X-change: Electricity

On track for net zero

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About RMI

RMI is an independent non-profit, founded in 1982 as Rocky Mountain Institute, that transforms global energy systems through market-driven solutions to align with a 1.5°C future and secure a clean, prosperous, zero-carbon future for all.

We work in the world's most critical geographies and engage businesses, policymakers, communities, and non-governmental organizations (NGOs) to identify and scale energy system interventions that will cut greenhouse gas emissions at least 50 percent by 2030.

RMI has offices in: Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; and Beijing.

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1. Summary

Solar and wind generation are on an exponential growth path which will lead to disruption of the global electricity sector this decade, but not to 1.5°C — that requires faster change.

What is the X-change? The X-change isolates and models exponential growth and assumes the rest of the system is forced to adjust. Its conclusions are very different from the orthodox approach, which focuses on barriers, models linear change, and has been consistently wrong.

The past has been exponential. Solar, wind, and batteries have been following a typical path for new technology. Learning curves led to falling prices, which led to rapid growth in new capacity, which led to change in the generation mix on an S-curve.

Powerful change drivers are still in place. Learning curves, superior economics, energy security, geopolitical competition, efficiency, climate necessity, and local pollution remain a powerful combination for change. Solar, the cheapest energy source in history, will halve in price by 2030.

Leading indicators signal continuity. New solar and battery capacity, policy targets, the momentum of change, short-term deployment forecasts, and the logic of S-curves all point to continued exponential growth in solar and wind generation for the rest of this decade at 15–20% a year.

Solutions are bigger than barriers. There is a conundrum at the heart of renewable growth: Barriers are everywhere, but growth keeps happening. The reason is that barriers are specific and local, but solutions are generic and global, hence likely to overwhelm resistance to change.

Change is fast or faster. Linear change is no longer credible. Change to the electricity system will take place either fast (on a typical technology S-curve) or faster (continued exponential growth).

Solar and wind power will grow by 3–4 times by 2030. Fast growth will lead to a tripling in solar and wind generation by 2030 while faster growth will mean a quadrupling in generation, to produce more than 14,000 terawatt hours (TWh) and overtake fossil fuel supply.

The fossil fuel era is over. Fossil fuel demand in electricity has reached a peak at around 18,000 TWh, will plateau for a few years, and will fall by between 16% and 30% by the end of this decade.

We have agency. In the same way as Moore's Law required constant innovation and action to stay on track, so we have to work hard to stay on the exponential path. We need to build out grids, change permitting laws, scale up flexibility solutions, improve regulatory and market systems, and speed up deployment in the Global South.

There is always room to go faster. We are on the path to net zero by 2050 but we are not on the path to limit warming to 1.5°C. Each death induced from fossil fuel air pollution matters, each dollar spent on importing expensive fossil fuels has an opportunity cost, and each fraction of a degree is a threat multiplier. In this context, there is no such thing as "fast enough." Speed is justice.

We can do it right this time. Renewable energy is distributed, clean, and universal. Falling costs unlock renewables globally and are a superior tool for more equitable economic development. We need to ensure good mining practices, circularity, and integrative design to fully capture the benefits of the renewables revolution. Most importantly, we can use energy more efficiently and timely, mix optimally with renewables, and displace even more fossil fuel sooner.

2. Exponential change so far

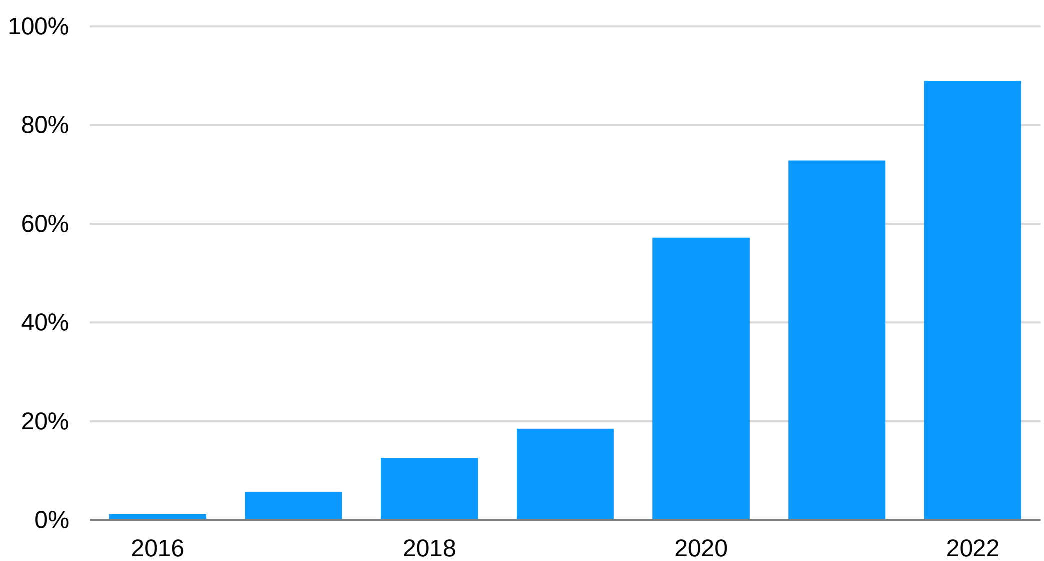
The last decade has been characterized by exponential change in the electricity sector. Policy pressures rose. Solar, wind, battery and grid technology improved. Barriers were overcome. Costs fell. Capacity deployment increased exponentially, and solar and wind increased their share of generation along the typical S-curve which characterizes technology revolutions.[1]

In the next three chapters we describe the following in more detail: first, the exponential change in electricity generation so far; second, why it's likely exponential change will continue in the near term; third, what this continuity implies for electricity generation. In the Appendix we outline the methodologies in more detail.

2.1 Policy pressure rose

It is worth recalling how far we have come since 2013. Over the course of the decade, the share of the global economy with net-zero targets by mid-century increased to 90% (see Figure 1). [2] Reinforcing feedbacks between corporate action and ambition, policies, and policy pressures promoted the rapid deployment of solar and wind electricity generation.[3] This started with subsidies and targets but has moved on to detailed reform of grid regulations and work to speed up permitting and grid deployment.

Figure 1: Share of global emissions covered by country net-zero targets



Source: IEA,[4] Climate Action Tracker[5]

Putin's invasion of Ukraine was a 'Sputnik moment' for policy, making apparent to Europe its degree of dependency on Russian fossil fuel energy, and making clear to the West its degree of dependency on Chinese renewable energy technology. This helped make possible the IRA in the US and drove the European Commission's REPowerEU plan.

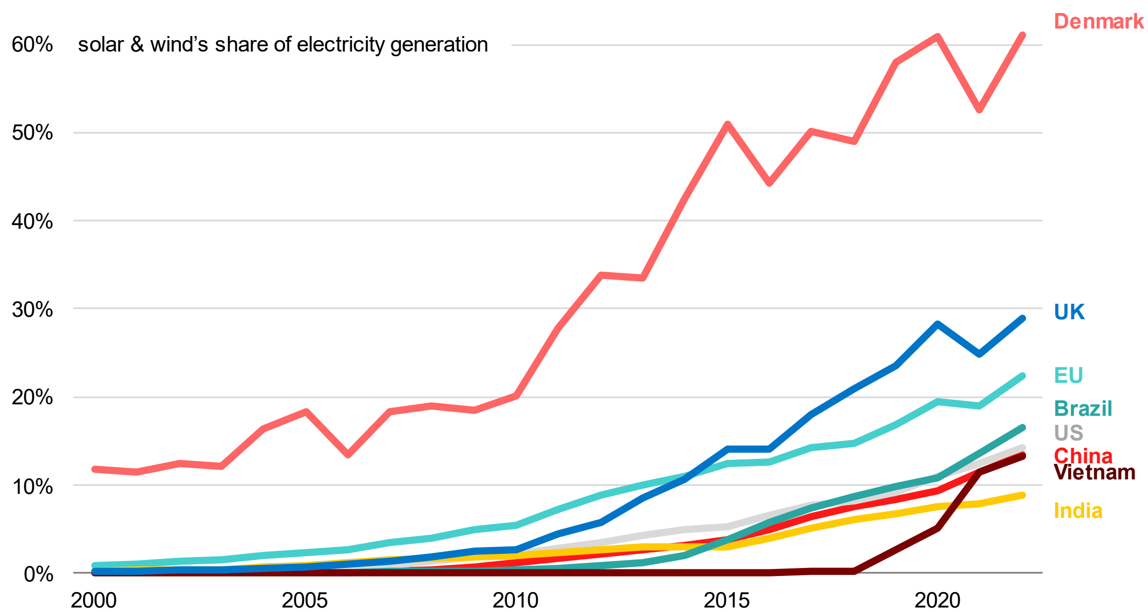
2.2 Technology solved barriers

Technology improved significantly over the course of the decade, and this enabled technical, economic and policy barriers to be solved. Here we do not provide a comprehensive overview of the feedback loops between policy, technology, and market creation, but highlight four examples to illustrate the point:

- **Variability**. Grid operators in Germany and Ireland once argued that only 2% of the grid could be supplied by solar and wind because of intermittency.[6] Improved and superior technology solutions mean that some countries are already over 80%.
- **Economics.** Solar and wind once needed subsidy. Now they are the cheapest electricity sources in history[7,8] while the fossil and nuclear industries crave subsidies.
- **Policy**. Policymakers have taken advantage of the superior technology and are ratcheting up their ambition to deploy solar and wind faster.[9]
- **Corporates**. The private sector has stepped up to improve technology performance and the business case for renewables. For example, the Danish manufacturer Vestas is capturing first-mover advantages because they invested in superior technology early,[10] and demand signals were created through corporate commitments and buyer's initiatives such as the Clean Energy Buyers Association (CEBA).[11]

As a result, the share of solar and wind has risen rapidly in leading countries.

Figure 2: Share of solar and wind in electricity generation: selected countries

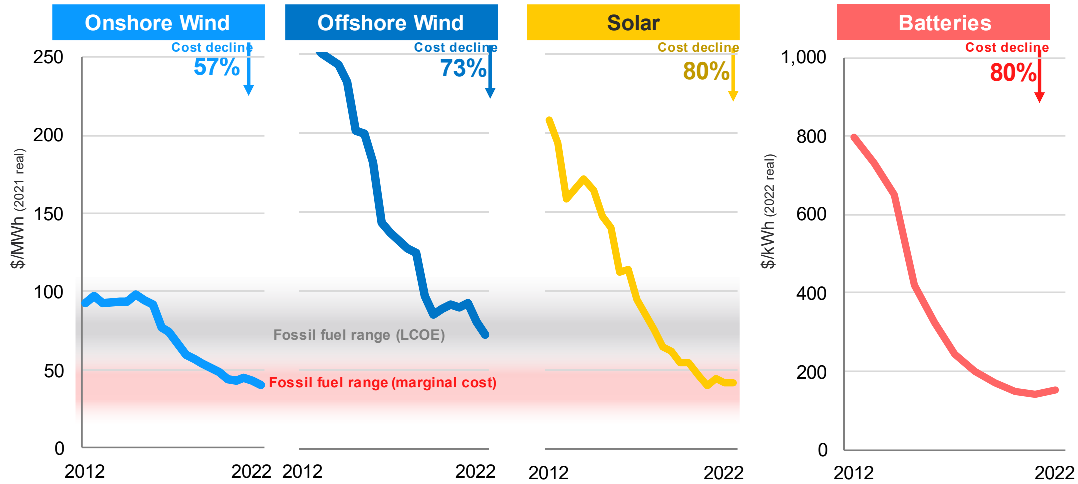


Source: Energy Institute Statistical Review of World Energy,[12] RMI analysis

2.3 Costs fell

Costs of the key renewable technologies are on established learning curves and have been falling for decades. During 2012–22, the cost of solar and onshore wind power fell by 80% and 57% respectively.[13] The levelized cost of energy (LCOE) of solar and wind in H1 2023 was just over $40 per MWh, about half that of coal and gas.[14]

Figure 3: The collapsing cost of renewables



Source: BNEF,[15] RMI[16]

BNEF calculates that solar and wind are now the cheapest sources of new electricity in 82% of the world for new electricity and in 57% of the world for existing electricity (where new renewables can outcompete existing fossil fuel assets).[17] Because renewable costs keep falling, the share of the world where the economics of renewables are superior will rise.[18]

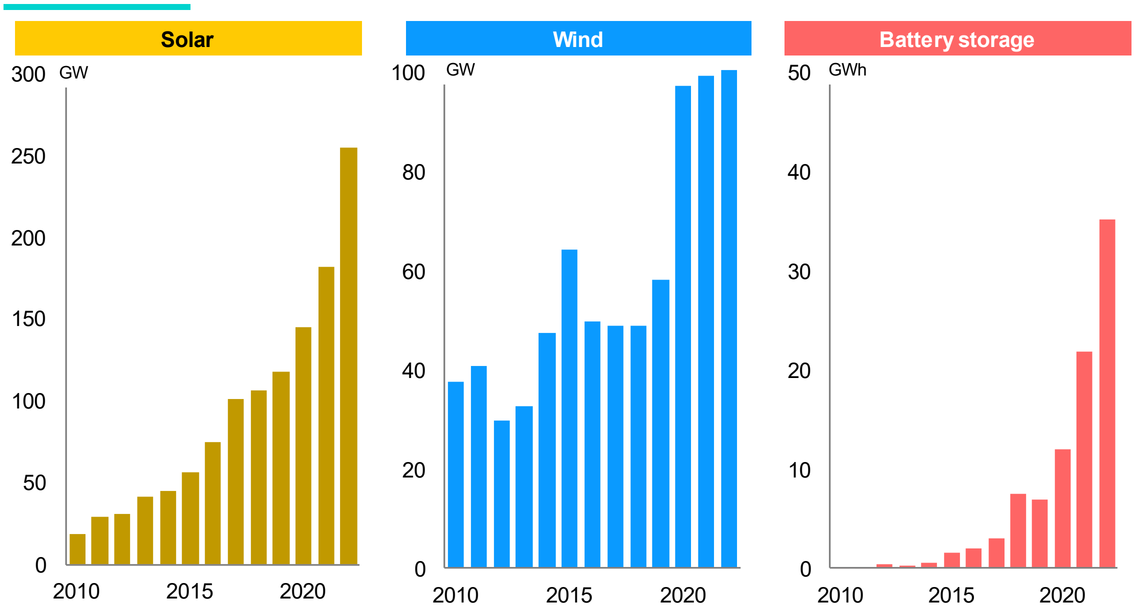
2.4 Sales increased exponentially

Falling costs and rising technology solutions have led to exponential growth in the deployment of solar, wind and battery storage. We illustrate below the deployment of new capacity, the shift in capital expenditure, the growth in generation and the rise in market share.

2.4.1 New capacity

As the result of falling costs, volumes of new renewables capacity have been rising rapidly.

Figure 4: Annual additions of key renewable technologies



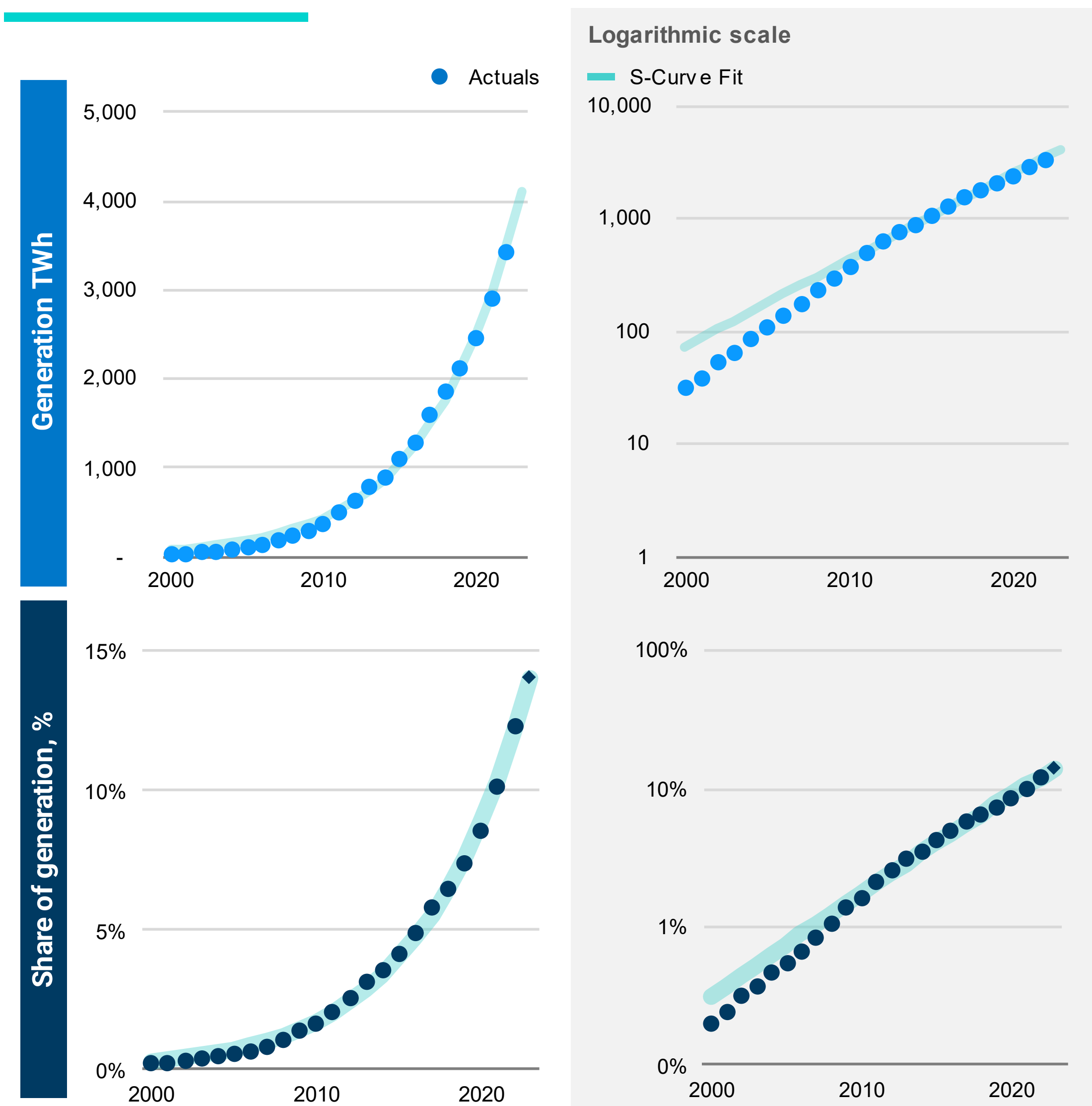
Source: BNEF[19]

Capital has been shifting to low-carbon energy and out of fossil fuels. The International Energy Agency (IEA) expects 87% of capital investment in electricity generation in 2023 to be for low-carbon energy, almost all of which is solar and wind.[20]

2.4.2 Total generation

The fall in prices and exponential growth in new capacity have given solar and wind a rising share of electricity generation. This rose to 12% in 2022 and is likely to be 14% in 2023.[21] Solar and wind are moving up an S-curve which characterizes past technology shifts.[22] The strong S-curve fit is demonstrated on linear axes (left-hand side) and log scales (right-hand side), with remarkably little slowing during the pandemic.

Figure 5: Solar and wind generation, TWh (top) and % of generation (bottom)

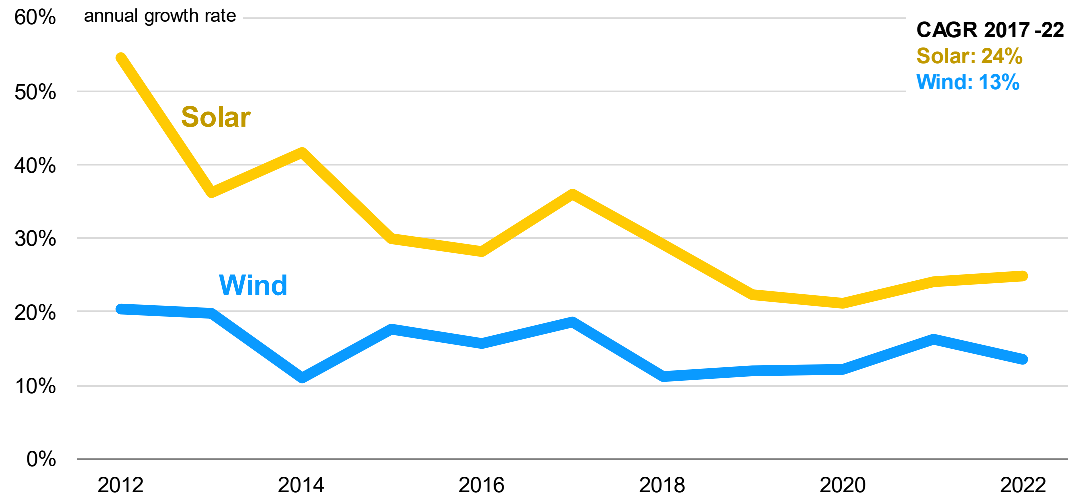


Source: Energy Institute Statistical Review of World Energy,[23] RMI analysis

2.4.3 Growth rates

The annual growth in generation has been remarkably stable over the past five years at a compound annual growth rate of 24% for solar and 13% for wind (see Figure 6).

Figure 6: Growth rates of solar and wind generation



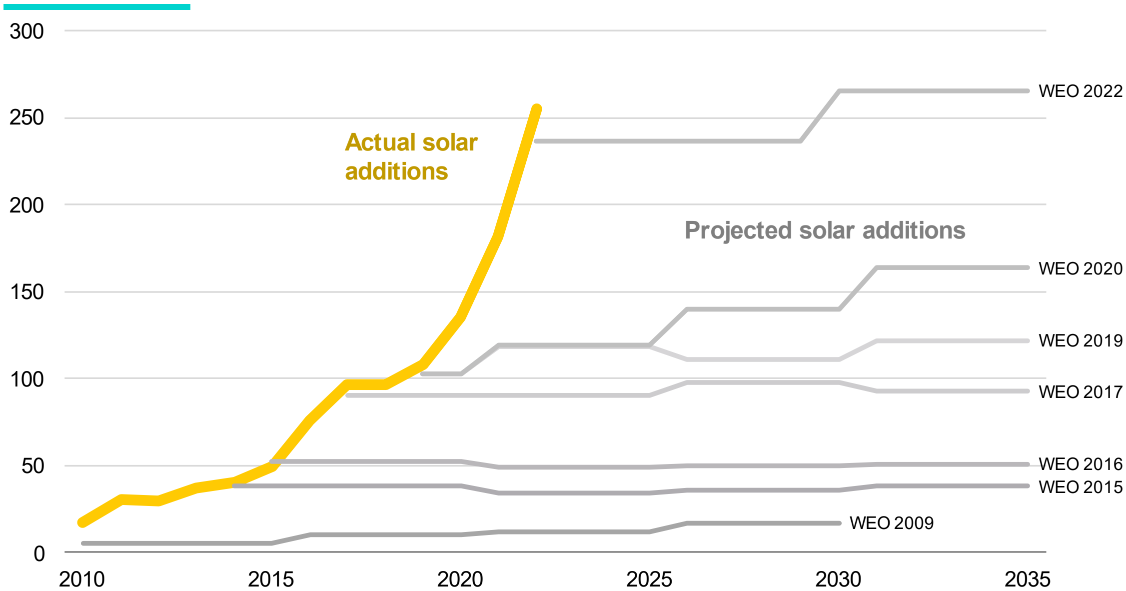
Source: Energy Institute Statistical Review of World Energy[24]

2.5 Most energy modelers did not see change coming

Most modelers did not see this rapid change coming. They argued that barriers to change would mean linear growth. The well-known chart below of actual and forecast solar capacity deployment illustrates the point.

For many years, the IEA forecast linear supply growth of solar under its business-as-usual scenarios, even as solar supply continued to rise exponentially. But the IEA was not alone — even BNEF has been surprised by the speed of deployment of solar.[25]

Figure 7: New solar capacity installations, GW



Source: IEA STEPS scenario,[26] Auke Hoekstra methodology[27]

As a result, the forecasts were wrong for the rest of the system as well. If you understate the growth of the main driver of change, you will overstate demand for fossil fuels and underestimate actual and prospective climate progress.

3. The drivers of change will continue

In the period to 2030, we believe it is likely policy pressure will increase, technology will improve, renewable costs will fall, barriers will continue to be solved and exponential growth will continue.

3.1 More policy pressure

Increasingly ambitious policy targets, roadmaps, subsidies, and regulations are likely to support acceleration of the energy transition and create more market tipping points.[28] Drivers of this increase in policy pressure include:

- **Climate change**. Rising temperatures will raise pressure from society to reduce emissions. That will mean voters are more likely to elect politicians who drive change as well as rising legal and financial pressure on the fossil fuel system. In practice this means that politicians will move increasingly from top-down targets to detailed policy. That means increasingly specific and substantive policy changes such as feed-in tariffs, contracts for difference, public procurement, grid upgrades, permitting reform, and detailed regulatory changes.
- **Energy security.** The hunt for energy security is encouraging many more countries to produce their own renewable electricity. This is most clearly seen at present in Europe, which is increasing its targets for solar, wind, heat pumps, and electric vehicles (EV) because of the Russian invasion of Ukraine and the collapse in Russian energy exports.[29,30] Distributed supplies are also often favored for their greater resilience.
- **Geopolitical competition**. Competition between the US and China for leadership is leading them both to focus on producing the technologies of the future; in energy, that means renewable technologies[31] and efficient use.
- **Lower costs**. Falling renewable prices help politicians encourage change by banning the deployment of machines[32] that use fossil fuels or increasing taxation on fossil fuel externalities.[33]
- **More efficiency**. As efficiency gains succeed in one area, they can be deployed in the next. The IEA for example holds regular workshops to speed up efficiency gains.[34] Policymakers have doubled planned annual efficiency gains to 4% under the Sønderborg Action Plan.[35]
- **A shift in the relative power of vested interests**. As solar and wind get larger and cheaper and it becomes more obvious that they will be the energy sources of the future, their lobbying power rises. And as fossil fuel demand falls and the product moves from being essential to merely one option, the industry's lobbying power weakens.[36]
- **Gain not pain**. As costs continue to fall, a new paradigm is emerging for diplomacy: opportunity sharing. Countries can work together to get up the S-curve faster.[37]

This means policy will become more aggressive over time in supporting solar and wind deployment. This continues the increasingly ambitious renewable policy roadmaps and commitments of the past two decades.

3.2 Lower costs

It is highly likely that costs for key renewable technologies will continue to fall on learning curves; solar, the cheapest energy source in history, will halve in price by 2030. As Doyne Farmer points out, learning curves are sticky.[38] They persist, and that should be our default assumption. Detailed reasons to believe that they will persist include:

- **Better technology**. Solar panels get more efficient and wind turbines get bigger. Over time, companies use cheaper and lighter materials; for example, the polysilicon per kilowatt (kW) of solar keeps falling,[39] and the energy density of batteries keeps rising.[40]
- **Learning-by-doing**. This is what lies at the heart of all manufacturing technologies. The more you do, the better you get.
- **Copy the leaders**. Some countries are leading the energy transition while others are still learning.[41] For example, the UK sends heat pump engineers to Sweden to train.
- **Evolution is cleverer than you are** — Orgel's second rule.[42] We are likely to find solutions that we cannot forecast in detail today.
- **Pandora's box has been opened**. In every area of the energy system, people are hunting for solutions to improve efficiency, reduce carbon emissions, and lower costs. Many solutions blend to spawn new ones. They're not just in technology but also in design, finance, business models, behaviors, memes, and more.

Assuming learning rates and growth rates, it is possible to calculate the likely future prices for solar and wind as below. For example, a growth rate of 25% and a learning rate of 20% would imply a 2030 solar cost of $25 per MWh.

Figure 8: Cost of solar and wind in 2030 based on different annual learning and growth rates, $/MWh

Solar

Growth rate \ Learning rates	20%	25%	30%	35%
15%	31	28	25	22
20%	28	24	21	18
25%	25	21	18	15

Wind

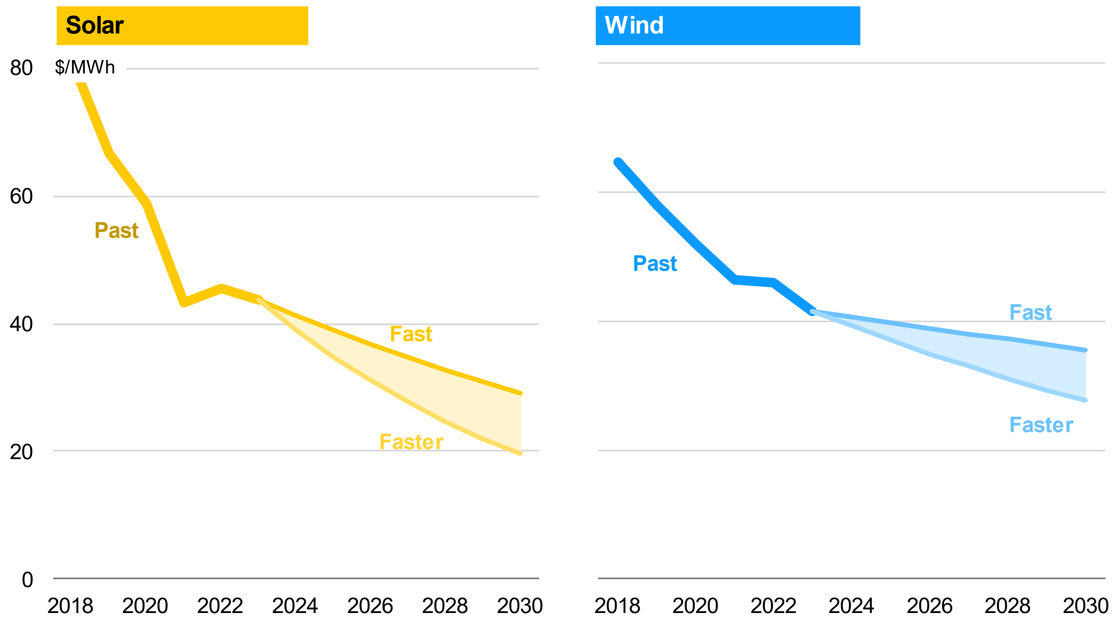
Growth rate \ Learning rates	10%	15%	20%	25%
10%	37	35	33	31
15%	35	32	29	26
20%	34	30	26	23

Source: RMI

According to INET Oxford, the learning rate (cost decline per doubling of cumulative production) over the past 40 years has been 20% for solar and 13% for wind.[43] That would imply a likely 2030 solar price around $25–28. The average learning rate over the past decade has been significantly higher (36% for solar and 38% for wind). If that continues, the price of solar will be near $15 and wind around $20 per MWh.

We create a range between the lower long-term INET learning rate (Fast) and the higher learning rates seen in more recent years (30% for solar and 25% for wind) (Faster). The importance of this range is not the end point but the simple insight that prices are likely to be much lower than today.

Figure 9: Expected solar and wind costs at different learning rates, $/MWh



Source: BNEF,[44] RMI analysis

3.3 More solutions than barriers

3.3.1 The growth conundrum

There is a conundrum at the heart of the energy transition: barriers to change are everywhere, yet exponential growth continues. We explain below why this happens and why it is reasonable to argue that barriers will not be sufficient to stop exponential growth. The key issue is to distinguish between barriers that are impossible and those that are difficult. All changes to the current system are difficult and some are impossible in certain locations today. Our contention is that none of the key changes are both impossible and universal.

3.3.2 What can other technology shifts tell us about barriers?

All technology shifts need to overcome barriers. They do so through technology learning, economies of scale, and other better policies and designs. The classic example is Moore's Law.[45] It essentially argues that the number of transistors on a microchip doubles every two years, enabling ever more capable computers.

This has been a useful approximation for decades. But change did not happen by itself. Every step of the way was fraught with complexity and difficulty. Tens of thousands of people devoted their careers to the challenge, and billions of dollars were spent to make possible this continued rapid change. Problems were solved in one area, the number of transistors per chip increased, and immediately new problems were faced.

In a similar way, every step of the energy transition is fraught with difficulty. And yet we have solved each difficulty as it arose, and we are likely to continue to do so.

3.3.3 What is the right analogy?

A few analogies help to show that when the forces of change are powerful enough, the barriers prove insufficient to stop it.

- **The rising tide**. The tide comes in inexorably. People throw up barriers to the tide, and they last for a while. But eventually the tide either swamps them or turns the barriers into islands.
- **The mountain stream**. Water falls onto a hillside and collects in a stream that then races downhill. It encounters boulders and barriers all the way to the sea, but it finds a way around them.
- **The rising sun**. As the sun rises on a village in the mountains, it brings light and warmth to the houses. Some villagers chose to keep their shutters closed and freeze in the dark. Others choose to fling them open and rejoice in the light. As news of the benefits of sunlight filter out to households freezing in the dark, they eventually rise and eject the tyrants holding up the fossil curtain.

3.3.4 How did we solve barriers so far?

Renewable energy technologies have already solved many barriers, as noted by Greg Nemet in his book *How Solar Became Cheap.*[46] The first decades were spent solving technology barriers and then it took a few more to solve economic barriers to change. The answers included technology and design innovation, talent, policy, capital, and market creation.

3.3.5 Why will we continue to solve barriers?

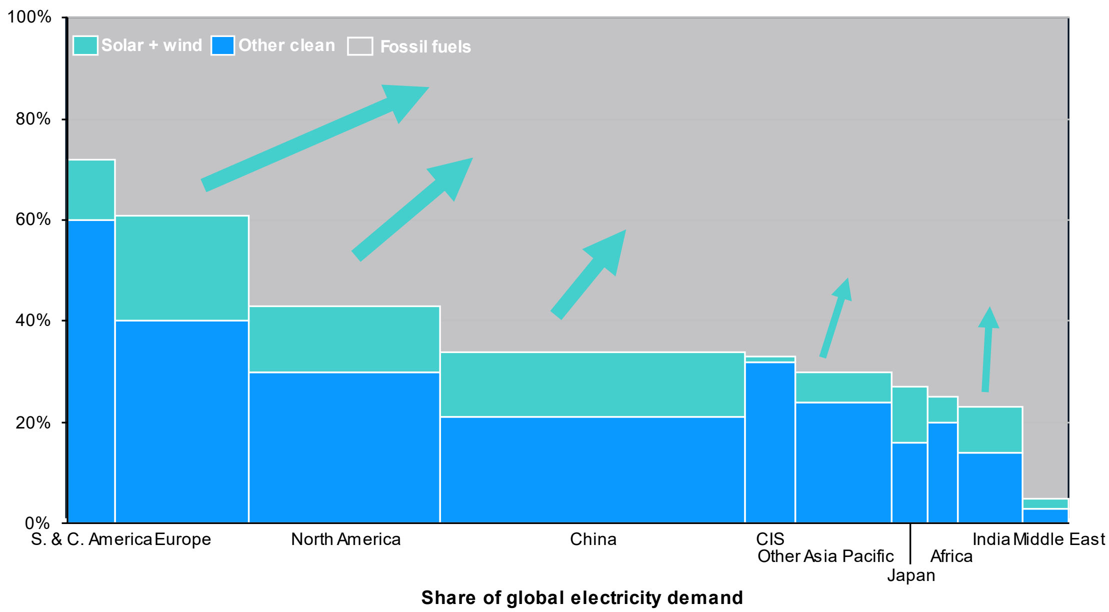
In broad terms, we have largely solved our technology and economic barriers and the main remaining ones are political. And here, numbers are on the side of change. Some 80% of people live in countries that import fossil fuels,[47] 100% of people live in countries that have more renewables than fossil fuels, and fewer than 1% of people work in the fossil fuel industry.[48] There are billions of people with a very strong incentive to find ways to deploy nearly unlimited renewable energy.

In more prosaic terms, there are four general drivers:[49]

- **Problems are specific but solutions are universal**. When an entrepreneur figures out how to improve the efficiency of a solar panel or how to increase the stored energy per kilogram of a battery, that innovation soon spreads around the world, enabling change in every area.
- **Innovation is constant**. People keep coming up with new solutions.
- **China is leading the transition**. The barriers to change faced in countries with a more powerful oil and gas lobby are simply not faced in China which lacks oil and gas. Moreover, China as the factory of the world can drive down costs and innovate faster.
- **Key supporting technologies enjoy exponential change**. Battery deployment and digitization are enjoying rapid exponential growth, enabling the needed flexibility.

The chart below illustrates how change is moving out from a central core across the world. It makes clear that there can be barriers to change in one country (e.g. Russia), but change is driven by countries that remove those barriers (e.g. China or Europe).

Figure 10: Share of electricity generation by region



Source: Energy Institute, Statistical Review of World Energy 2023,[50] RMI

3.3.6 What are the specific solutions?

This is not the report to examine specific solutions in detail, but we can point to several examples and more detailed pieces of work which give us confidence that there are solutions to the various barriers for the foreseeable future. We are not seeking to gloss over the very real issues that some countries and regions face, nor to suggest that change will be easy.

Change will require leadership and innovation and will be fought every step of the way by some incumbent interests. The strategic question we can ask is whether these barriers are likely to prove sufficiently powerful to stop change. Given the success of renewable technologies over the past few years and the drivers we have identified above, the onus surely lies on the sceptics to demonstrate that the barriers can and will derail growth.

Specific reports looking at more detail at these points include:

- **Variability**. The National Renewable Energy Laboratory (NREL) notes that there are many solutions to solar and wind variability, classified into supply side flexibility, demand side flexibility, and energy storage. Even with current technology, the cost of dealing with variability in the US becomes an issue only above 70% solar and wind penetration — and even then, added costs are probably smaller than without renewables. In 2022, solar and wind supplied only 12% of global electricity. Of course, the US may be in a better position than others, but in most places the ceiling of opportunity is a long way above us.[51] And as climatologist Ken Caldeira says, "Controversies about how to handle the endgame should not overly influence our opening moves."
- **Minerals**. We have enough key minerals to meet the requirements of the energy transition, as detailed by the IEA and other researchers.[52,53] There are certain minerals such as lithium, cobalt, nickel, and copper where we would struggle to provide enough new supply in the period to 2030 if we do not increase efficiency, ramp up recycling, and build more mines. However, that is exactly what we are now planning to do: producers and users of minerals can also see change coming and are reacting accordingly. New mines are being built, new battery chemistries are being adopted that use less or no cobalt, new recycling facilities are being built to ensure that

battery metals will be recycled, and more-efficient vehicles can greatly reduce the needed batteries.

- **Land use**. At a global level, there is plenty of land on which to deploy solar and wind. In a forthcoming report, the Energy Transitions Commission (ETC) notes that the global land surface is 149 million square kilometers (km^2), of which up to 100 million km^2 is suitable for deploying solar and wind. They calculate that the total land requirement is 0.4–0.8 million km^2 — less than 1% of the total. Mark Jacobson reaches a similar conclusion.[54] For comparison, livestock now use 40 million km^2. Some countries have less land available[55] and will need to be more careful about how they use land. Some, such as Singapore, will need to import renewable energy through cables. It is best to say that land availability is not a constraining factor, but it will require careful management.

- **The Global South**. Parts of the Global South face profound challenges to deploy either renewable energy or fossil fuel energy, and there is a strong moral argument for solving them. The fossil fuel system has clearly failed to solve this problem. The latest report from the International Renewable Energy Agency (IRENA)[56] on the issue notes that 675 million people still do not have access to electricity, and 2,300 million people do not have access to clean cooking. Challenges include the high cost of capital, the lack of domestic capital sources, weak offtakers, and inadequate grid distribution. Solutions go far beyond the energy system, but importantly, renewable energy brings a new suite of solutions to solve this problem, because the Global South has enormous renewable resources.

  For example, Africa is a renewables superpower, with 39% of global renewable potential[57] but only 4% of worldwide fossil fuel reserves. In the IRENA analysis of the issue, solar and wind are forecast to provide electricity to 90% of those who currently lack it.[58] Meanwhile, there is a growing movement to refocus the activity of the World Bank and the multilateral development banks to provide more capital to help solve this issue.[59] And, as Systems Change Lab notes , some countries in the Global South have seized the opportunity and deployed renewables at scale and speed. They range from Vietnam to Namibia, Barbados to Uruguay.

- **Capital requirements**. The ETC note that we have enough capital to cover the renewables buildout, [60] but many[61] still argue that the costs are high. We need to be very careful to compare like with like when looking at the capital requirements of the renewable energy transition. It is important to look at annual data rather than supposed requirements over 30 years, because it is highly likely the future solution suite will be better than what we have today and because future renewable costs will continue to fall on learning curves. We need to *compare* the costs of building a renewable system with the cost of sustaining a fossil fuel system rather than counting renewables' gross cost without netting out the fossil fuels they'll displace. The third factor often missed is that capital costs are only one of the six elements of cost — the others being operating costs, rent (the gap between cost and selling price), subsidies, local pollution, and global warming.

  When you account for these often-omitted factors, it rapidly becomes clear that the capital costs of the energy transition are comparable with those of maintaining the fossil fuel system and are highly unlikely to be a constraint on change. In broad terms, the extra capital cost of the energy transition in isolation will be matched by the reduction in the rent that the users of fossil fuels need to pay to petrostates.

- **Equity**. The issue of equity is central to the energy transition and has been examined by IRENA[62] and others. We plan to write about this in more detail in a separate piece. A failure to reduce emissions puts at risk the livelihood of millions of people, as noted by the Intergovernmental Panel on Climate Change (IPCC).[63] Meanwhile the local energy source of renewables, if properly deployed, can both help to bring millions out of poverty and reduce the pollution and deaths that result from the fossil fuel system. Nevertheless, there are legitimate issues to be addressed concerning appropriate land and resource use to ensure that any burdens are minimized. A renewable system offers an opportunity to get it right. It would be unwise not to take it.

3.3.7 What about the insoluble barriers?

There are some insoluble barriers to change. For example, a friend Matthew loves his diesel car and argues vehemently why he will never buy an electric car. Russia is highly unlikely under its current dictatorship to embrace the energy transition. A neighbor, John, hates solar panels and will never put them on his property. Such recalcitrant perspectives are common, and they are often used to argue by example that change cannot happen.

However, these are the islands in the tide analogy noted above. They are not large enough to prevent the energy transition. Matthew can keep his diesel car, Russia can stick to its guns, and John can keep his roof unsullied. But the system will still change because the areas of change are larger than the areas that resist.

Petrostates are home to less than 10% of the global population, and some like Norway are embracing change in any event. Fragile states,[64] where change is difficult, make up just 2% of energy demand, and with help they can improve both their energy system and the wider issues they face. Fewer than 1% of people work for the fossil fuel industry, and some are embracing change.

Some remnants of the old system will of course cling on. You still see a rare horse and cart roaming the streets, some canals are still used for boating, and some people enjoy candlelight dinners. But they are simply relics of a past era, notable by their rarity.

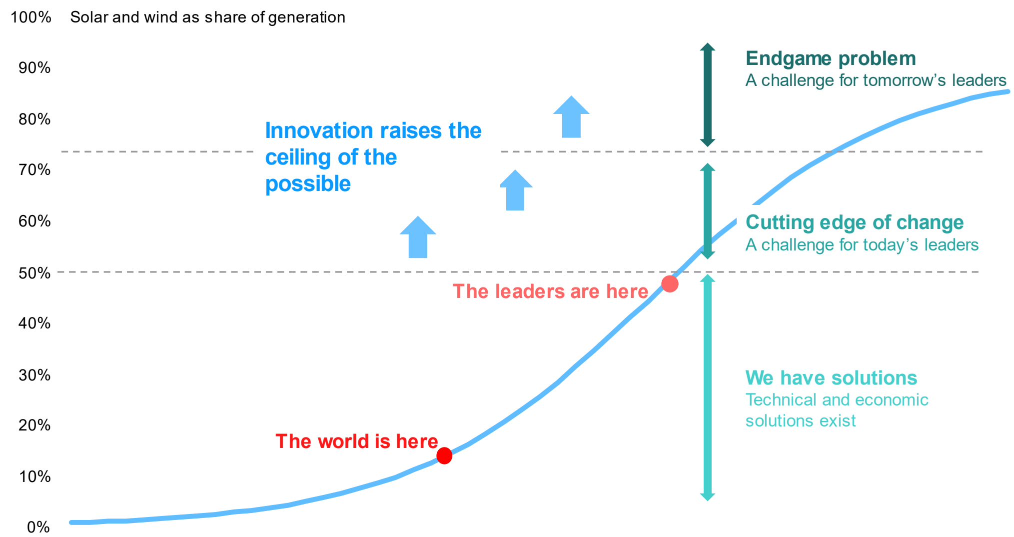
3.3.8 What about the endgame?

Many barriers to change are best seen as endgame problems: ones we will have to face someday, but do not hold up change for the foreseeable future. The classic example is variability, where people will admit that we have solutions up to 50% or 70% or more but assert that we cannot get to 100% renewable energy tomorrow with current technology. Of course, no one claims we can do that tomorrow. It will take decades.

As we evolve technology, design, and policy, these seemingly intractable problems will become much more soluble. The semiconductor industry illustrates the point. The leading chip in 2000, the Pentium 4, had 42 million transistors and used 180-nanometer technology.[65] It was inconceivable in the year 2000 to deploy a billion transistors on a commercial chip. Yet in 2023, the Apple M2 Ultra has 134 billion transistors and uses 5-nanometre technology.[66]

As the chart below illustrates, endgame problems are real and we need to work on them, but they do not stop change. The leaders push the boundaries of change, and the rest of the world can adopt and deploy the solutions.

Figure 11: Barriers and solutions (concept chart)



Source: RMI analysis

4. Implications of continuity

We summarize several ways to model the future of solar and wind electricity, focus on two of them, and show what they imply for solar and wind supply and the electricity system. We conclude by noting the importance of agency: we are on the path of change, but need to walk it, not just stand there.

If the energy transition has had a lesson thus far, it is that the ceiling of the possible is continuously rising. That the dynamism and creativity of directed markets surprises us on the upside, not the downside. That change moves faster than analysts can update their assumptions and models. If anything, we fear our range is more likely to be too low than too high.

Data for the first six months of 2023 from Ember[67] suggests that renewable electricity supply is continuing to grow rapidly in a flat market. Meanwhile, BNEF argues that the long-anticipated surge in polysilicon supply will bring solar panel prices down to 17–18 cents per watt and that exponential growth is ongoing; its short-term solar forecast is for 2023 solar additions of 344 gigawatt (GW)[68] in the medium forecast, which would be 36% growth — above the top end of the range we set out above.

Data from Global Energy Monitor[69] suggest that China is on track to reach its 2030 solar and wind deployment goals by 2025, installing 1,400 GW of capacity by then. BNEF expects new solar installations in 2023 in China to rise from 107 GW in 2021 to 155 GW, a 44% increase.

The IRA is leading to a surge in new solar capacity in the US, with expected new solar deployment of 32 GW, a 37% increase on 2022.

4.1 What are the options?

In the Appendix we explore five ways to model the future of solar and wind supply:

Exponential, continued. Solar and wind are growing approximately exponentially. What is the future if this continues for seven more years?

S-curves. Solar and wind will dominate the long-term future of electricity generation. Technologies follow S-curves. If we combine these two convictions, where does mathematics take us?

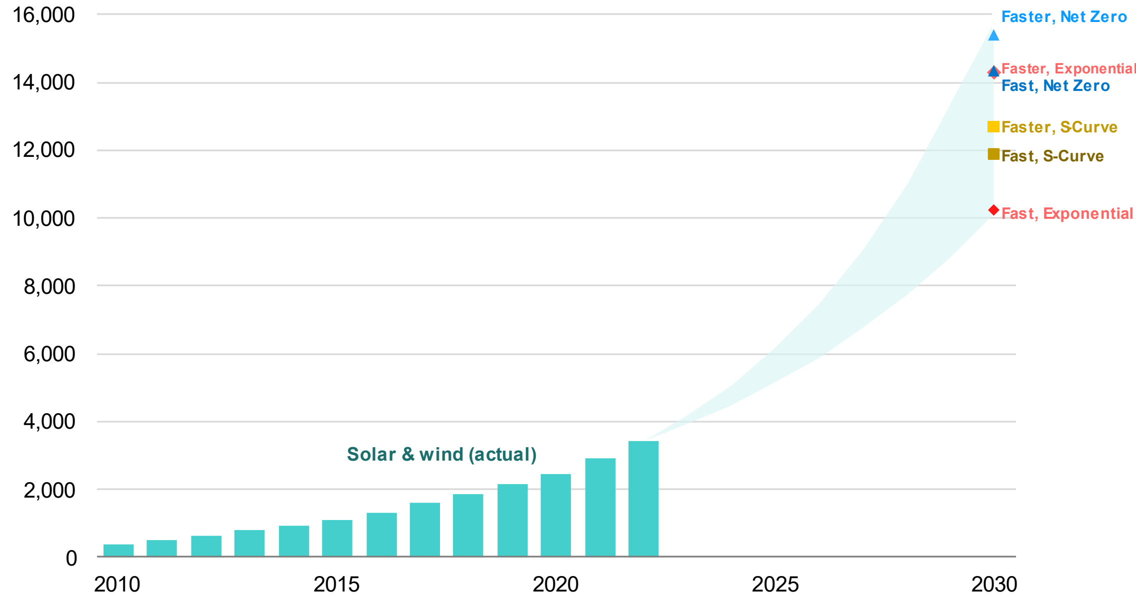
Net zero emissions. There is a clear trend of faster climate change, ratcheting climate ambition, and the strong feedback between technology and policy. If the path to net zero continues to pull us, what can 2030 expect from solar and wind?

Manufacturing. What are the solar and wind industries gearing up for? What is feasible from the perspective of manufacturers' plans and capacity?

Market sizing. Solar and wind already provided 80% of net electricity demand growth in 2022, and the flow trend is clearly heading towards 100%. How big is the size of the 2030 electricity prize once we include demand growth, depreciation, and green hydrogen?

For each method, we illustrate two scenarios: fast and faster. They provide us with the range below:

Figure 12: The range of global solar and wind generation to 2030, TWh



Source: Energy Institute (past),[70] RMI forward. For more details see the Appendix

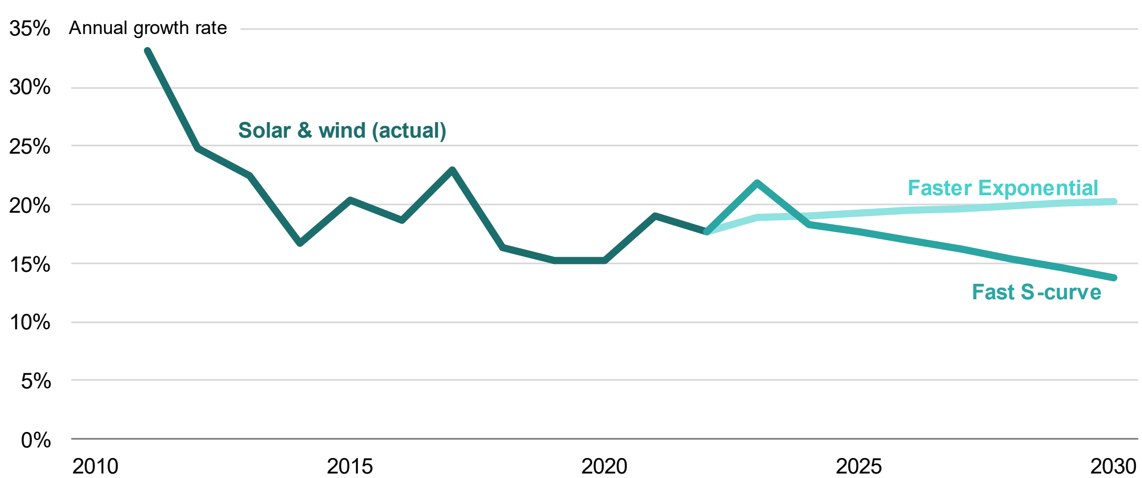
4.2 Which two are most likely?

We believe that the two most reasonable ways to model the future of solar and wind generation growth are the pure exponential and the S-curve. The pure exponential simply assumes continuing the growth patterns of the last decade. The S-curve approach tempers down growth rates based on experience with past technology shifts.

The key analytical debate today is then: does solar and wind growth continue at its approximately exponential rate for another seven years to create very rapid change (a 'faster' scenario)? Or does the maths of the S-curve and the law of large numbers begin to kick in to create rapid change (a 'fast' scenario)?

We illustrate the difference between these two futures by looking at the annual growth rates of solar plus wind in each.

Figure 13: Annual global growth in solar and wind generation in Faster Exponential and Fast S-curve



Source: Energy Institute (past),[71] RMI forward

For the past decade, the world's foot has been on the accelerator of renewable energy deployment. The question is: do we keep it there for another seven years or does it *slowly* ease off? In both cases we travel fast, but the difference will determine whether we travel fast or very fast. It is very unlikely, for the reasons we detail in this piece, that our foot just falls of the accelerator immediately. Technology transitions have a momentum of their own, as noted by Carlota Perez,[72] Thomas Hughes,[73] and Alasdair Nairn[74] among others.

To avoid doubt, two observations: First, the exponential will of course not last forever. If we stay focused and sustain it for this decade, then the declining growth rates characteristic of S-curve logic will start after 2030, though by then we would be in the 1.5°C lane.

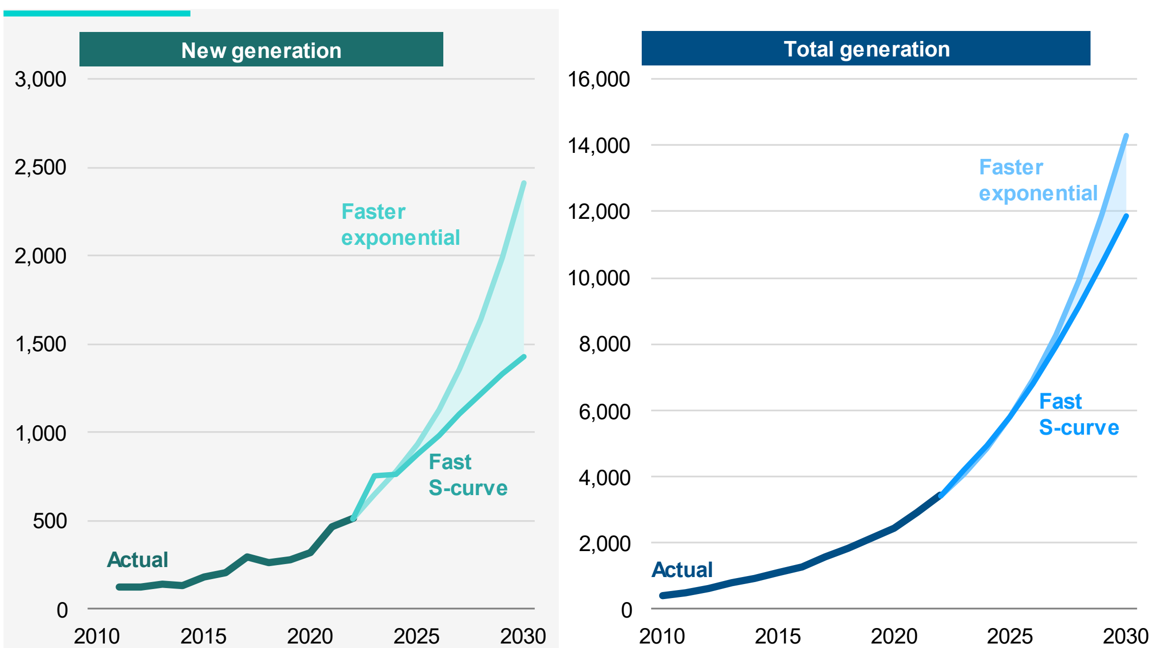
Second, there are many ways to calculate an S-curve and pick a given exponential growth rate (as is the case for any future projections), and we provide the details of these approaches in the Appendix. There is no single future. There is no way of thinking about the range of futures that does not involve judgment and assumptions.

4.3 What are the implications of these two options?

Below we compare Faster Exponential (about 20% combined solar plus wind growth) with the lower bound of our S-curve projection. As we show in the Appendix, this S-curve uses the past three decades of growth to assess the likely growth trajectory to an endpoint in which solar and wind supply 70% of total electricity. That is not an upper bound.

The Faster Exponential implies over 14,000 TWh of solar and wind generation in 2030. The Fast S-curve implies 12,000 TWh.

Figure 14:
Global solar and wind new and total generation in Faster Exponential and Fast S-Curve, TWh/y



Source: Energy Institute (past),[75] RMI

The Faster Exponential implies new solar and wind generation in 2030 of 2,400 TWh per year while the S-curve implies 1,500 TWh per year.

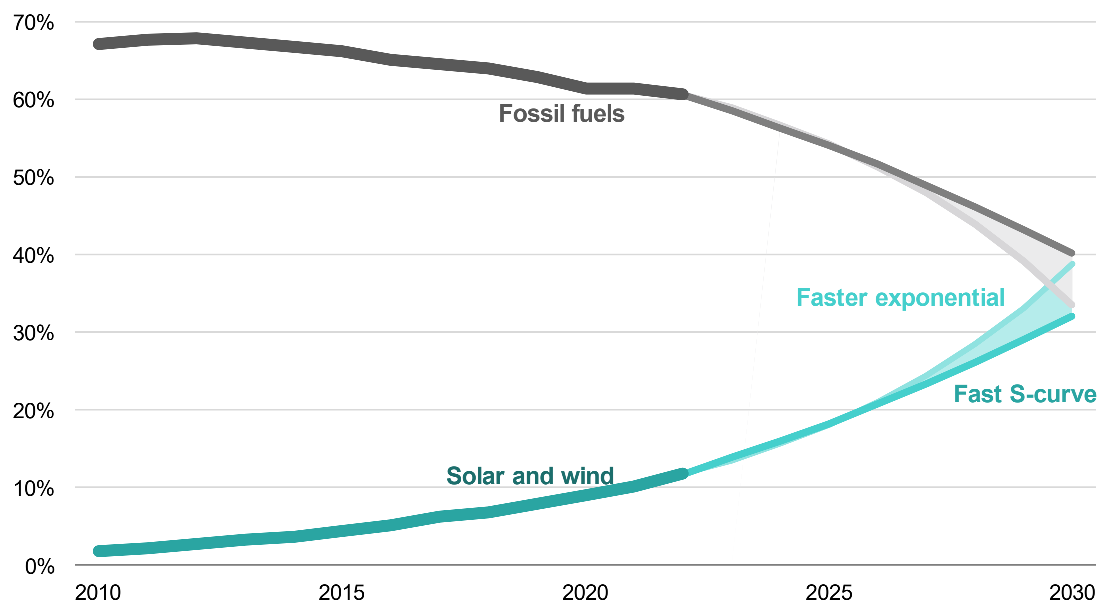
4.3.1 What does this mean for the electricity system?

Both scenarios see rapid, disruptive change in this decade, with solar and wind providing one-third of global generation by 2030 and getting to 40% by 2032-3 in the slower scenario.

There are three main parts to the electricity system: solar and wind, fossil fuels, and other low-carbon electricity. The other low-carbon electricity sources are likely to maintain growth rates roughly in line with total demand growth. So the higher share of solar and wind will mean a decline in the share of fossil fuels, as shown in Figure 15.

Assuming the Faster Exponential, solar and wind overtake fossil-fueled electricity generation to supply over 14,000 TWh and 39% of electricity in 2030. The Fast S-curve has 33% of electricity generation coming from solar and wind in 2030. The Faster Exponential is in line with the share of solar and wind that is required in the electricity system under the IEA net zero scenario (41%) and the Rystad 1.6 scenario (39%).

Figure 15: Global share of electricity generation by source

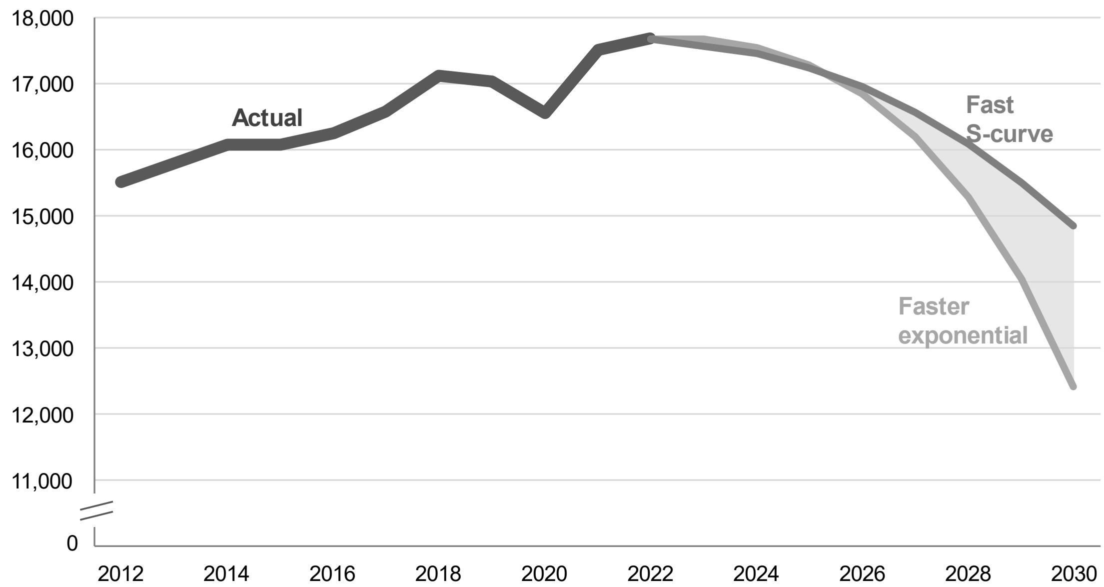


Source: Energy Institute (past),[76] RMI forward

We can also use this framing to calculate the implied demand for fossil-fueled electricity generation. Under either scenario, fossil fuel demand has peaked at just under 18,000 TWh in 2022,[77,78] and will plateau until the middle of the decade.

Under the Faster Exponential scenario, fossil fuel demand for electricity would decline this decade by 30% and under the Fast S-curve it would decline by 16%.

Figure 16: Global fossil-fueled electricity demand, TWh/y



Source: Energy Institute, RMI

4.4 Where is the agency in inevitable exponential change?

We are on the path to Paris, but no path walks itself. The path requires travellers — fore-runners paving the way towards this better world powered by renewables. These travellers come with diverse motives, from security to social justice to profit. We see no shortage of travellers; no deficit in humanity's wit and will.

Policy is needed. There is no room for policymakers to sit back and let the market take its own course. Energy markets are heavily regulated and controlled, and they need detailed policy action to unleash the change.

Action begets action. A deep case for hope and agency is at the logical core of exponential change: more begets more. The faster it goes, the faster it gets. Each cent shaved off a watt of solar brings more deployment which opens up the possibility to cut the next cent. And each solar panel installed on a roof increases the chances of a neighbor buying the next.

There is always room to go faster. We are on the path to net zero by 2050 but we are not on the path to limit warming to 1.5°C. Each death caused by fossil fuel air pollution matters, each dollar spent on importing costly fossil fuels has an opportunity cost, and each fraction of a degree is a threat multiplier. In this context, there is no such thing as "fast enough". Speed is justice.

5. Appendix 1. How to model solar and wind supply

We set out the linear and the exponential approaches to modeling, and then look at a range of exponential models to get a sense of what are the likely growth rates this decade.

5.1 The linear approach

The linear approach to the electricity system is to start with today's system, in all its detail, and forecast each part of it using models of astonishing complexity, involving thousands of assumptions and hundreds of experts.[79] Such models are still used very widely and are incorporated into integrated assessment modeling as well as the Network for Greening the Financial System (NGFS).[80] The trouble is that models built for detail are not good at handling systemic change and are weak at handling change over long periods. You cannot use a microscope to look at the stars.

At a superficial level, the linear approach appears reasonable. After all, we may or may not be able to solve the various barriers to change, people may or may not build factories, renewable costs may stop falling, and politicians may or may not act.

But it is also profoundly unlikely. It requires change to stop dead. Innovation to finish, policymakers to act to preserve the status quo, civil society to tolerate the climate crisis, stagnation to set in globally. This is of course possible, but it is important to realize that this is an outlier scenario not a central one.

It is not difficult to criticize the linear approach. To highlight a number of the most obvious weaknesses:

- **The linear approach does not work**. This type of approach has led to a multitude of business as usual (BAU) forecasts, which have been wrong for years.
- **It has systemic bias**. That is to say, it always underestimates renewable supply and overstates fossil fuel demand.
- **It assumes linear change**, not exponential. Because solar and wind are just one part of a super-complex system, they are often missed.
- **Limited feedback loops**. For example, some key models do not have endogenous learning curves, by which solar and wind costs fall as deployment rises. This flaw overstates their long-run cost by severalfold to manyfold.[81]
- **Failure to think about structural assumptions**. Many models assume continuity but do not think about the wider implications of profound change. As we start to generate very cheap renewables in Australia, for example, it is likely that energy-intensive industries like steel will move there. Such detailed forecasting is very difficult.
- **Overly complex**. Models are often extremely complex and unable therefore to handle rapid technology change. When you have ten thousand variables, it is hard to focus on the key one.
- **Conservative**. The linear approach assumes little change in policy or technology. Therefore, it seeks to apply today's solutions to tomorrow's problems.
- **Too much emphasis on barriers**. It is axiomatic that those dealing every day with barriers to change find it hard to believe that solutions can be found to issues that they cannot solve.[82] However, as noted above, it is important to distinguish between barriers that are insoluble and those that are difficult but soluble.
- **It looks at stocks, not flows**. And at lagging indicators rather than leading ones.

5.2 The exponential approach

The exponential approach isolates the exponential driver of change, models this in detail, and assumes that the rest of the system is forced to adjust. That is how change tends to work in most areas, of course; from the growth of the mobile phone to the rise of the Internet, it was the new that drove the system, not the old. Models using their own variants of an exponential approach include the approach of the Oxford INET team[83] as well as BNEF, Rystad,[84] and DNV.[85]

Exponential decline in price and growth in volume has been happening in the solar and wind sectors for decades. It is only recently that the numbers got large enough in size and low enough in price for people to notice.

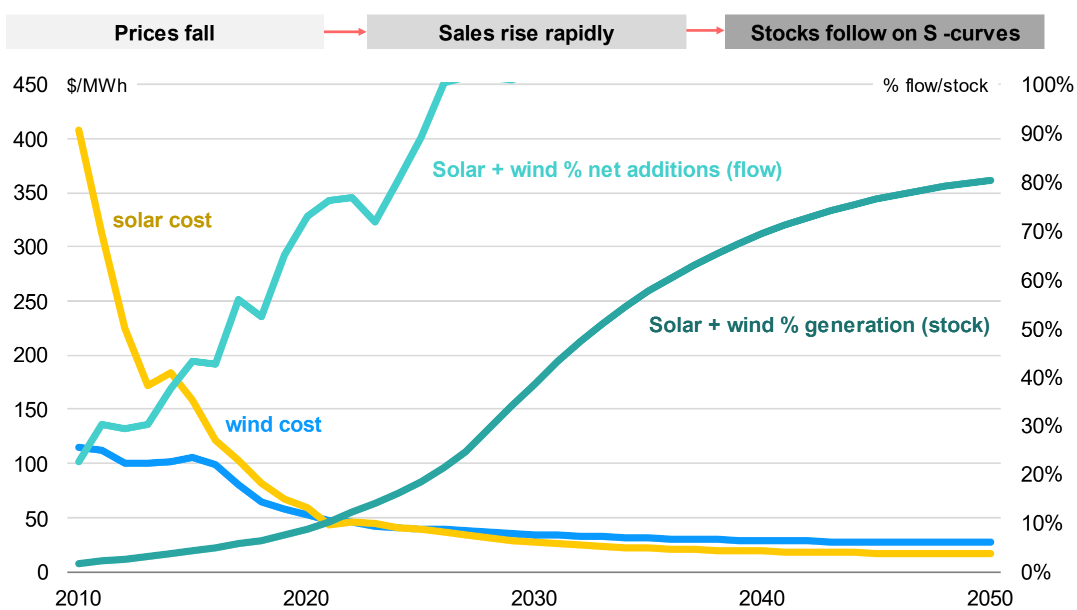
5.2.1 How change works

Technology shifts are led by insurgents, not incumbents. They are catalyzed by superior new technology, not tweaks to the old. And they are driven by leading countries and companies deploying them at scale and dominating the market before others have the chance to catch up. To understand them, it is vital to look at the flow (sales) of new technology in the leading markets.

There are three key stages in the growth of new technology.

- **Prices fall.** The price of the new solution falls to price parity with the old solution.
- **Sales take off.** As price parity approaches, so sales take off.[86]
- **Rollout.** Eventually new sales reach a peak and we move from rapid growth to rollout.[87]

Figure 17: Technology revolutions move from prices to sales then to stocks, illustrative



Source: BNEF historic,[88] Rystad 1.6C,[89] & RMI forward.

The process is sped up by many feedback loops.[90] To highlight three:

- **Price-volume feedback loop**. As prices fall, so the volume of demand increases. And as volumes rise, so prices fall on learning curves. It is therefore important to have endogenous learning curves incorporated into models of the energy future.

- **Peak–volume feedback loop**. As sales of the new race up the S-curve, so demand growth for the old starts to dry up. And people shift across to the new technology. That speeds up change. A classic example would be the car industry moving platforms from internal combustion engine (ICE)-based models to electric vehicles (EVs) long before EVs become the dominant technology. Industry players try to milk revenue from the old technology before the new one destroys it.
- **Volume–vested interests feedback loop**. As renewable industries get larger, so their lobbying power increases. And as fossil fuel industries get smaller and start to face terminal decline, their lobbying power reduces. It is notable that according to the IEA, the number of people working in the renewable energy industry is already larger than those working in the fossil fuel industry.[91]

It follows that the two key drivers to watch very closely are price and sales of key new technologies. Are prices falling on learning curves? And are sales rising on S-curves? If these two criteria hold, the rest of the system will fall into place around them.

There are three key simplifying assumptions in how to model this.

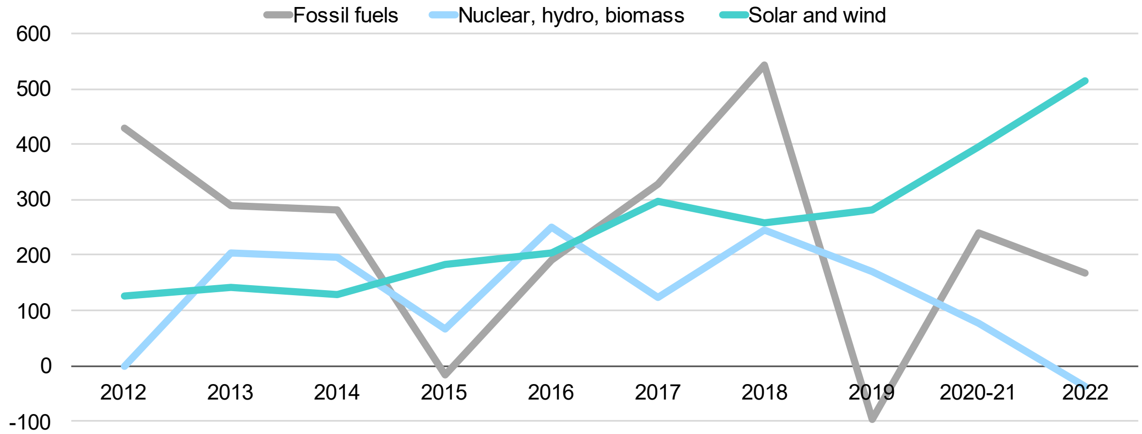
- **Model the new technology**. There is no need to model all sources in a technology shift. You can simply model the new one and assume that the old one has to adjust to accommodate. There is no point modeling iPhone sales with reference to Nokia production plans.
- **Model the leaders**. Some countries will lead and others will follow. You can model the leaders and assume that others will follow.
- **Assume enabling infrastructure will be built**. We do need new grids, more flexibility and better regulatory structures. And people are working on this. The classic example is charging infrastructure for EVs. It used to be argued that EV charging infrastructure would be an insoluble impediment to change. Then people noticed that in practice, EV infrastructure gets built out at the same time as EV sales. It moves from being an insoluble barrier to an issue that needs to be managed and carefully thought through.

5.2.2 Solar and wind are the exponential in generation

In broad terms there are four parts to the electricity generation system:

- **Fossil fuels.** Coal, gas, and oil. The dominant technology, but the residual in the electricity supply equation: the stuff you use while other solutions are growing. In 2022, fossil fuels supplied just over 60% of electricity according to Energy Institute data. We believe that demand has reached a peak, will plateau until the middle of the decade, and will be in rapid decline by 2030.[92] Over time, fossil fuels are moving from baseload to backup as their business case and operational need dwindle.
- **Established low-carbon energy solutions.** Hydro, nuclear, and biomass. These grow slowly (at a compound annual growth rate of 2%),[93] albeit with some lumpy fluctuations.
- **Solar and wind as exponential drivers**. The only technologies that combine three key facets: large scale (they were 12% of supply in 2022 and 80% of growth);[94] enormous potential (potential supply is more than 100 times total world energy demand right now);[95] and on established exponential growth curves. These are the big supply-side drivers of change.
- **Possible future drivers.** Geothermal, nuclear fusion, small modular reactors (SMRs), tidal wave, and others. They have potential to be significant, and their success depends on technology innovation. They are not yet core drivers of change, but they may add to the speed of change.

Figure 18: Change in electricity generation supply, TWh/y



Source: Energy Institute Statistical Review of World Energy[12]

5.2.3 New generation capacity is the key driver of change

There are four broad ways to look at the future of solar and wind deployment.

- **Targets**. Government and corporate targets. Some countries set targets they struggle to achieve, but sometimes (notably in China[96]) the targets are far behind what is typically installed.
- **Factories** (Capacity). The amount of factory capacity available to build new solar and wind generation. This is already racing up to nearly 1,000 GW of solar production capacity per year, exceeding requirements for net zero.[97]
- **New generation capacity** (Flows). The amount of new capacity installed each year. In 2022, this was just over 250 GW of solar and 100 GW of wind according to BNEF.[98,99] This is linked of course to capital expenditure, but as costs fall, less expenditure buys more new capacity. Thus INET Oxford finds that a faster shift to renewables costs less because they get cheaper sooner.
- **Total generation capacity** (Stocks). The total amount of solar and wind capacity installed cumulatively. At the end of 2022, this was 1,200 GW of solar and 900 GW of wind according to BNEF.[100] This determines potential electricity generation and thus the share of solar and wind in total electricity production.

In a perfect world, targets lead to factories which lead to flows which then lead to stocks, with each moving up an exponential growth path. In practice, the key factor is the new generation capacity. In 2022, solar and wind already made up 80% of capital expenditure on new generation capacity.[101]

5.2.4 The difference between the linear and the exponential

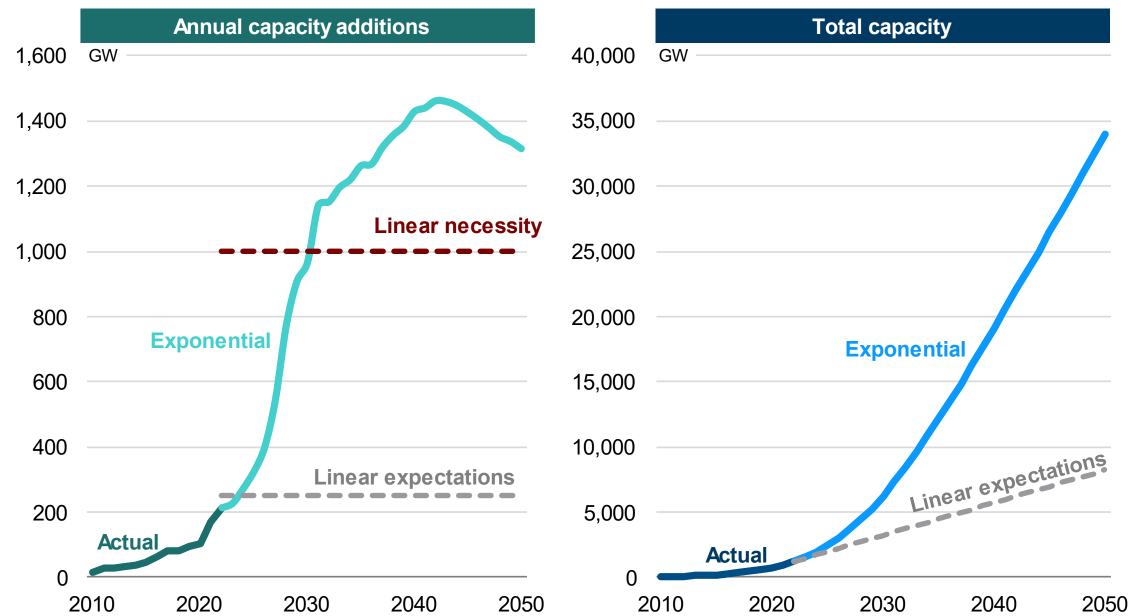
To illustrate the difference, consider the question of solar capacity in 2050. Let us assume that it is necessary to deploy 30,000 GW of solar panels by 2050 to get to net zero. In just the year 2022 we deployed 250 GW of solar panels, bringing total deployment at the end of the year to 1,200 GW.[102]

- The orthodox approach argues: we need to deploy 1,000 GW per year; we are only deploying 250 GW per year; therefore we will be unable to get to our goals. There is a huge gap of 750 GW per year.

- An X-change approach notes that the solar flows are growing exponentially. To get to 30,000 GW in 2050, we need to get to around 1,000 GW per year in 2030 and rise to a little above that pace for the next 20 years. That will get us to (or beyond) 30,000 GW of solar capacity, and it is completely feasible so long as we stay on our current S-curve.

We illustrate the gap below using data from the Rystad 1.6 scenario to show the exponential and contrast with the assumption of stagnant solar deployment at 250 GW a year. And this leads to very different stock expectations. A linear framing implies fewer than 10,000 GW of solar by 2050, whilst an exponential framing takes us to over 30,000 GW.

Figure 19: Linear versus exponential, solar additions (left) and total (right)



Source: Rystad 1.6 for actual and exponential capacity additions,[103] BNEF for 2022,[104] RMI illustrative framing of linear expectations

5.3 Ways to model exponential change

We set out below five ways to model likely exponential growth of solar and wind generation in the period to 2030. For each method we set out a fast and a faster option. We calculate the likely total electricity generation in 2030 as well as the annual change in 2030 to compare the results as below. To put this in context, in 2022, according to the Energy Institute, global total electricity demand was 29,000 TWh (3,400 from solar and wind) and growth was 650 TWh (510 from solar and wind).[105]

Figure 20: Electricity generation from solar and wind in 2030, total (left), incremental (right), TWh/y

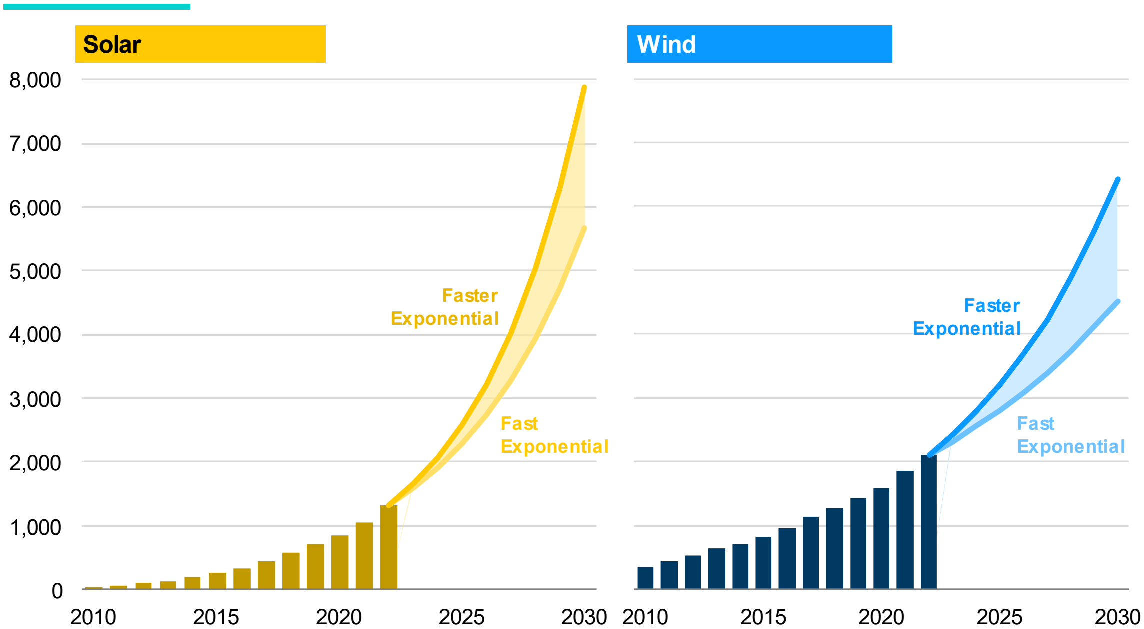
Source: RMI analysis

5.3.1 Continued exponential growth

As we have seen, solar and wind have enjoyed exponential growth for many years. Over the past five years, the compound annual growth rate (CAGR) of solar generation has been 24% and wind 13%.[106]

If we assume solar continues at annual growth rates of 20–25% and wind at growth rates of 10-15%, then we will see total 2030 annual solar supply of 6,000–8,000 TWh and wind supply of 4,500 to 6,500 TWh. So in the Faster Exponential model solar growth is 25% per year and wind is 15%.

Figure 21: Exponential model: Solar and wind growth, TWh/y



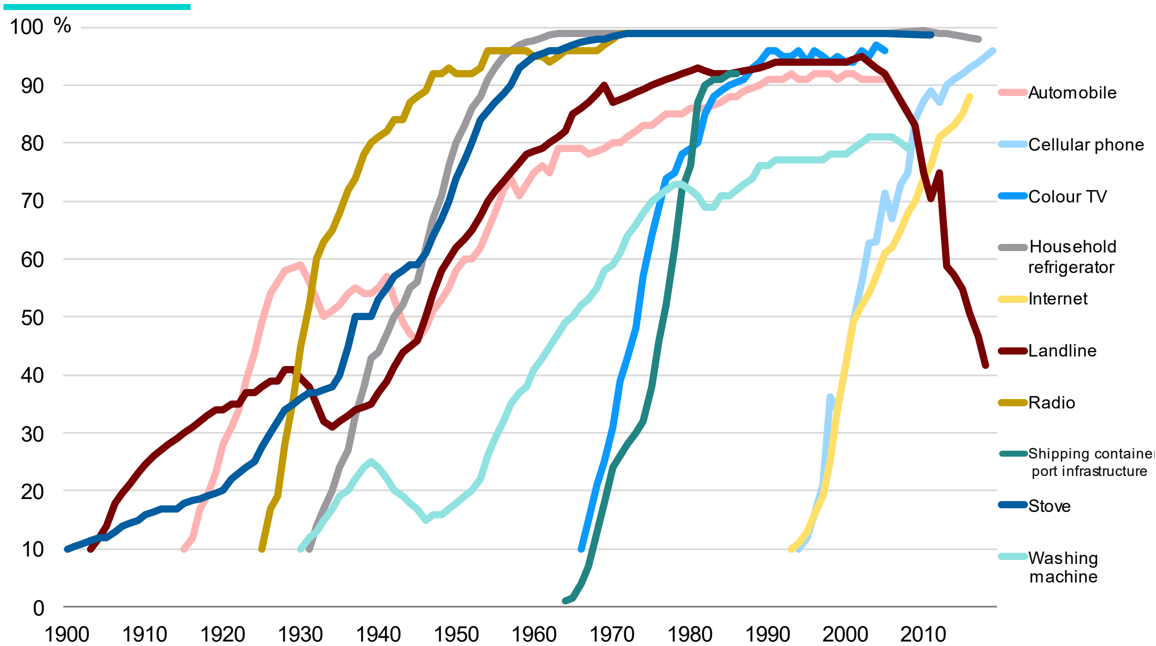
Source: Energy Institute (past),[107] RMI forward.

And that implies new electricity supply in 2030 of 950–1,600 TWh/y of solar and 400–800 TWh/y of wind.

5.3.2 S-curve

Hundreds of other technologies have shown a classic S-curve of deployment. Their penetration has moved quickly up S-curves from around 10% to over 80%.

Figure 22: Past examples of S-curves — share of US households using specific technologies



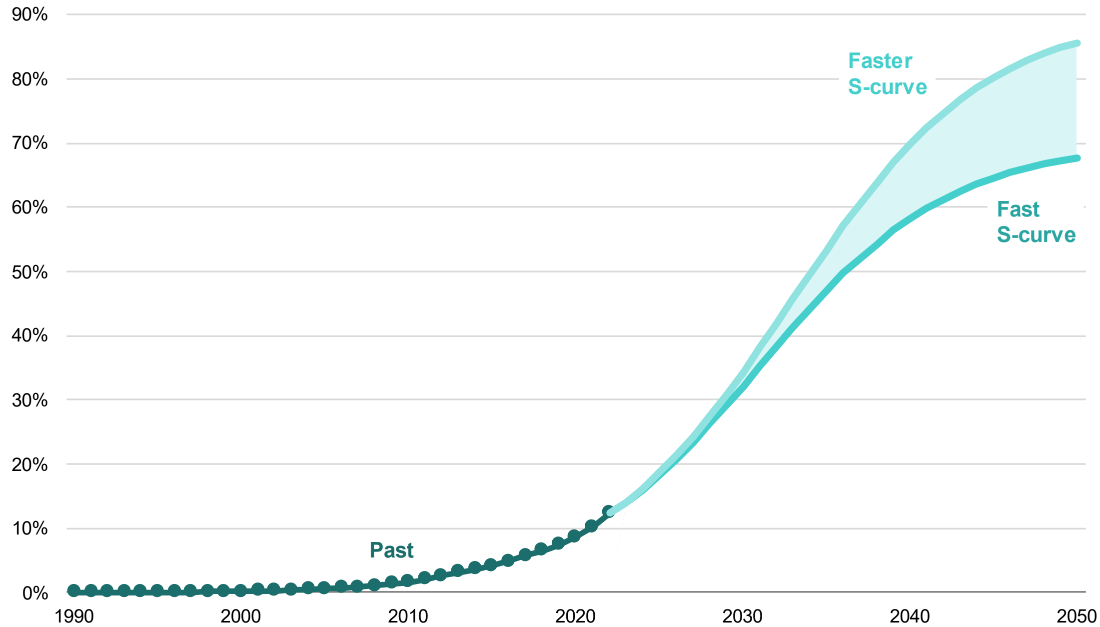
Source: Our World in Data[108]

The equivalent issue to model for the electricity system would be the share of electricity from solar and wind. To calculate an S-curve based on historic data, we need simply to choose an endpoint (but not a date), calculate the growth rate (k) and the midpoint (x_0) based on the historical data and least-squares modeling, and then extrapolate a standard S-curve (logistic S-curve) from the historical data to this endpoint.

We show below how this looks, using endpoints of 70% and 90% share of solar and wind in the electricity system. We believe this is a reasonable framing; at present the share of other low-carbon energy is around 30%, and the assumption then would be that fossil fuel is replaced and that other low-carbon energy is either flat or falls over time. In the real world, change will of course be a bit bumpier, and it's hard to know when we reach the top of new deployment. Nevertheless, this is clearly a more credible framework than linear growth models.

In any event, the choice of the endpoint is not especially important from the perspective of 2030, as the chart below makes clear. Both S-curves show rapid growth in the share of solar and wind until 2030 (a share of 32% to 34%), rising to 40% of the total by 2032 or 2033.

Figure 23: S-curve model: Share of electricity from solar and wind



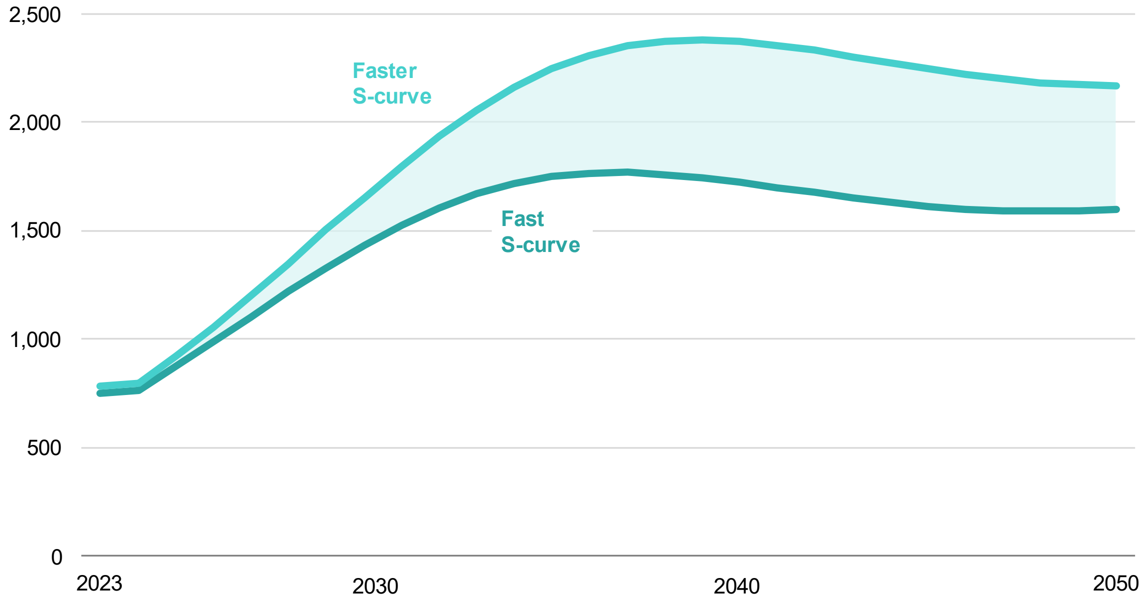
Source: Rystad,[109] RMI analysis

Assuming 3% annual electricity demand growth we can calculate the total sales of solar and wind electricity in 2030 at between 12,000 and 13,000 TWh.

And we can calculate the implied level of annual incremental solar and wind supply in 2030, which is 1,400-1,700 TWh/y. This provides a useful way to judge current progress: solar and wind generated over 500 TWh/y of additional supply in 2022, and they would need to generate around three times as much of that by 2030 to be on the S-curve of deployment. But they would only need to increase to a maximum of 1,800 to 2,500 TWh/y in the 2030s to maintain the S-curve of deployment.

The challenge that once seemed insurmountable starts to look achievable. Moreover, it becomes clear that the hardest work of the energy transition is behind us (getting annual increases in supply up from 50 TWh/y to 500 TWh/y). The rest of the decade is critical as it requires tripling the annual increase in supply. But after 2030 we can slow down the pace of change; to stay on the S-curve, the total growth in new deployment between 2030 and 2040 is between 20% and 43%.

Figure 24: S-curve model: Annual additional electricity generation from solar and wind, TWh/y



Source: RMI

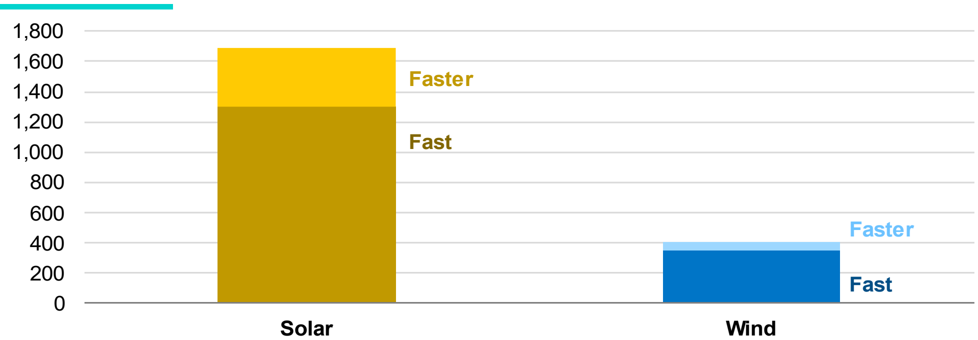
5.3.3 Manufacturing

It is also possible to get a sense of the potential future of the solar and wind industries by looking at production capacity that is planned. As noted by the IEA, solar already has announced capacity expansion to almost 1,000 GW/y by 2024, and it is reasonable to assume that there will be more growth planned in the next seven years.[110] Wind is currently lagging, but as the numbers below make clear, the growth in solar is more important.

- **Solar.** If the industry is already scaling for 1,000 GW/y of new capacity in 2030,[111,112] then it is reasonable to assume more announcements in the next seven years, and we conservatively set an upper bound at 1,300 GW/y.[113] Assuming 1.3 TWh/y of electricity generation per GW of capacity[114] implies between 1,300 TWh/y and 1,700 TWh /y of incremental supply in 2030.
- **Wind.** The industry is scaling for up to 140 GW/y of manufacturing capacity by 2025 according to the IEA.[115] Expected capacity in 2030 could be 160 GW/y according to BNEF.[116] Assuming 2.5 TWh /y generated per GW (because of the rising share of offshore wind) implies annual incremental supply of 350 to 400 TWh/y by 2030.

The conclusion: Annual new solar and wind supply of 1,700–2,100 TWh/y of is feasible.

Figure 25: Manufacturing model: New solar and wind generation potential in 2030, TWh/y



Source: RMI analysis

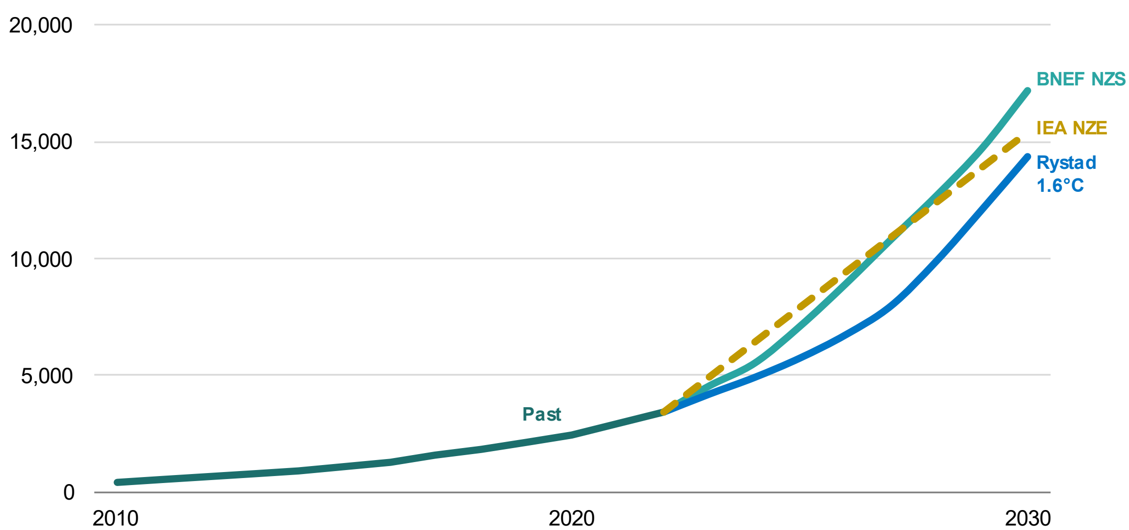
5.3.4 Net zero emissions

As noted above, countries with 90% of global carbon emissions have net zero goals. There are a number of ways of working out what this means for the electricity system. We take as examples the models of the IEA NZE,[117] Rystad 1.6,[118] and BNEF Net Zero.[119]

All three models meet the goals of the Paris Agreement and reach net zero by 2050. They give us a way to look at some of the detailed assumptions that are required and benchmark our framing against that. However, they are not in line with the 1.5°C goal. The Rystad 1.6 scenario (as the name suggests) reaches 1.6°C, the BNEF net zero scenario implies 1.8°C of warming,[120] and the IEA NZE goes a little over 1.5°C in the 2040s before returning to 1.5°C in the 2050s.[121]

One of the primary drivers of change in these models is the rise in deployment of solar and wind as below. The IEA does not give annual data, but the 2030 generation from solar and wind in the NZE model is 15,000 TWh — 41% of total electricity generation. The Rystad 1.6 scenario calls for 14,000 TWh from solar and wind, which is 39% of total electricity generation in their model.

Figure 26: Net zero models: Electricity generation from solar and wind, TWh/y



Source: Energy Institute, IEA, BNEF,[122] Rystad.[123] Note: IEA doesn't provide annual data, so the dotted line represents an assumed linear trajectory.

The net zero models imply incremental electricity supply of solar and wind in 2030 of 2,250–2,500 TWh/y. This is at the top end of the range we argue is reasonable. However, including more energy efficiency in the models would need less incremental solar and wind capacity to displace the same amount of fossil fuel.

5.3.5 Market sizing

Solar and wind already provided 80% of the net increase in electricity demand in 2022 and are on track to provide all the future net growth.[124] Because solar and wind are already the cheapest source of electricity and on robust learning curves, it is reasonable to assume that they will supply all gross incremental electricity demand in 2030. There are three parts to that:

Net increase in electricity demand

In 2022 the net increase in electricity demand was 645 TWh according to the Energy Institute.[125] Assuming growth of 2.5–3.5%/y, the net increase in electricity demand in 2030 would be between 900 and 1,200 TWh/y. The compound annual growth rate of electricity demand growth has been 2.5% over the past decade. The higher assumption of 3.5% assumes one percentage point additional growth from the rising electrification of the energy system.

Depreciation of the fossil fuel system

In 2022 the fossil fuel system generated 18,000 TWh of electricity, but financial depreciation was below 1% because so much of the capacity was new,[126] and solar and wind are not yet large enough to force fossil fuels out of the global system. By 2030, solar and wind will be much larger and cheaper, and we can expect fossil fuel retirements to be running at 2–3% per year (based on Rystad estimates), and more if governments are serious about climate change.

That would imply growth from the replacement of retiring fossil fuels of 350 to 530 TWh/y.

Electricity for hydrogen

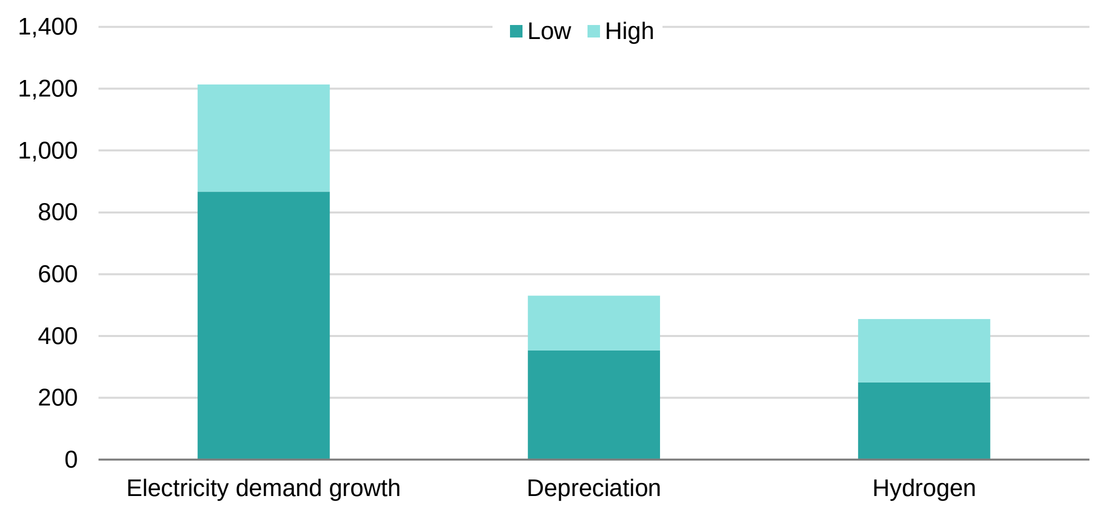
The third key variable for 2030 is the amount of green electricity required to make hydrogen.

If we assume annual new electrolyzer deployment of 50–100GW, that would require 250 to 450 TWh/y of green electricity.[127]

Summary

The total size of the market for new solar and wind then would be between 1,500 and 2,200 TWh/y in 2030.

Figure 27: Market sizing model: 2030 increase in electricity demand, TWh/y



Source: RMI analysis

6. Appendix 2. What is the X-change?

The X-change is a series of reports analyzing the impact of exponential change (the X in X-change) on the energy system. It contrasts with the orthodox view of linear change. The baseline scenario for the future of energy should assume continued exponential growth of renewable energy in the period to 2030.

Principles of the X-change

- Identify the exponential.
- Model the exponential in a variety of ways to understand the likely future.
- Figure out if there are any insuperable barriers to change.
- Human ingenuity will continue to find ways around impediments in ways that are not foreseen today.
- Focus on the period to 2030. Costs and volumes will be very different by that point.
- Better roughly right than precisely wrong.

Conclusions of the X-change

- Linear change is highly unlikely.
- Fast change is continuity on the S-curve.
- Faster change is more exponential growth.
- We are on a path to go fast or faster, but we must keep pushing.

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