of getting to 100% penetration is often used by sceptics to argue that there will be no energy transition. But this is a false narrative. Most countries are well below the ceiling of what is possible. The chart below for example shows the number of people in each country graphed against the share of solar and wind in electricity generation. Just 3% of the world's population lives in the countries like Germany or the UK which are at the cutting edge of change. Everyone else can simply copy what the leaders do.

[5] *See for example* IEA, *Status of Power System Transformation,* 2019, *or* IEA, *Wind and solar integration,* 2016, *or* IRENA, *Power System Flexibility for the Energy Transition,* 2018.

FIGURE 4 - MARKET SHARE OF SOLAR AND WIND 2018 VERSUS POPULATION



Source: BP

5 The further advantages of renewable electricity

The advantages of renewable electricity have been well covered elsewhere, but we summarise them briefly below. The main point is that there are sound reasons for policymakers to deploy renewables apart from the economics. As soon as the economic tipping points are crossed, these factors will be given a greater weight in policy discussions.

5.1.1 Paris

As matters stand today, the world is heading for global warming of over 3°C by the end of the century. If policymakers are serious about hitting the targets set in the Paris Agreement, then they need to step up their level of ambition. The electricity sector is the easiest area in which to do this.

5.1.2 Pollution

Ambient air pollution kills over for million people a year, and is especially acute in the emerging markets like India where 140 million people breathe air 10 times over the World Health Organisation (WHO) safe limit. As economic growth continues, the problem will only intensify if alternatives to fossil fuels cannot be found.

5.1.3 Geopolitical advantage

Four out of five people live in countries that import fossil fuels. The fossil fuel dependency of rapidly growing markets like China and India will only increase as their energy consumption rises. Renewables are a local and continuous source of energy, and reduce dependency on foreign imports. This increases the geopolitical influence of importing nations and makes them less dependent on the exporters.[6]

5.1.4 Industrial advantage

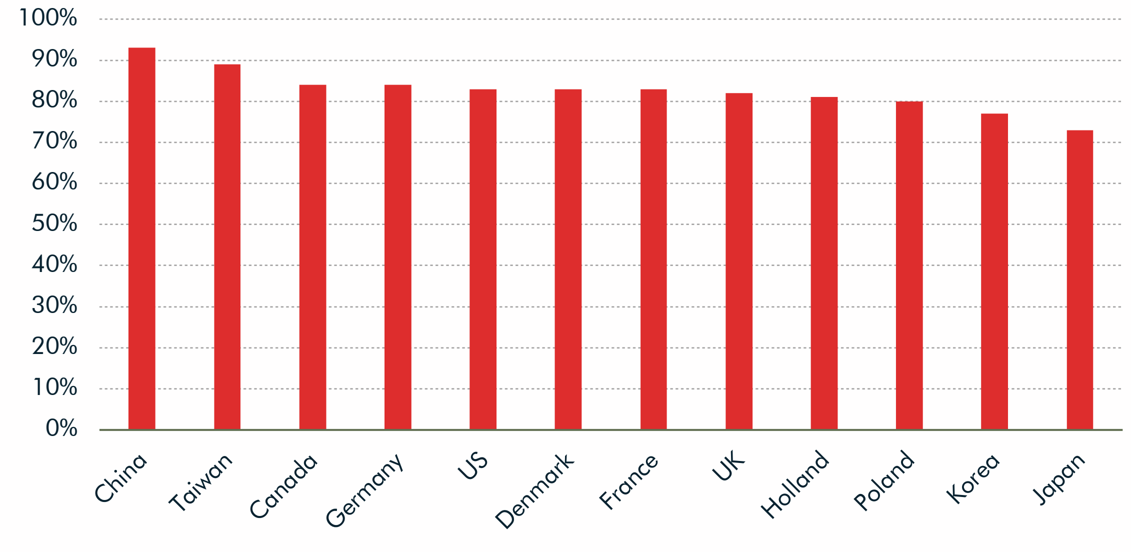
The first round of the industrial revolution was won by countries which exploited and dominated the new energy technologies of coal and steam engines. In the same way, this new environment gives an opportunity to countries to seize dominance in the new energy technology sectors. The classic example at present is China, which leads the world in EV technology.

5.1.5 Votes

Renewable energy is extremely popular in most countries. Orsted, the Danish renewable energy developer, surveyed 28,000 people across 13 nations in 2017 to ask them their view on renewable energy. Over 80% wanted to move to a world powered by renewable energy, 80% wanted more solar, and over 80% wanted to phase out coal. We show below the results of the survey by country.

[6] IRENA and Carbon Tracker, *A new world – the geopolitics of the energy transformation,* 2019.

FIGURE 5 - SHARE OF THOSE WHO REPLIED 'YES, *IT IS IMPORTANT TO CREATE A WORLD FULLY POWERED BY RENEWABLES?*'



Source: Orsted, Green Energy Barometer

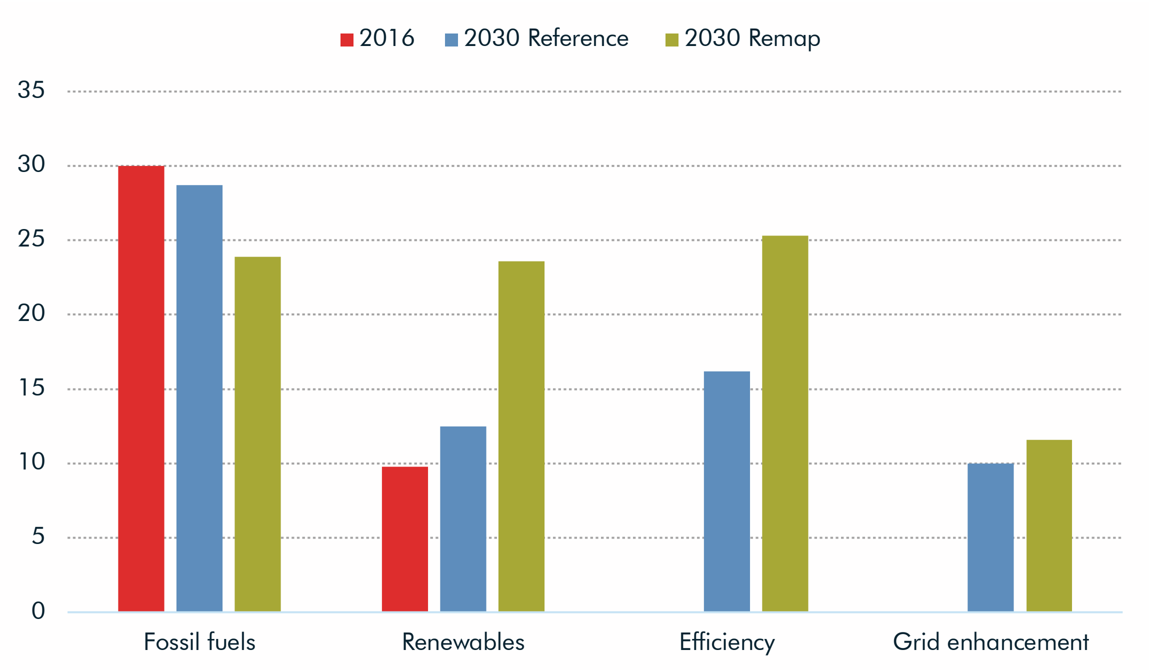
5.1.6 Jobs

The fossil fuel sector employs around 30 million people. According to IRENA,[7] a shift to renewable energy would require an extra 17 million jobs by 2030. We show below the number of jobs in each sector in 2016 and under their reference scenario in 2030 and their renewable transition scenario in 2030.

New jobs will be needed in solar and wind equipment manufacturing and installation, efficiency, and grid enhancement.

[7] IRENA, *Energy Transition and Jobs,* 2018.

Figure 6 - Energy sector jobs (million)



Source. IRENA

5.1.7 Justice

A world powered by renewables holds out the promise of being a considerably more just world than one powered by fossil fuels. Renewables will create abundant energy available both to the energy poor in rich countries and the billion people lacking energy in the emerging markets. Renewables will avoid the massive rents (3% of global GDP) which are amassed by the leaders of the fossil fuel sector. Renewables can help reduce the conflicts over fossil fuels which have been such a feature of the fossil fuel system. And will help to rescue the people of the petrostates from the curse of oil.

This is an issue examined in more detail in a companion paper by Nick Robins.[8]

[8] Nick Robins and James Rydge, *Why a just transition is crucial for effective climate action*, 2019.

6 How big is the harvest – the Gigafall

6.1 The size of the opportunity

The remarkable fall in costs and the raising of the intermittency ceiling have opened up a huge opportunity for the policymakers of the world to embrace this new local and cheap energy source.

In the same way as the discovery of a new oil deposit in the twentieth century was described as a windfall, this new opportunity is also an energy windfall. Given the huge size of the opportunity, and in homage to Elon Musk's Gigafactory, it feels right to call this energy opportunity a Gigafall. For those who struggle to see how we could talk about an energy windfall from something that is already there, an analogy can be made with shale. Shale rocks have been present for millions of years and their existence and potential was widely understood decades ago. However, the opportunity and the energy windfall have only been only released by technological innovation within the last decade or so.

The question then is how to value the Gigafall. In the same way as the discovery of a billion barrels of oil gets policymakers excited because they can see the profit to be made, we believe that it is possible to quantify the size of this Gigafall. We answer three questions – how big, the value per unit, and how to capitalise, and then calculate the size of the Gigafall. We deliberately keep the calculation simple as it will differ in each country, and there is no point in overcomplicating.

6.1.1 How big

We believe it is perfectly reasonable to argue that the world could have 25% of electricity generated from solar and wind. As noted above, there are an increasing number of energy leaders who are already crossing this threshold and planning for much more.

The world produces 27 PWh of electricity a year at present, of which 2 PWh is from solar and wind. One way to quantify the opportunity is to consider the amount of growth in electricity demand that we can expect to see over the course of the next decade. At 2% growth rates, it would be 6 PWh and at 3% growth rates it would be 9 PWh. The IEA forecasts 2% annual electricity demand growth to 2040, so we take the lower of these numbers, 6 PWh.[9]

In addition to this, there is of course the opportunity for renewables to replace existing capacity, the second tipping point. However, we do not consider that in this calculation, and see it as an upside.

6.1.2 How much per MWh

The second question is how to ascribe a value to this generation. We think it is reasonable to seek to do this on a per MWh basis as it makes the calculation simple. There are two main sources of value which one can ascribe to renewables – cost savings and externality.

The cost advantage of renewable technologies will vary by country and location. However, the broad framework is that the cost of renewables will fall over the course of the decade from around \$50 per MWh to around \$30 per MWh, whilst the cost of the cheapest fossil fuels will remain at around \$50. That gives an average annual advantage of say \$10 per MWh. Again, it is likely to be higher than this, and will vary country by country.

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[9] *By way of a sense check, an additional 6 PWh in a decade would mean that renewables produced 8 PWh out of 33. That is 24%, which is below the intermittency ceiling we noted above. And of course by the end of the decade the ceiling will be much higher.*

In addition, there is the cost of the avoided externality. The cost of global warming, deaths from ambient air pollution and so on. The best estimate of this is the social cost of carbon, although Lord Stern points out that there are many costs not captured by this. The most recent estimates are that the social cost of carbon (SCC) is around $50 per tonne of carbon dioxide.[10] In 2017, fossil fuels generated 17 PWh and released 14 Gt of emissions, or around 0.8. tonnes per MWh. At $50 per tonne, this implies an externality cost of $40 per MWh. So a first order approximation for the saving on externalities by using renewables would be $40 per MWh.

6.1.3 How to capitalise

The final question is how to capitalise the opportunity. We have identified that 6 PWh of electricity can be produced at a lower cost. But we want to compare an annual renewable flow with the stock (barrels of oil) which is how a windfall is conventionally seen. So it is necessary to capitalise the annual flow.

At a 5% discount rate, the standard way to capitalise is to multiply by 20. And we take this.

6.1.4 How big is the Gigafall

The calculation in then very simple. We take the size of the opportunity (6 PWh), multiply by the benefit per MWh ($10), and get an annual windfall of $60 billion by the end of the decade. We capitalise this by multiplying by 20, and we have a $1,200 billion opportunity.

If externalities were included, the Gigafall would be five times as much as this, at $6 trillion.

6.1.5 Who gets the benefit

When coal or gas is discovered and exploited, the beneficiaries are usually the owners of the asset and the government under whose land the fossils lie. The cost of the externality is usually shouldered by society. And because of the oligopolistic nature of fossil fuels, the rents flowing to the owners of resources (oil in particular) are huge.

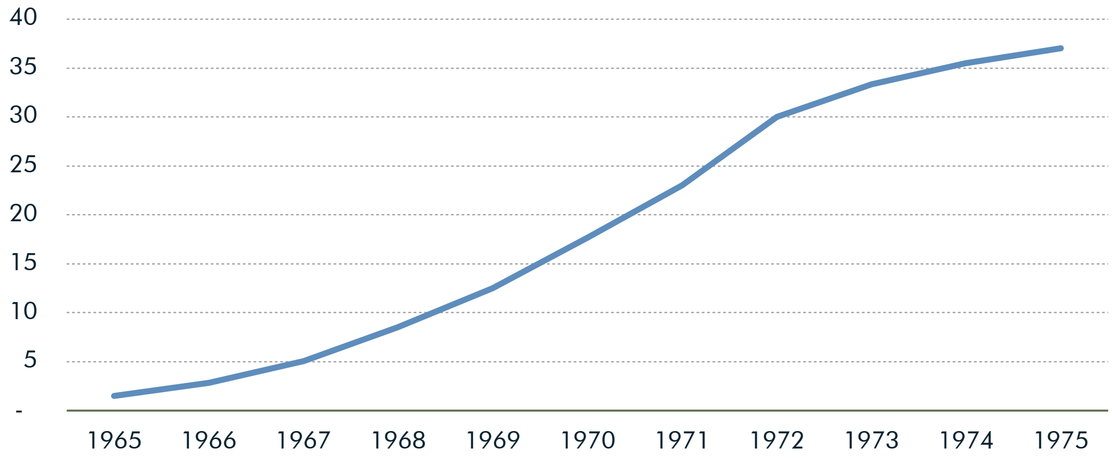
But when renewables are developed, there is much more competition. As a result, there are simply no super profits available. The beneficiary is society. Moreover, the beneficiary of avoided externalities is once more society as a whole.

[10] *Lord Stern estimates the SCC at $45 to $180. The interagency working group under President Obama estimated it at $51 in 2018 US dollars. The World Bank estimates it at $46 at 4% discount rates and $97 at 3%.*

6.2 What do countries do when they have an energy windfall

It is a well-documented aspect of energy history that when countries discover local cheap energy sources, they figure out pretty quickly how to use them. The classic example is the increase in gas production in Holland in the decade after gas was discovered. Production rose from 1 bcm to 37 bcm in the course of a single decade.

FIGURE 7 - GAS PRODUCTION IN THE NETHERLANDS (BCM)



Source: BP

The glory of the renewable energy Gigafall is that this story applies not just to Holland but to every country on earth.

7 Who goes first

There are still forces which hold back the rise of renewable electricity: the resistance of incumbents and inertia. Appximately 30 million people work in the fossil fuel industry, the asset value of fossil fuel infrastructure is over $25 trillion, and global energy systems and expertise are largely geared to the exploitation of fossil fuels. Many commentators have pointed with despair to the continued use of lignite mines in Germany, the seizure of the reins of government by fossil fuel backed incumbents in the US and Australia, and the resistance of the Polish government to close down its coal mines.

The detail of change is complex, and we approach it with caution. The forces of political economy vary in every country, and not always predictable from a top-down basis. For many years, Japan, which has almost no fossil fuels, was a staunch supporter of the fossil fuel incumbency. Whilst Norway, which grew rich from the export of fossil fuels, has been a leader in the energy transition, and Saudi Arabia has been quick to commit large amounts of capital to solar developments. Moreover, the forces of change can play out very differently within countries; in the US, California is embracing change whilst some other states are resisting it.

Nevertheless, we believe it is possible to identity the main areas where renewables will face least and most resistance, to provide a rough sequencing for how the transition will play out, and then to split markets into four key groups for the first phase of the transition.

7.1 Where is least resistance to renewable electricity

There are three areas where resistance to renewable energy will be less intense: in growth markets; in importers; and where pollution levels are high.

7.1.1 Growth markets

Incumbents will resist being shut down, but they are less able to stop cheaper renewables from supplying the growth in electricity demand. Therefore, in countries with rising demand, there will be less resistance to renewable energy deployment. For example, India has rapidly rising demand and it is anxious to use all energy sources to fill it.

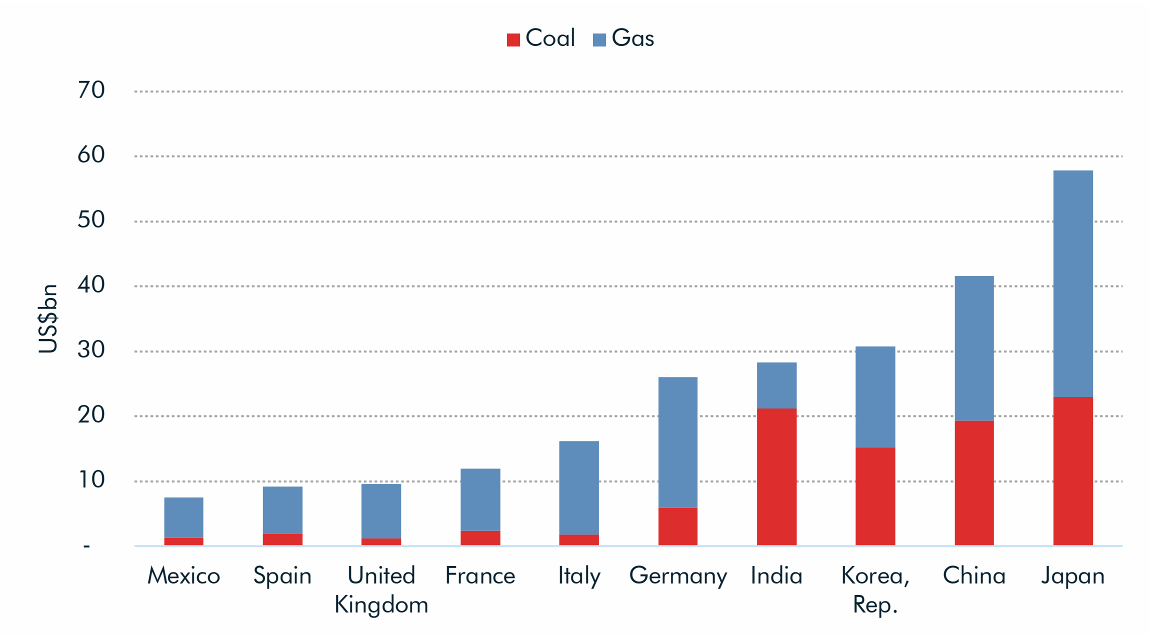
7.1.2 Importers

Where a country imports its fossil fuels for electricity generation, policymakers and the public are more likely to be receptive to having their own domestic energy sources. When it comes to electricity generation, we focus specifically on coal and gas. Coal supplies 38% of electricity generation, and gas supplies 23%. Oil supplies just 3% of electricity generation, and this is mainly for self-consumption by oil exporters like Iran.

Although the trading levels are not so great as for oil, large volumes of coal and gas are nevertheless traded across borders. In 2018 for example 24% of gas production (943 bcm out of 3,900) and 22% of coal (860 mtoe out of 3,900) was traded internationally.

The world's top ten largest imports of coal and gas include Japan, India, China and Germany.

FIGURE 8 - GAS AND COAL IMPORTS 2017 (US$BN)

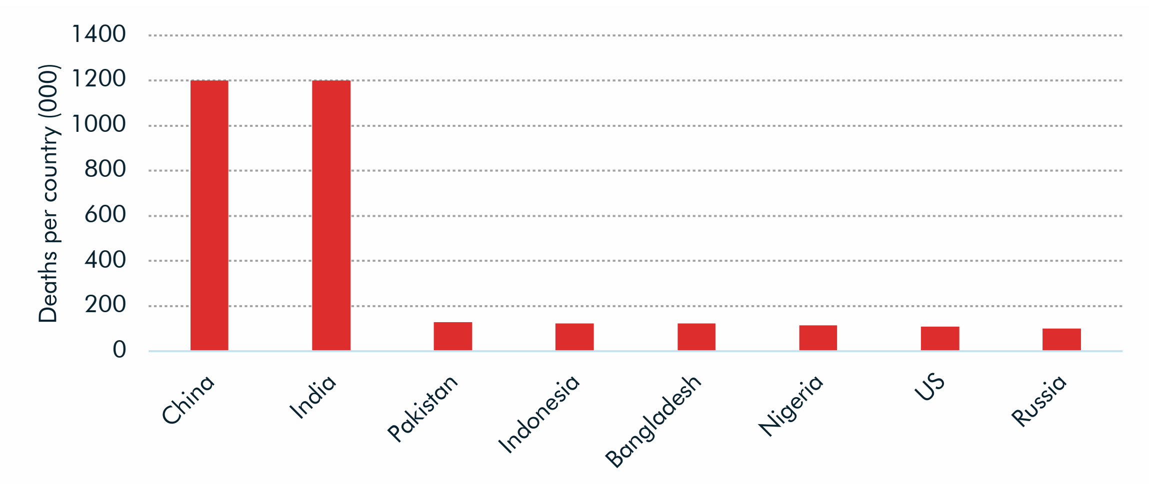


Source: World Bank 2017

7.1.3 Pollution and vulnerability to climate change

Countries which suffer from high levels of pollution or which are more exposed to the negative consequences of climate change are more likely to embrace renewables. This applies above all to the emerging markets, especially hot densely packed countries like India, Pakistan or Bangladesh. It is well known that the desire to limit pollution and to improve air quality has been a key feature in the push for renewables in both China and India.

FIGURE 9 - THOUSAND DEATHS FROM AMBIENT AIR POLLUTION IN 2017



Source: Health Effects Institutre, *State of global air report 2018,* 2018.

7.2 Where is most resistance to renewable electricity

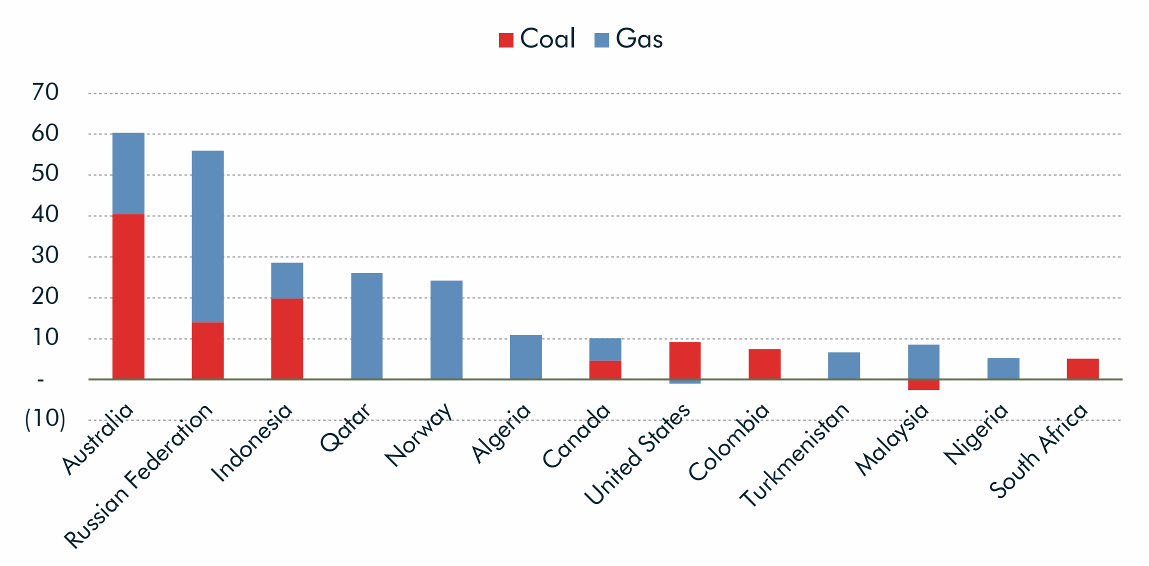
We highlight three areas where there is likely to be most resistance to renewables: in fossil fuel exporters; in countries with large domestic fossil fuel sectors tied into electricity generation; and in countries where demand is falling, meaning that renewables may force the closure of existing capacity.

7.2.1 Exporters

As Norway has demonstrated, being an exporter of fossil fuels does not necessarily prevent you from seeking to reduce domestic usage. But Norway is an unusual country, and most coal and gas exporters will find it convenient to like the product.

The world's largest exporters of coal and gas are very different to those of oil, as we set out below. In this sector, Australia is a superpower, which helps to explain the result of their recent election.

FIGURE 10 - EXPORTS OF COAL AND GAS (US$BN) 2017



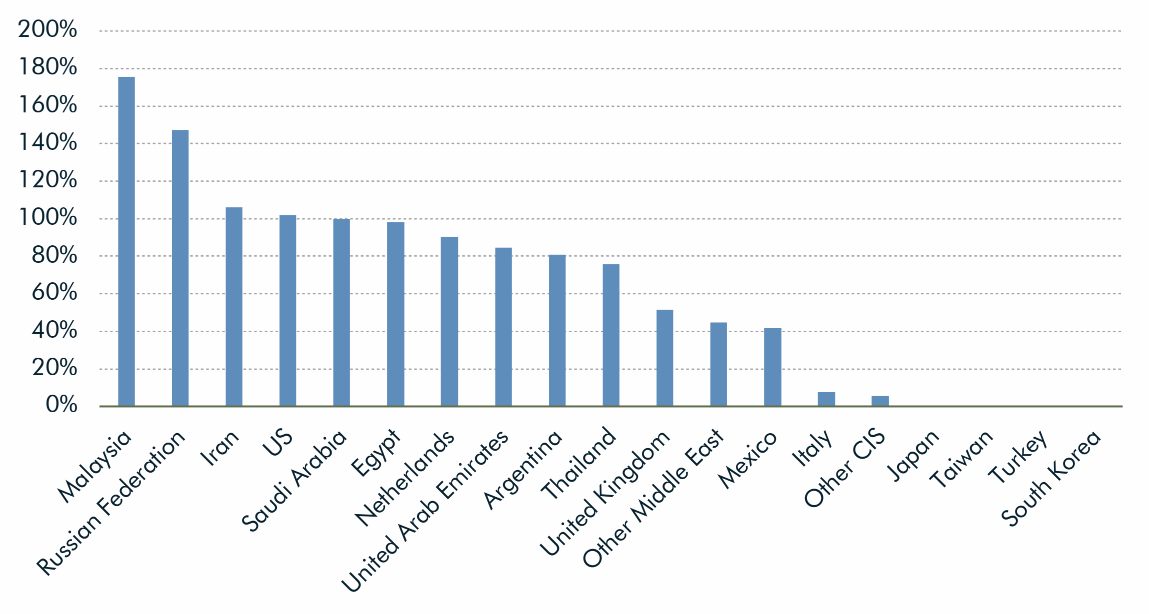
Source: World Bank

7.2.2 Large domestic fossil fuel sources for electricity

A clear impediment to the transition is the existence of a large domestic fossil fuel sector which produces domestic electricity. The classic example is Poland, which has large coal deposits and large amounts of electricity generation from coal. As a result it has a powerful lobby to resist change.

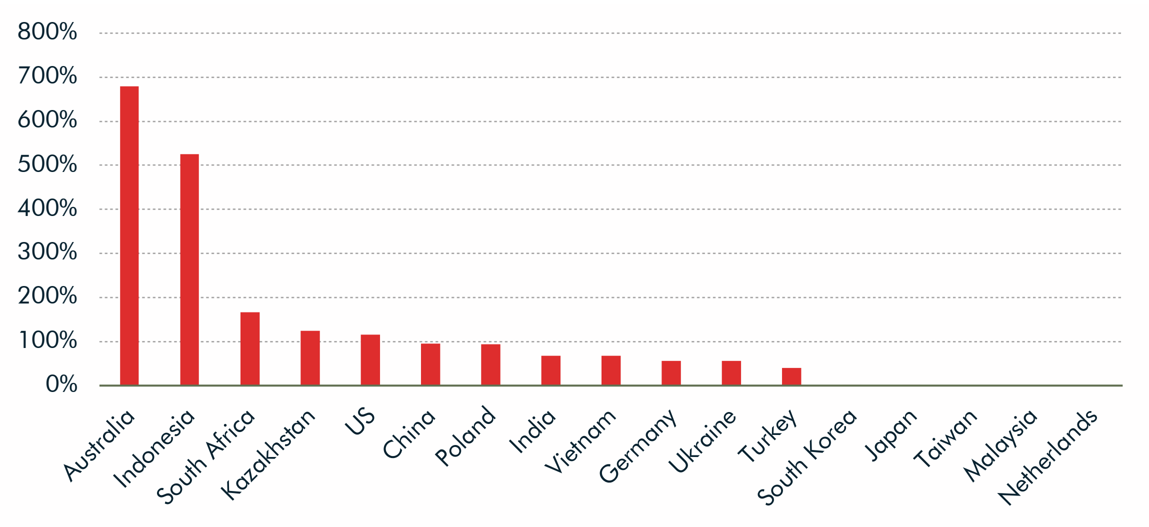
To ferret out these sources of resistance to change it is necessary to consider coal and gas separately. We put a filter of 25% of domestic electricity generation coming from coal or gas in order to identify more clearly those countries where these sectors are likely to be powerful.

FIGURE 11 - GAS: DOMESTIC PRODUCTION AS % OF CONSUMPTION 2018



Source: BP

FIGURE 12 - COAL: DOMESTIC PRODUCTION AS % OF CONSUMPTION 2018



Source: BP

Amongst those where coal or gas play a major role in their electricity sectors, it is possible then to draw out four groups of sectors within countries.

- Exporters. Countries which have large electricity sectors fuelled by gas or coal and which also export. For example Australia for coal or Russia for gas.
- Domestic self-sufficient. Countries which have over 80% of their consumption coming from domestic sources of coal or gas. For example Poland for coal or Holland for gas. These are large and powerful industries that will resist change.
- Domestic major player. Countries which have 50-80% of domestic consumption from internal sources. For example Germany for coal or the UK for gas. These are major industries which will need to be taken into account.

- Minimal domestic energy. Countries which have electricity systems highly dependent on imports. For example Italy for gas and Taiwan, Japan and Korea for gas and coal. These are countries which have every incentive to find alternatives to gas and coal.

The attraction of looking at markets in this way is that it draws out differences between them. So for example, Italy has much lower domestic gas production than Holland, and so is likely to find change easier. Spain has much lower domestic coal production than Germany, which is why they have been able to close down their coal sector more easily. Korea, Taiwan and Japan have much lower coal and gas production than Indonesia and Malaysia and are more likely to embrace change.

7.2.3 Declining demand

Where demand is declining, it is harder to embrace new capacity because it means the write-down of existing assets. The classic example of this is the huge write-downs in Europe as renewables expanded into a declining system in the 2010s.

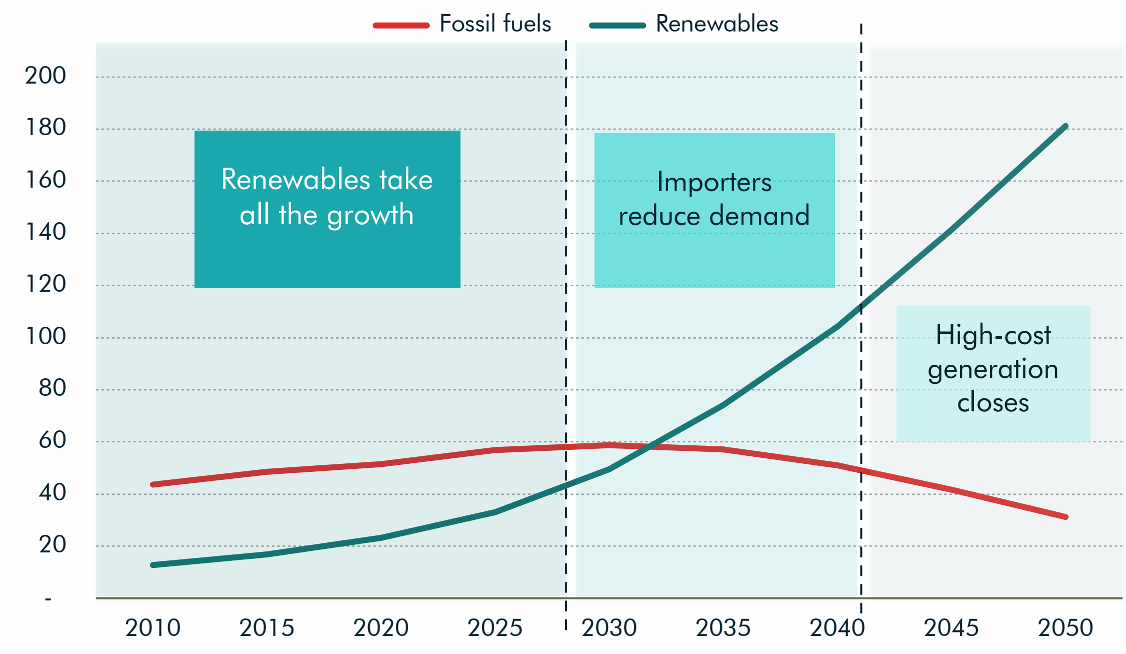
7.3 The phases of the transition

We believe that there are then three distinct phases in the electricity transition. The key point is that the transition can start in spite of the existence of countries and sectors which resist it. The greater levels of resistance from entrenched incumbents will need to be faced in later phases.

- Phase 1. Renewables take the growth. Renewables are already three quarters of the growth in electricity capacity and over half the growth in supply. Over the next five years, we expect them to make up 100% of the growth in electricity supply. This is a relatively easy phase, as there are less vested interest to tackle.
- Phase 2. Importers reduce demand. Importers such as Korea or Taiwan can turn to renewables and reduce their usage of fossil fuels. As noted above, imports are around one quarter of all coal and gas consumption, so there is considerable scope for a reduction in demand. Again this is likely to prove relatively easy to achieve.
- Phase 3. Closure of existing assets. This stage is considerably harder and will take political leadership, as Angela Merkel has demonstrated. Within this, there will also be some phasing – countries with small amounts of fossil fuel generation are likely to close it (e.g. UK) before those with large amounts (e.g. Poland) However, by the time we get to this stage, the economic case will be so compelling that governments will be more averse to implement change to avoid falling behind.

We illustrate this by using the data from the Shell Sky scenario on the amount of fossil fuels and renewables required in the electricity sector. Although, the transition is likely to happen rather faster than this, it also illustrates the point that the driver of change in the 2020s will be taking the growth.

Figure 13 - Electricity supply (EJ) and the stages of the energy transition



Source: Shell Sky Scenario. Carbon Tracker annotation

7.4 How to split markets in phase 1

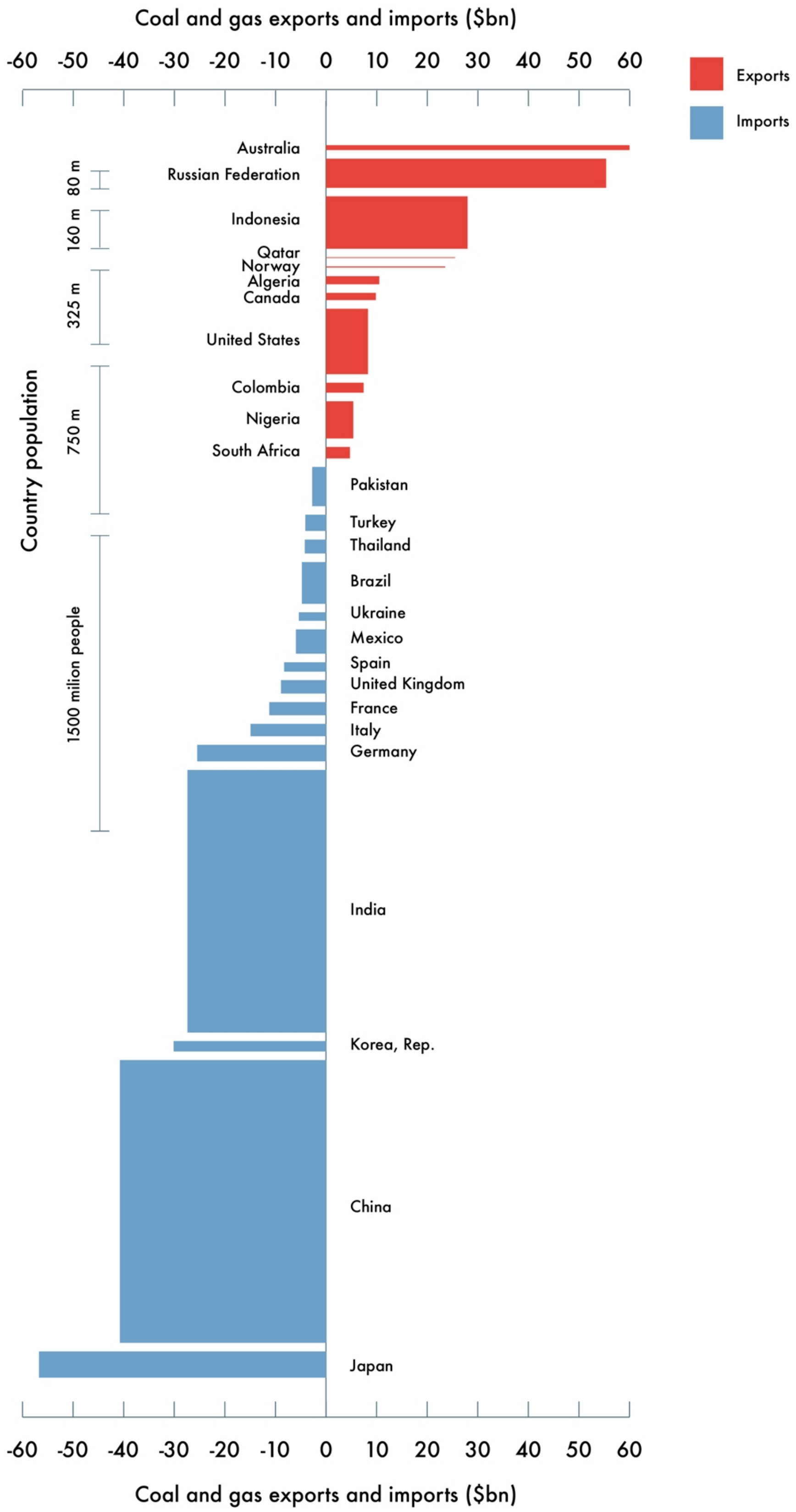
The final question is whether there are enough markets able to countenance change during the first phase. We believe it is reasonable to split markets two ways – by exporters or importer of coal and gas; and by high income versus the rest. High income is a pretty good proxy for weak demand growth as well as lower pollution problems.

7.4.1 Importers or exporters

It is possible to split the world into two main groups:

- Exporters. For example Russia or Australia. Change will be challenging. 25% of people live in countries that are exporters of coal and gas. As so often there is concentration even within this. 75% of global coal and gas exports come from seven countries with just 5% of the global population.
- Importers. For example UK or India. Change will be easier. 75% of people live in these countries.

FIGURE 14 - COAL AND GAS EXPORTS AND IMPORTS $BN 2017 VERSUS POPULATION



Source: World Bank

7.4.2 High income vs the rest

The other split is between high income and low income.

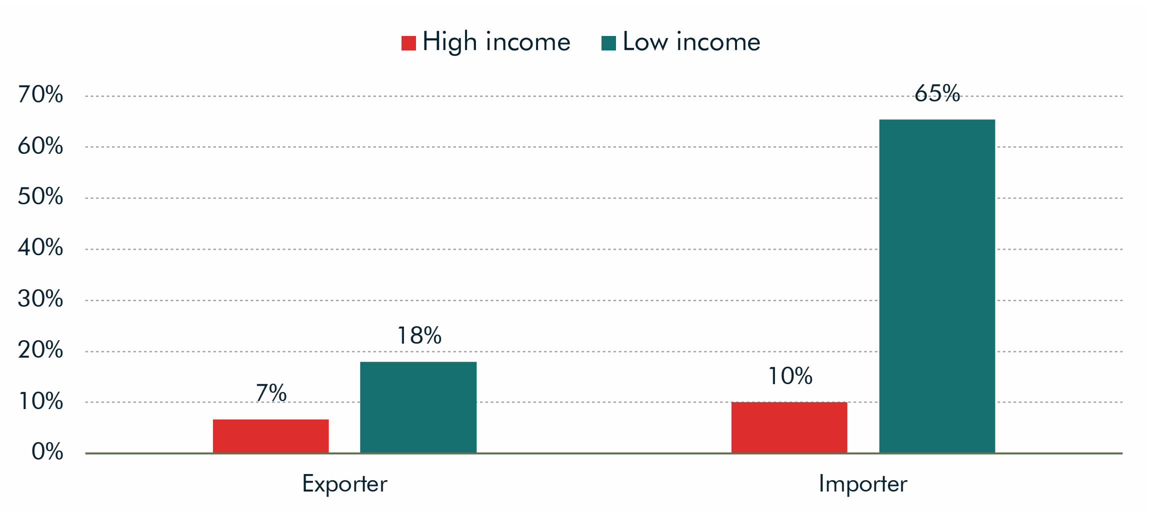
High income. 17% of the global population lives in high income countries as classified by the World Bank. As a rule these countries do not have rapidly rising demand or a pollution issue.

Low income. The rest of the world lives in the emerging markets which tend to have faster growth and more pollution. Growing markets find it much easier to implement renewables than declining ones.

7.4.3 Conclusion

Therefore it is possible to create four groups of markets and to consider their share of global population. As one might expect, the largest group, with 65% of the world's population, lives in low income importers of coal and gas. This includes China and India. And the smallest group, just 7% of the total, is in the most intractable sector, the high income exporters. It includes Australia, Poland, and the United States.

FIGURE 15 - SPLIT OF GLOBAL POPULATION BY INCOME LEVEL AND COAL AND GAS IMPORTS/EXPORTS



Source: World Bank

8 Policy in the energy transition

It remains to consider what is the role of policymakers in this energy transition and what are the rewards to those who succeed.

8.1 The role of policy in the energy transition

There are multiple roles of policy: to remove barriers and enable change to take place; to tax externalities via fiscal policy; to force the transition where necessary, including improved monitoring and oversight of environmental policy; and to enable a just transition, including retraining fossil fuel workers. We also note the importance of international policy collaboration.[11]

8.1.1 Remove barriers and enable change to take place

The first role of policy is to remove barriers to the energy transition and to enable change to take place. Given the complexity of energy systems this is a key role. It involves a host of actions, from amending domestic electricity codes to organising energy auctions, tackling the cost of energy innovation, counter lobbying (policy capture) and ending policy uncertainty.

One key solution is the deregulation of electricity markets. Take-up of lower carbon energy sources has been much faster in countries that have done this as opposed to those that are characterised by higher levels of regulation and state control.

Enabling change to take place could include cross-ministry alignment on climate policy (this is important as we often see ministries apply different degrees of commitment on climate, thus sending a market signal that climate is not important), training, culture, market signals (enabling policy environments for energy, but also for other polluting industries) and organising energy auctions.

One key enabler of change is introducing regional grids to balance load and intermittency issues.

8.1.2 Fiscal policy

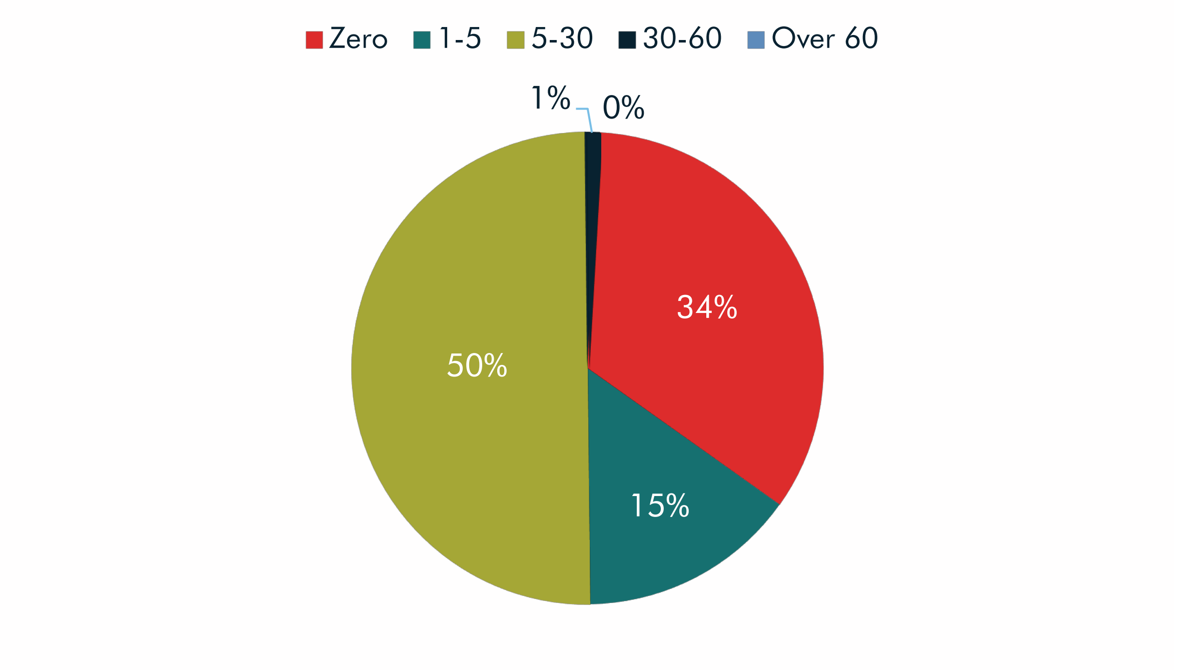
Fiscal policy in support of the energy transition could include ending fossil fuel subsidies, tax policy on green finance, government investment in new technologies, as well as tax policy, such as taxing externalities.

Using fossil fuels has a cost. Around four million people a year die of ambient air pollution, in large part from the combustion of fossil fuels. Fossil fuels drive global warming, which leads to drastic and escalating physical consequences. The social cost of carbon is variously calculated at around $50 per tonne as we have seen. As matters stand, fossil fuel electricity generation is very undertaxed. The OECD calculates a 'price gap to €30' of 84% in electricity, which means that the average tax on fossil fuel in electricity generation is around €5 per tonne.[12] Furthermore they note that only 1% of electricity is taxed at over €30 per tonne.

[11] *There are many excellent manuals for policymakers by organisations such as IRENA and the IEA. They include* IRENA, *How to Accelerate the Energy Transition, 2018, or Power System Flexibility for the Energy Transition, 2018, and* IEA, *Status of Power System Transformation,* 2019., *and Energy transitions in G7 countries.*

[12] *The methodology is more complex than this. See* OECD, *Effective Carbon Rates,* 2018

FIGURE 16 - EFFECTIVE CARBON TAXES ON ELECTRICITY (€/TONNE OF CO^2)



Source: OECD, Effective carbon rates, 2018

When renewables were expensive, taxing the externality meant that the externality costs were passed straight onto the consumer. As renewables grow in size and fall in cost below fossil fuels, fossil fuel producers will find that they themselves have to absorb the taxed externality cost if they want to compete at all. The impact of higher taxation therefore will be to reduce superprofits in the fossil fuel sector.

8.1.3 Force the transition where necessary, including improved monitoring and oversight of environmental policy

Policy makers need to ensure a resilient policy environment to oversee the change. Ultimately, policy makers may need to force efficiency on the system, through bans on combustion engines or sectors like coal fired power plants, particularly as the costs of new renewables fall below the operating costs of coal plants.

Improved monitoring and oversight of environmental policy removes industry uncertainty (including, perceived 'optionality' around environmental policy), rewards first-movers and can facilitate increased efficiency.

8.1.4 Enable a just transition, including retraining of fossil fuel workers

Millions work in the fossil fuel sector, and there are cities and communities which are dependent on fossil fuels. Some argue that this is insurmountable problem: the short-term interest of 30 million people should take precedence over those of the global population of 7,700 million people, all their descendants, and the future of the planet. But fortunately the problem is not so stark as this.

- Fossil fuel demand is not going to decline to zero overnight. It will peak and then decline gradually.
- Natural wastage through retirement will allow many people to complete their working careers. Forced redundancy can therefore be kept low.

- Many fossil fuel workers have remarkable skills. Which can be put to new use in the building of the brave new world of renewables. The classic example of this 'wells to wind' transition is oil rig workers in the North Sea who are now building and maintaining wind turbines.

Therefore, the solution for governments is to provide retraining and reskilling of their fossil fuel workforces, to prepare communities for the change to come, and to facilitate the rise of those industries that are needed to support the energy transition.

This issue is examined in more detail in a companion paper by Nick Robins[13].

8.1.5 Global policy collaboration

It is important that domestic policy makers work with their international counterparts. This could include the role of multilateral policy forums, such as G20, UNFCCC or OECD in setting high international performance standards that support the energy transition.

This is an issue which is considered in more detail in a forthcoming paper on policy levers by Vivid Economics.

8.2 Rewards of good policy

There are also of course rewards which await policymakers who implement policies which allow their people to reap the renewable harvest. We summarise a number of these below.

- Save money. Cheaper energy means that countries can save money. As an aside this is an issue which applies to exporters as well as importers. If a new Polish coal mine and generator require a price of $70 per MWh, then the Polish government would save money by allowing new wind turbines to generate electricity at $50 per MWh.
- Avoid stranded assets. Stop the building of assets which are likely to get stranded by changing technology and lower costs. Because most electricity networks are controlled by governments, it is in their own interest to avoid building assets which are likely soon to become redundant.
- Reduce imports. Lower imports will mean more stable domestic currencies and less risk of external shocks.
- Improve health. Lower pollution from fossil fuels means better health.
- Increase jobs. Renewable systems have more local jobs that fossil fuel systems. As well as being the jobs of the future not those of the past.
- Enhance energy independence. Lower imports means more energy independence and more geopolitical clout.
- Get elected. Not coincidentally, these policies will be highly popular. Those that embrace them will get elected. Or more specifically, those who fail to embrace them, and are seen to be a tool of the fossil fuel oligopoly, will not get elected.

[13] Nick Robins and James Rydge, *Why a just transition is crucial for effective climate action,* 2019.

9 The counterarguments

There are of course many counter-arguments made by incumbents who believe that change is not possible. We have addressed above the two most important of these – intermittency and incumbency. And we consider briefly below some of these.

The weakness at the heart of most of these arguments is the assumption that humanity will be unable to adapt. The assumption is that whatever systems operate today will have to operate in the future. This linear thinking was wrong when humanity moved from slavery to fossil fuels, wrong when we moved from horses to cars, and will be wrong again.

We do not deny that the transition will be difficult, that the forces of incumbency and inertia will seek to slow and hold back change, and that there are some countries where they will succeed in doing so for a while. However, it is important to distinguish between teething troubles, which can and will be solved, and insoluble impediments which cannot. We see plenty of impediments which will slow change and make it hard, but none that are insuperable.

9.1 System costs

One argument beloved by fossil fuel incumbents is to raise the spectre of system costs. The levelised cost of energy (LCOE) is not good enough, and it is necessary to look at system costs, defined as the additional cost needed to bring renewables into an electricity system.

There are some weaknesses in this argument

- System costs are not very much. For example, the IEA argues that the US system cost will add $5 per MWh to the cost of solar electricity in 2040.
- Renewables keep falling in price anyway. Solar costs usually fall by $5 per MWh in one to two years. So this is not really an impediment to change.
- The highest system costs are expected far into the future. Higher systems costs are projected when renewable energy penetration levels are much higher than they are today.
- System calls keep falling. As technology improves, so the system costs get lower. For example, rapidly falling battery costs are enabling renewables to compete with US gas peaker plants already. This is, as noted before, our third tipping point.
- Countries can design their systems to accommodate renewables. For countries with rapidly rising electricity demand, it will undoubtedly prove cheaper to design their system to handle renewables from the outset. They thus avoid the redundant assets and stranded costs associated with the transition of an existing system.

9.2 Lack of space

The supposed lack of space is a favourite argument of the sceptics. And of course it is easy to point to specific locations where the population is large, and the amount of space land is limited. However, this is simply not an issue for most locations. As many organisations have pointed out, around 1% of the world's land would be sufficient to supply all global energy.

The calculations are pretty simple. According to BloombergNEF, the world in 2018 used 52,000 square km to produce 2 PWh of renewable electricity from solar and wind. So 26,000 square km per PWh. Global demand for electricity is 27 PWh, using 40% of the world's primary energy. Scaled up, that implies 68 PWh of total electricity demand.[14]

[14] *In fact electricity demand will be less than this because electricity is a much higher quality energy source than fossil fuels.*

At 26,000 square km per PWh this would require 1.75 million square km. The global land mass is 168 million square km, meaning that this is indeed 1% of global land.

In reality of course, the number would be less than this. Future energy supply will be more efficient, and there will be the opportunity to use offshore wind. Moreover, 1% of the total is the amount of land that might be required in 50 years. In the meantime, the levels of land demand will be much lower.

9.3 Lack of minerals

There are concerns about the lack of some key minerals required for the renewable system. Rare earths or lithium or cobalt are the current favourites and there will no doubt be others. However, this is simply a timing issue and to be expected at the time of rapid growth. What we have seen consistently is that rapid growth has driven up pries which have sparked new supply and taken down price.

BNEF has examined this issue in detail[15] and found no evidence that a lack of raw materials would hold back the energy transition.

9.4 Regulation cannot handle renewables

There are a series of regulatory and structural issues which have the capacity to impede the growth of renewables. We mention two aspects of this and then suggest a likely solution.

Renewables are a zero marginal cost energy source and as they grow in size in systems designed for the marginal economics of fossil fuels, so they have caused chaotic impacts. Sceptics argue that this is an insuperable impediment.

In Japan, the grid is heavily controlled by incumbent utilities who not only own the transmission assets but also the (largely fossil fuel) generation assets. They have a vested interest in delaying renewable penetration onto their grid, which appears to have slowed the growth in renewables.

There is no simple answer to this type of concern. Each country will be different. But the overall point is that regulators will adapt codes and systems to accommodate the new technology. Regulators in leading nations such as the UK or Denmark are teasing out solutions.

The pressure for regulators to act in the interests of the public will vary from country to country, but over time the cost and effectiveness gap between leaders and laggards will become so large that we would expect change to happen. An analogy can be drawn with the rise of the mobile phone. Incumbents in many countries were able to frustrate and resist change, but the technology was adopted everywhere in the end.

9.5 Grid capacity is too small

There are concerns that grid capacity is too small. Either because transmission capacity is not large enough or because local grids need to be broadened to handle electric vehicles, or because some renewables are located far from demand centres.

Again the answer is that come locations will find change harder than others, and that all will be obliged to adapt and change. But it is simply not credible to suggest that this is an insuperable

[15] *See for example the* BloombergNEF, *New Energy Outlook*, 2019.

barrier in light of the fact that the entire global electricity infrastructure has been built in a just over a century. It will need to be improved and changed, as we have done in the past.

9.6 Renewable costs have stopped falling and renewable growth has stalled

For the last three decades the sceptics have made the same argument – that renewable costs have stopped falling. And for three decades they have been wrong. Solar, wind and batteries are on clearly defined learning curves, which have persisted for many years and are likely to continue. Organisations such as IRENA or BloombergNEF or Rocky Mountain Institute are able to identify many new drivers of continued falling renewable costs.

In 2018, the installation of solar and wind capacity was about the same as in 2017, leading many excited commentators to argue that renewable growth had stalled. Again, this is an argument that the IEA has been making for 20 years, and for 20 years they have been wrong. Solar installations stopped rising in 2018 for the very specific reason that China removed subsidies because the cost of the technology was approaching cost parity with fossil fuels. This type of boom bust growth patterns as subsidies are removed has marked the industry for decades. But on each occasion, after a brief respite, growth has come roaring back. Indeed, as costs have continued to fall, so growth is returning, and most forecasts for 2019 already foresee a marked increase in solar installations.

The right question to ask is why would growth not accelerate now that costs have fallen below those of fossil fuels and more and more resources are being put into driving change?

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