Whitepaper | January 2023

The economics of renewables

Challenges and solutions

Contents

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The economics of renewables: Key takeaways

Meeting 2050 net-zero targets will require adding renewable energy capacity at scale and speed. Significant challenges lie ahead, including supply-chain risks in rare earths, metals and water, and planning permission delays. But energy and materials efficiency, combined with recycling and changing demand patterns, will reduce the need for scarce materials and those that pose social or environmental concerns.

Renewables' LCOEs are also increasingly competitive and projected to fall further still.

Renewables could thus displace fossil fuels much faster than anticipated. Supportive policies and regulation will be critical to de-risk projects, but the transition is creating investment opportunities in the short, medium and long term.

Introduction

The world's first coal-fired power station, the Edison Electric Light Station, was built in London in 1882.[1] Since then, fossil-fuel power has underpinned the global energy system, pervading every corner of the economy. With the net-zero transition, humanity is embarking on the first industrial-scale rethink of this system in 140 years.

The reason behind this is, of course, climate change. However, as the *Financial Times*' Martin Sandbu recently noted, energy price behaviour is also "at the core of politics and economic prospects". The strange nature of electricity cost curves, driven by prices in the marginal fuel – namely natural gas – means geopolitical crises have distorted markets and sent governments scrambling to ensure energy security for the short and long term.[2] And while European gas prices briefly turned negative on October 24, 2022, largely thanks to falling demand, on average they remain at twice their historical level.[3]

Watch the Energy Transitions Commission's short video on *How to achieve a net-zero economy by 2050*

In parallel, wind and solar costs have been falling for years, making them increasingly competitive compared to fossil fuels, even though recent inflation has slowed this down (Figures 1 and 2).

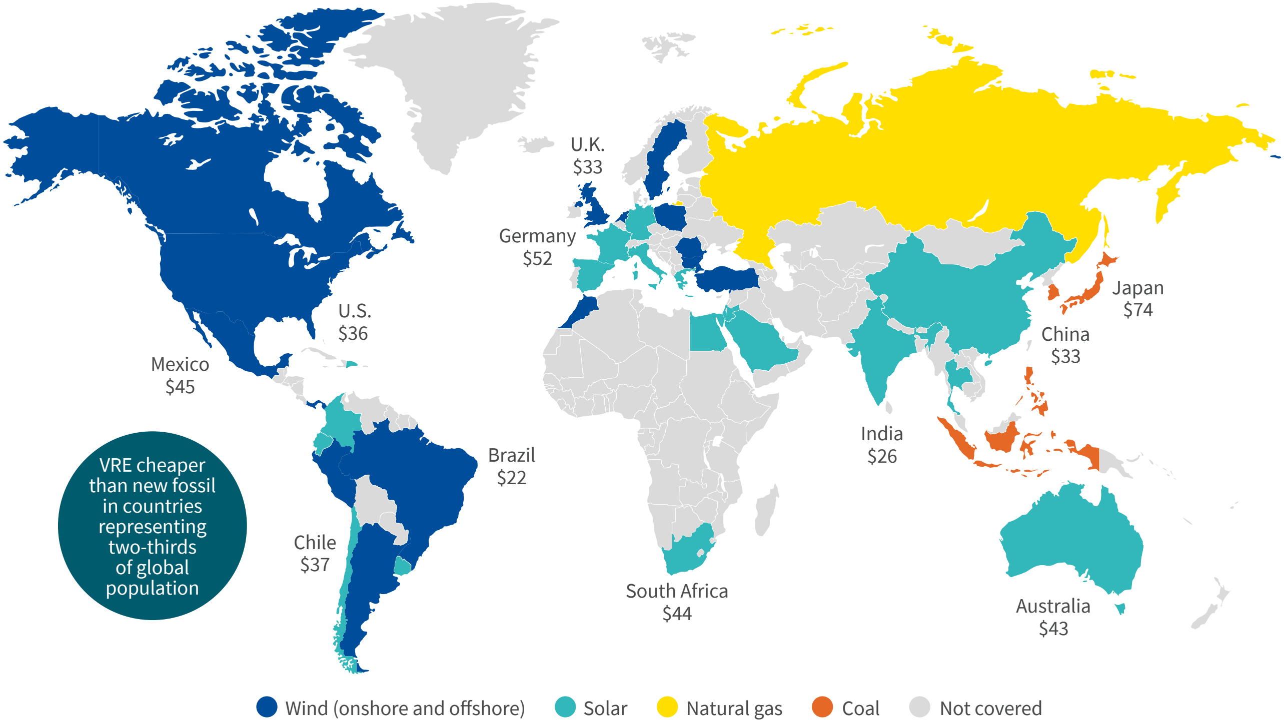
Added to existing plans like the EU's energy roadmap for 2050 and the US Inflation Reduction Act, this will give further momentum for the transition to pick up pace.[4,5] In May 2022, for example, the EU updated its REPowerEU plan to accelerate the net-zero transition and reduce the region's dependence on Russian gas. The plan targets 600 gigawatts (GW) of solar and 480GW of wind by 2030, multiplying the EU's renewable capacity by almost four in eight years (from 350GW today).[6]

1. 'The history of energy in the UK', National Grid, as of October 31, 2022.
2. Martin Sandbu, 'The strange world of energy prices', Financial Times, August 25, 2022.
3. Chris Giles, 'The end of Europe's energy crisis is in sight', Financial Times, October 27, 2022.
4. 'Energy roadmap 2050', European Commission, 2012.
5. 'By the numbers: The Inflation Reduction Act', The White House, August 15, 2022.
6. 'REPowerEU: A plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition', European Commission, May 18, 2022.

Yet the UN Environment Programme recently warned these commitments still fall far short of the emissions cuts needed to limit temperature rises to 1.5 degrees Celsius.[7] According to the International Energy Agency (IEA), green investments must reach $4 trillion a year globally by 2030 to meet net-zero targets, compared with $1 trillion currently.[8] And, although the trend in costs is encouraging, renewables have some way to go to become the cheapest option everywhere.

The big questions are: will a clean energy system be built on a global scale in the next 30 years, and can it make financial sense? This whitepaper explores the challenges ahead, the potential economic benefits of building renewable capacity at scale, and the political support needed to achieve clean electrification. We also imagine what the energy system could look like in 2050 and the investment opportunities this could create in the short, medium and long term.

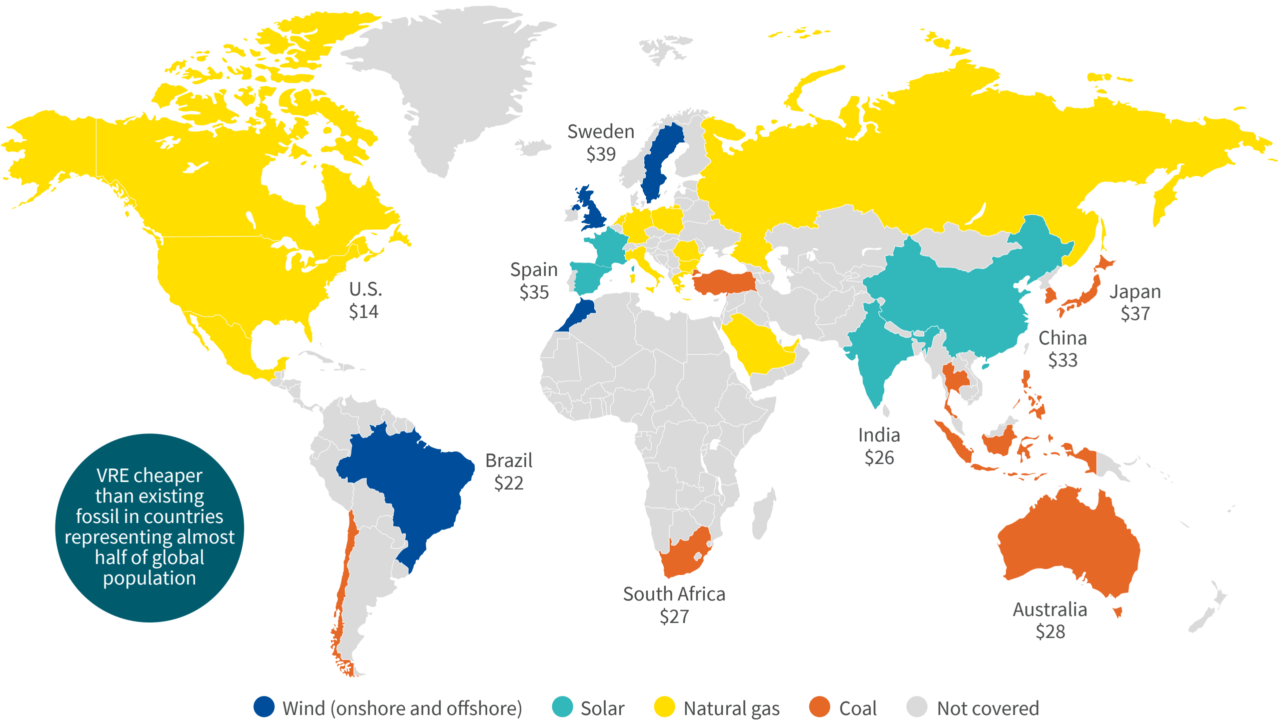
Figure 1. **Cheapest source of bulk generation globally: New-build variable renewable energy (VRE) versus new-build fossil (2020)**



Source: Energy Transitions Commission, April 2021.[9]

7. 'Emissions gap report 2022', UN Environment Programme, October 27, 2022.
8. 'World energy outlook 2022', IEA, October 2022.
9. 'Making clean electrification possible – 30 years to electrify the global economy', Energy Transitions Commission, April 2021.

Figure 2. **Cheapest source of bulk generation globally: New-build VRE versus existing fossil (2020)**



Source: Energy Transitions Commission, April 2021.[10]

10. 'Making clean electrification possible – 30 years to electrify the global economy', Energy Transitions Commission, April 2021.

Challenges ahead

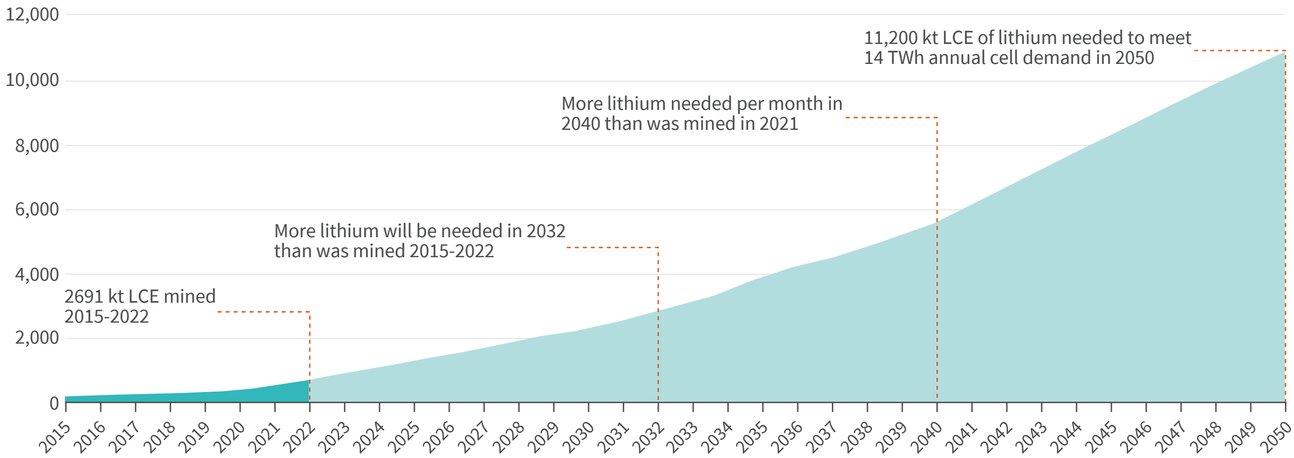
Significant challenges lie ahead given the scale of the necessary transformation. In particular, solar and wind power are also likely to face, if not shortages, at least bottlenecks in the supply of rare earths and metals (also see *What about water?*).

"Some numbers suggest that, by 2050, wind turbines and solar panels will need 12 times as much indium as we currently produce at a global level, seven times more neodymium, and three times more silver. These are quantities we don't currently know how we're going to mine, so there are huge pressures," says Sora Utzinger, senior environmental, social and governance (ESG) analyst at Aviva Investors.

> *"By 2050, wind turbines and solar panels will need 12 times as much indium as we currently produce at a global level"*
>
> **Sora Utzinger**
> Senior ESG Analyst

Copper demand is also expected to more than double by 2050, outpacing supply between now and 2035.[11] Nickel demand could jump by 200 per cent by 2040 from 2020 levels, and resources could be depleted in 40 years even at the 2020 production rate.[12]

Figure 3. **Forecast of the lithium market balance (in kt)**



Source: CleanTechnica, October 20, 2022.[13]

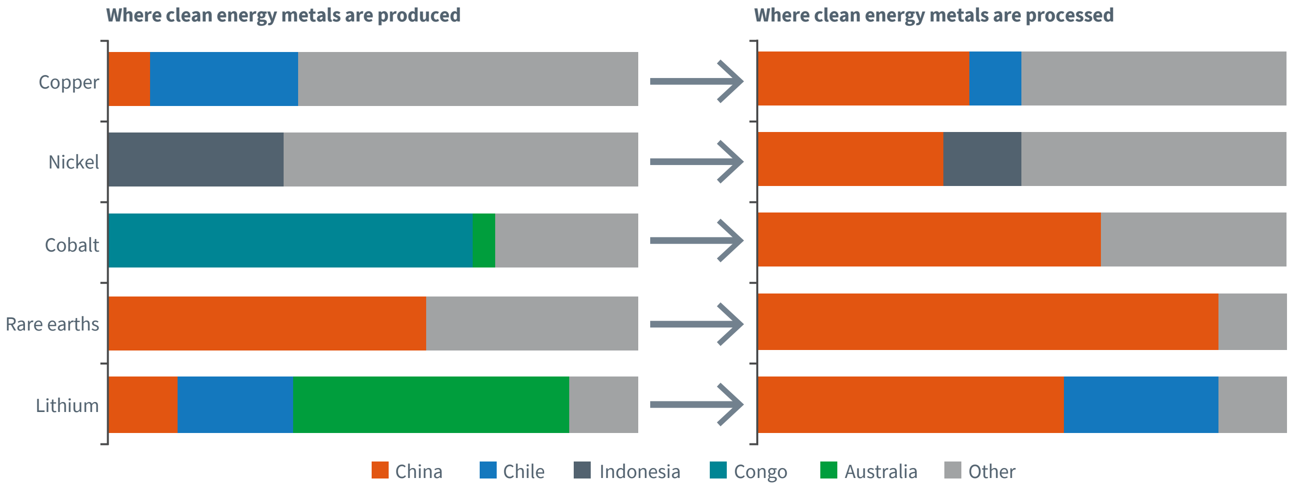
However, most materials are plentiful enough to meet the needs of the transition. The likely constraints will rather stem from demand competition – not only do solar and wind require these rare earths and metals, but chips, batteries and grids do too. They will also stem from geopolitical, social and environmental risks, and the time it takes for a new mine to become operational (between five and 20 years).[14]

11. Mohsen Bonakdarpour, et al., 'The future of copper: Will the looming supply gap short-circuit the energy transition?', IHS Markit, July 2022.
12. Christian Breyer, et al., 'On the history and future of 100% renewable energy systems research', IEEE Access, July 29, 2022.
13. Zachary ShahanPu, 'World needs to mine 25× more lithium by 2050', CleanTechnica, October 20, 2022.
14. François de Rochette and Greg De Temmerman, 'Fluxes, not stocks: The real challenges of metallic resources for the energy transition', Zenon Research, February 10, 2022.

"Where we see the real challenge is around ensuring a smooth development of the supply chain for these resources," says Elena Pravettoni, senior analyst at the Energy Transitions Commission (ETC)[15] and lead author of its 2021 report, *Making clean electrification possible*.[16] "The first step is unlocking investment to ensure we bring on capacity ahead of need, in upstream – building the mines – midstream and downstream – building processing facilities."

Resilience capacity also needs to be built across geographies to mitigate geopolitical risk (see Figure 4), and responsible approaches adopted to minimise social and environmental disruptions.

Figure 4. **China's dominance in clean energy metals (per cent)**



Source: Visual Capitalist, January 20, 2022.[17]

"We need to be mindful of where production is happening," says Darryl Murphy, managing director of infrastructure at Aviva Investors. "Most solar PV panel producers manufacture in China. What happens in a scenario where geopolitics moves in a different direction? It's important to diversify the supply chain, but you don't see many governments talking about that."

Difficult political sells

Governments also have national challenges to electrify their economies. They need to build – or allow companies to build – a huge amount of infrastructure, including smart grids and grid connections, long-distance transmission lines, and wind and solar farms.

"Over longer distances, high-voltage direct current (HVDC) is much more efficient than high-voltage alternating current, but very few countries have done that," says Luke Mulley, ESG utilities analyst at Aviva Investors. "Brazil has one HVDC cable, China around 20; no-one else has any long-distance ones operating on that scale."

> *"HVDC is much more efficient than high-voltage alternating current over longer distances"*
>
> **Luke Mulley**
> ESG Utilities Analyst

15. The ETC is a global coalition of leaders from across the energy landscape.
16. 'Making clean electrification possible – 30 years to electrify the global economy', Energy Transitions Commission, April 2021.
17. Bruno Venditti, 'Visualizing China's dominance in clean energy metals', Visual Capitalist, January 20, 2022.

Developing countries are struggling to get the financing they need (see *Building capacity is economically beneficial*), while developed nations face NIMBYism and lengthy processes for planning permissions.

“There are lots of constraints around permitting. In the US, the Manchin bill aimed to improve it, but it was pulled on September 27, 2022,” says Mulley.[18] “However, it is worse in Europe because permitting is approved predominantly by local governments. Taking a broad brush, it currently takes about three to five years from start to finish. Improvement is planned but may be delayed, because politicians will have to push it through opposition from local governments and consumers,” he adds.

Although the timeline is unclear, pressure will build for changes in planning permissions as the urgency around climate change intensifies, to allow construction to pick up pace. In parallel, innovation and substitution are constantly reshaping forecasts and expectations.

What about water?

Water scarcity is becoming a big issue as the planet warms and populations grow. While thermal energy requires more water than renewables, meaning the latter remain the better option, water constraints will have several impacts.

Mining, for example of copper and lithium, and manufacturing semiconductors require large quantities of water, often in water-constrained areas.[19] It is therefore important to monitor and mitigate local environmental impacts, including water consumption, and maximise circularity.

For instance, a typical semiconductor production facility uses over two million gallons of water a day. As Taiwan is water-constrained and has been suffering from water stress in recent years, a company like TSMC, the world’s largest semiconductor manufacturer, must carefully manage its water usage. It has introduced more wastewater recycling systems, improved water-use efficiency throughout its operations and set up a drought-emergency team to monitor resources and reduce consumption.[20]

But global warming is also making water an issue for complementary low-carbon energy production, including nuclear and hydropower. Due to heatwaves in the summer of 2022, France had to make difficult decisions between keeping its plants online and protecting wildlife from dangerously hot discharge waters (used to cool reactors).[21] And Norway’s hydroelectric capacities were so constrained by low reservoir levels, the government considered suspending energy exports.[22]

As water scarcity worsens, relations between countries that share resources – rivers or lakes – also risk being impacted, and trade-offs between the needs of people, agriculture and energy could become harder to balance. This could cause growing tensions within and between countries.[23]

With thermal, nuclear and hydropower more constrained than wind and solar, renewables development – with careful water management – cannot happen fast enough.

18. Timothy Gardner and Nichola Groom, ‘U.S. clean energy backers: Permitting bill imperative in climate fight’, Reuters, September 29. 2022.
19. Serge Hulne, ‘Can we build wind turbines with wind turbines? Does a 100% wind turbine scenario make sense?’, Serge Hulne, April 2, 2022.
20. ‘Water management’, TSMC ESG, as of November 18, 2022.
21. Richard Lough, et al., ‘France tweaks rules to keep nuclear plants running during heatwave’, Reuters, August 8, 2022.
22. Nora Buli, ‘Norway grid operator says government should not curb winter power exports’, Reuters, September 30, 2022.
23. AIQ Editorial Team, ‘The climate wars: Why rising temperatures mean rising conflict’, Aviva Investors, September 23, 2021.

Reduce, reuse, recycle

Markets adapt remarkably fast to shortages. New sources of materials are found, such as extracting lithium from ocean water, which holds 6,000 times as much lithium as land.[24] As a result, resource estimates are often revised upwards. Identified lithium resources have gone up from 53 million tonnes in 2018 to 80 million in 2021.[25]

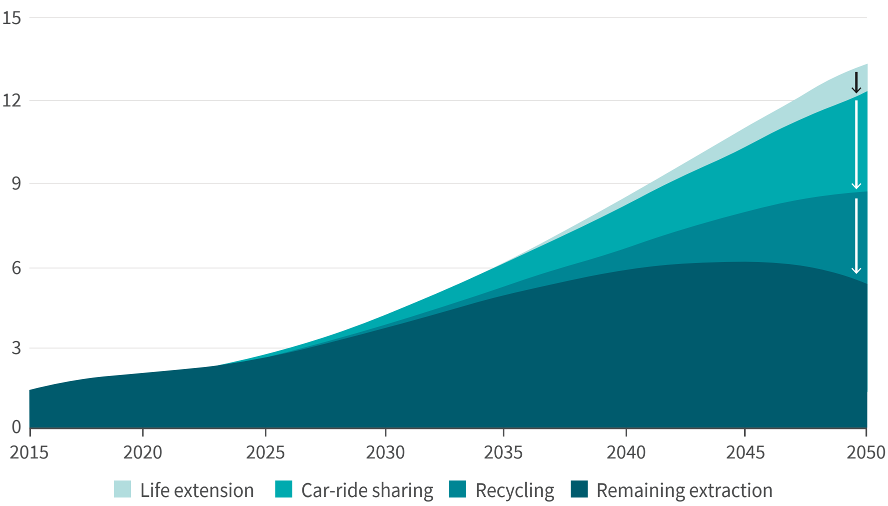
R&D also enables manufacturers to substitute scarce materials or those that pose social or environmental concerns. New battery technologies have significantly reduced the need for cobalt, for instance, while researchers recently found a possible replacement for the rare earths used in the magnets of wind turbines and electric cars.[26,27]

Additionally, as companies continue to innovate, production will become more efficient and use less materials. Combined with extended product lifecycles, improved recycling and changes in demand patterns, this drastically alters the outlook for materials consumption (Figure 5).

> *"Improving efficiency is critical to reduce the scale of the challenge"*
>
> **Elena Pravettoni**
> Senior Analyst, Energy Transitions Commission

"In the next 30 years, we need to grow the system – to give more people access to energy – while decarbonising energy supply," says Pravettoni. "Improving efficiency is critical to reduce the scale of the challenge on three levels. There is energy efficiency itself (for example, using more efficient technology such as heat pumps); material efficiency (using less inputs in production); and service efficiency – organising society to reduce overall consumption, for example through mobility as a service."

Figure 5. **Reduction potential of requirements in metal production for transportation (Gt/year)**



Source: Zenon research, February 2022.[28]

This is currently a big oversight in the UK, Europe and the US, despite clear gains to be achieved given current gas prices. Governments have taken some steps, such as in the REPower EU plan, which increased its energy efficiency improvement target for buildings from nine to 13 per cent in March 2022, but more can be done.[29]

24. Christian Breyer, et al., 'On the history and future of 100% renewable energy systems research', IEEE Access, July 29, 2022.
25. 'Making clean electrification possible – 30 years to electrify the global economy', Energy Transitions Commission, April 2021.
26. 'Making clean electrification possible – 30 years to electrify the global economy', Energy Transitions Commission, April 2021.
27. Bloomberg News, 'Researchers find possible replacement for rare earth in magnets', Bloomberg UK, October 25, 2022.
28. F. De Rochette and G. De Temmerman, 'Fluxes, not stocks: the real challenges of metallic resources for the energy transition', Zenon Research, February 10, 2022.
29. 'REPowerEU: A plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition', European Commission, May 18, 2022.

"It seems like such a no brainer to try and reduce demand but energy efficiency has struggled to gain traction politically," says Mulley.[30]

Because of the Jevons paradox, according to which some of the money saved through energy efficiency will be spent on additional energy, the gains are typically less than 100 per cent.[31] However, as explained by David Timmons, ecological economist and associate professor of economics at UMass Boston's College of Liberal Arts, many studies show efficiency is often much less expensive than buying the equivalent amount of energy.[32,33]

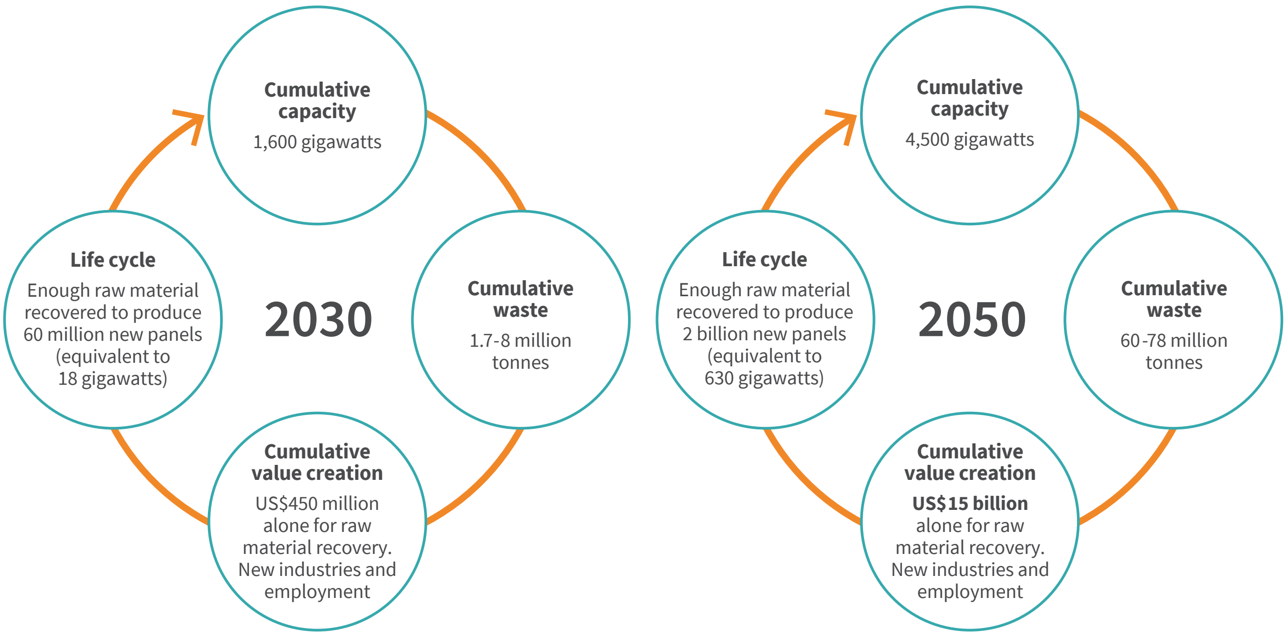
A circular economy

"There is also much upside potential for recycling," adds Timmons. "There is no recycling of fossil fuels; you burn oil or coal and it's gone. But once the materials needed to produce energy from renewable sources are mined – if it's copper or lithium – they become part of a global stockpile that doesn't shrink. Any new mining just makes that pool bigger."

There are challenges and costs, but with new legislation coming into force, manufacturers are increasingly developing circular management and production processes. If more batteries and solar panels are recycled, and materials recycling rates improve thanks to better technology, it will help reduce potential shortages, as well as create value.[34]

> *"Any new mining of renewables materials just makes the global stockpile bigger"*
>
> **David Timmons**
> Ecological Economist,
> UMass Boston

Figure 6. **Potential value creation through solar PV panel recycling**



Source: International Renewable Energy Agency (IRENA), January 16, 2017.[35]

30. Niko Kommenda, et al., 'How UK households could save £10bn a year by making homes more energy efficient', Financial Times, November 16, 2022.
31. In economics, the Jevons paradox occurs when technological progress or government policy increases the efficiency with which a resource is used (reducing the amount necessary for any one use), but the falling cost of use increases its demand, negating reductions in resource use. Source: Diana Bauer, 'Book review perspectives: The Jevons Paradox and the myth of resource efficiency improvements', Sustainability: Science, Practice, & Policy, March 18, 2009.
32. David Timmons, et al., 'Decarbonizing residential building energy: A cost-effective approach', Energy Policy, May 2016.
33. David Timmons and Benjamin Weil, 'A cost-minimizing approach to eliminating the primary sources of greenhouse gas emissions at institutions of higher education', International Journal of Sustainability in Higher Education, February 2022.
34. 'Gigafactories are recycling old EV batteries into new ones: It is a further step towards circular manufacturing', The Economist, October 26th, 2022.
35. Andreas Wade, et al., 'End-of-life management: Solar photovoltaic panels', World Future Energy Summit 2017, IRENA, January 16, 2017.

Research by the International Renewable Energy Agency (IRENA) estimates the development of solar PV panel end-of-life management "could become a significant component of the PV value chain and spawn new industries, supporting considerable economic value creation".[36]

"You can think of it another way, where an alternative use is found for products at the end of their life," says Edward Kevis, European equity portfolio manager at Aviva Investors. "For example, car batteries may be used as a battery storage solution in a petrol station or residential area. You might not be able to separate the battery's constituent materials, but its useful life could be extended for a considerable time."

"Rather than modelling existing demand in the grid, we find many loads have some flexibility"

David Timmons
Ecological Economist,
UMass Boston

Such batteries could be used to store energy from solar panels during daylight hours, for instance. Done at scale, this would reduce the need for energy storage in the grid, which is just one way assumptions on energy markets could change as economies electrify.

"As we start to describe the electricity demand for a system that's completely electrified, the nature of demand could change," adds Timmons. "Rather than modelling existing demand in the grid, we find many loads have some flexibility. The case for demand flexibility is even stronger around electric car charging, space heating and water heating."

While this can make it more difficult to model future energy usage, it can make renewable adoption easier. The good news is this also makes economic sense.

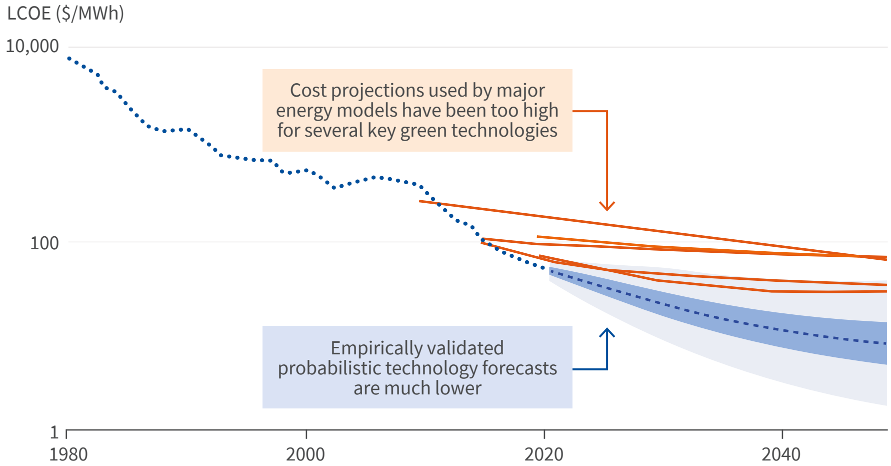
36. Andreas Wade, et al., 'End-of-life management: Solar photovoltaic panels', World Future Energy Summit 2017, IRENA, January 16, 2017.

Building capacity is economically beneficial

Some of the models used to make decisions on renewables are increasingly coming under fire for underestimating potential cost improvements and deployment rates, in particular models published by the International Energy Agency (IEA) and the Intergovernmental Panel on Climate Change (IPCC). Several studies have found that, if realistic costs are applied, renewables become the obvious solution.[37]

Models used to make decisions are underestimating potential cost improvements and deployment rates

Figure 7. **Cost projections have been too high for key green technologies**



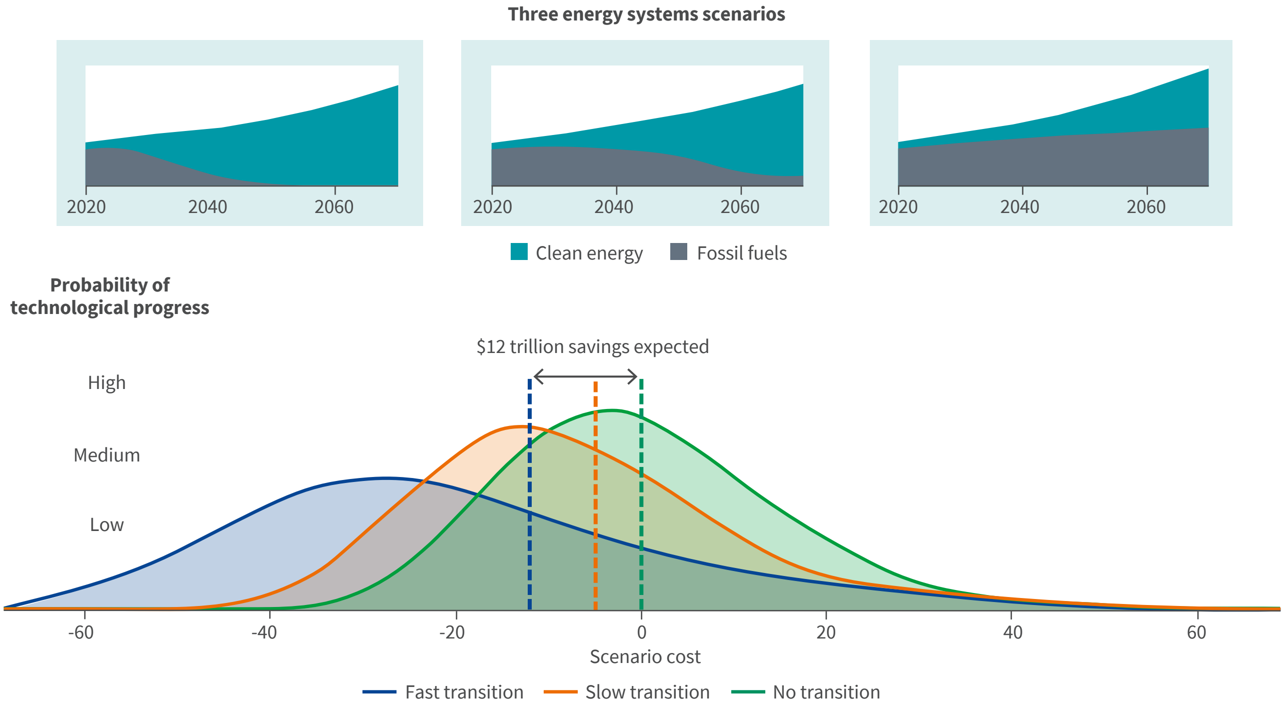
Source: Rupert Way, et al., September 21, 2022.[38]

One study even concludes a rapid green energy transition would likely result in "overall net savings of many trillions of dollars – even without accounting for climate damages or co-benefits of climate policy".[39]

Three factors are generally at play: methodological inconsistencies, a drastic underestimation of the learning curve and using point-of-extraction instead of point-of-use comparisons of energy returns on investment (EROIs: an EROI > 1 would indicate more energy is delivered than used in the extraction process).[40] Point of extraction favours fossil fuels by ignoring the costs of transporting and transforming the extracted fuels for end-use, whereas including them drastically lower these energies' EROIs. One study finds that, using point-of-use comparisons, solar PV, wind and hydropower have EROIs at or above ten, while the EROIs for thermal fuels vary significantly, with that for oil notably below ten.[41]

37. Christian Breyer, et al., 'On the history and future of 100% renewable energy systems research', IEEE Access, July 29, 2022.
38. Rupert Way, et al., 'Empirically grounded technology forecasts and the energy transition', Joule, Volume 6, Issue 9, September 21, 2022.
39. Rupert Way, et al., 'Empirically grounded technology forecasts and the energy transition', Joule, Volume 6, Issue 9, September 21, 2022.
40. Christian Breyer, et al., 'On the History and Future of 100% Renewable Energy Systems Research', IEEE Access, July 29, 2022.
41. David J. Murphy, et al., 'Energy return on investment of major energy carriers: Review and harmonization', Sustainability, June 9, 2022.

Figure 8. **Going green could deliver $12 trillion in savings**



Source: Rupert Way, et al., September 21, 2022.[42]

"In the framing of the climate discussion, oil and gas producers tend to talk about primary energy (i.e., how much energy is embedded in a lump of coal or a drop of oil). But once this is converted to a useful form of energy and transported to where it needs to go, there is a significant amount of loss of this primary energy," says Rick Stathers, climate lead at Aviva Investors. "Renewables are a much more efficient means of delivering useful energy. Thinking about the energy system in terms of useful energy is a much more accurate means of determining demand and technologies."

In addition, although the rise in fossil-fuel costs is impacting renewables, Mulley says higher power prices more than offset the increase in costs, while improving the economics of renewables relative to gas and coal.

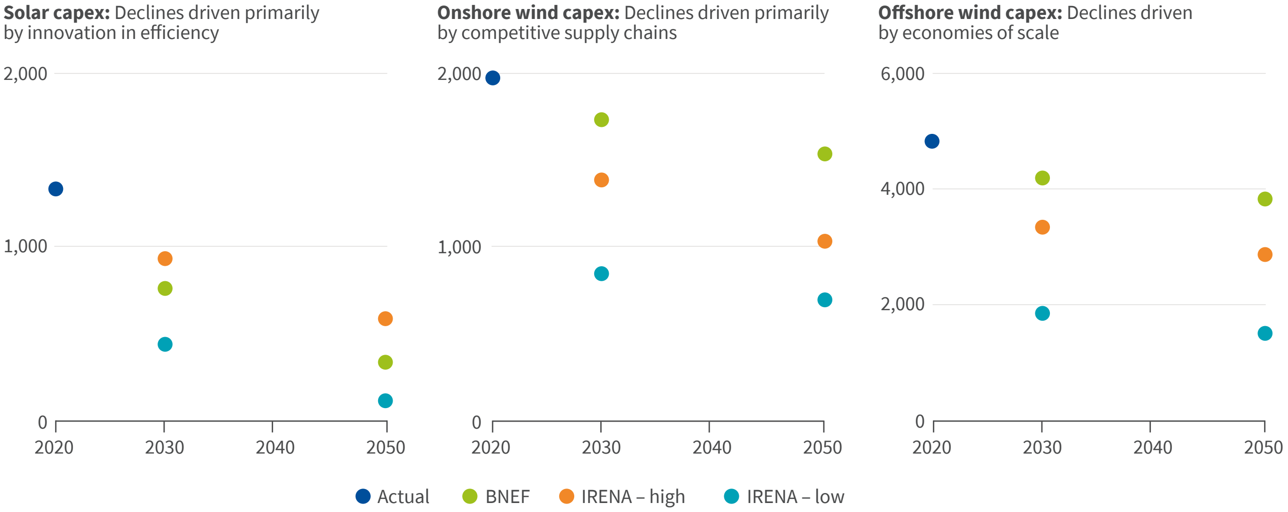
"To build a gas plant from scratch today, you could be looking at around €600 per MW/ hour," he says. "Renewables can be built at a worst-case scenario of €50 to €60 per MW/ hour. The EU inframarginal price cap will come in at €180, because the gas price is far above that, so on a pricing level, renewables win out."

> *"On a pricing level, renewables win out"*
>
> **Luke Mulley**
> ESG Utilities Analyst

Looking at the long term, whereas building a wind turbine or solar panel requires significant capital upfront, once it is in place, subsequent costs to produce the energy are almost non-existent. And, because sunshine and wind do not get depleted like fossil fuels, construction costs should fall over time as renewables benefit from technology improvements and economies of scale.

42. *Rupert Way, et al., 'Empirically grounded technology forecasts and the energy transition', Joule, September 21, 2022.*

Figure 9. **Renewables capex is expected to decline thanks to lower costs and economies of scale (thousands $/MW)**



Sources: Energy Transitions Commission, April 2021.[43]

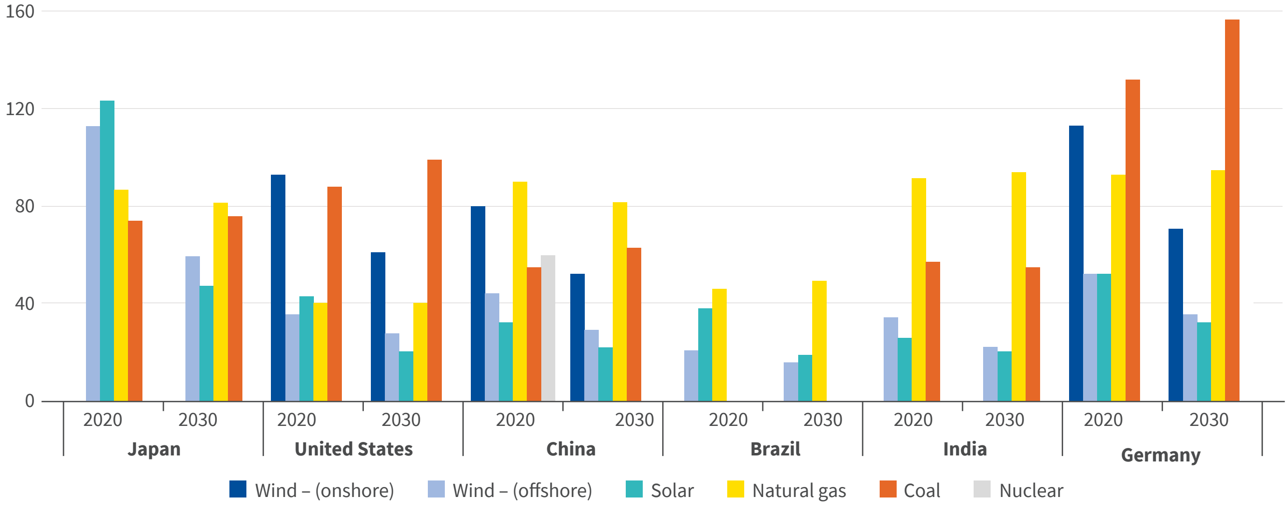
"The general expectation around renewable energy is that the prices we have today are probably the worst case," says Timmons. "It's a fundamentally different cost trend than in the fossil-fuel era, with the caveat about materials.

"It's not impossible to imagine the high prices of copper we see now relative to the last few decades could persist for a long time, because copper will be in big demand for electrification," he adds. "But that's only one piece of a technology that requires many other materials, so it shouldn't have a large impact on renewable energy prices."

As a result, although the levelised cost of energy (LCOE – a measure of the cost of operating an energy facility over its lifetime divided by the energy produced) varies by geography, renewable LCOEs have fallen dramatically over the last ten years and were increasingly competitive against the marginal cost of gas in places like the US and Germany before the 2022 energy price shock. They are projected to fall further still.[44]

43. 'Making clean electrification possible – 30 years to electrify the global economy', Energy Transitions Commission, April 2021.
44. 'Making clean electrification possible – 30 years to electrify the global economy', Energy Transitions Commission, April 2021.

Figure 10. **LCOEs by geography ($/MWh)**



Note: Solar refers to fixed-axis PV. Values refer to the 'mid-case' LCOEs. All LCOE calculations are unsubsidised.
Source: Energy Transitions Commission, April 2021.[45]

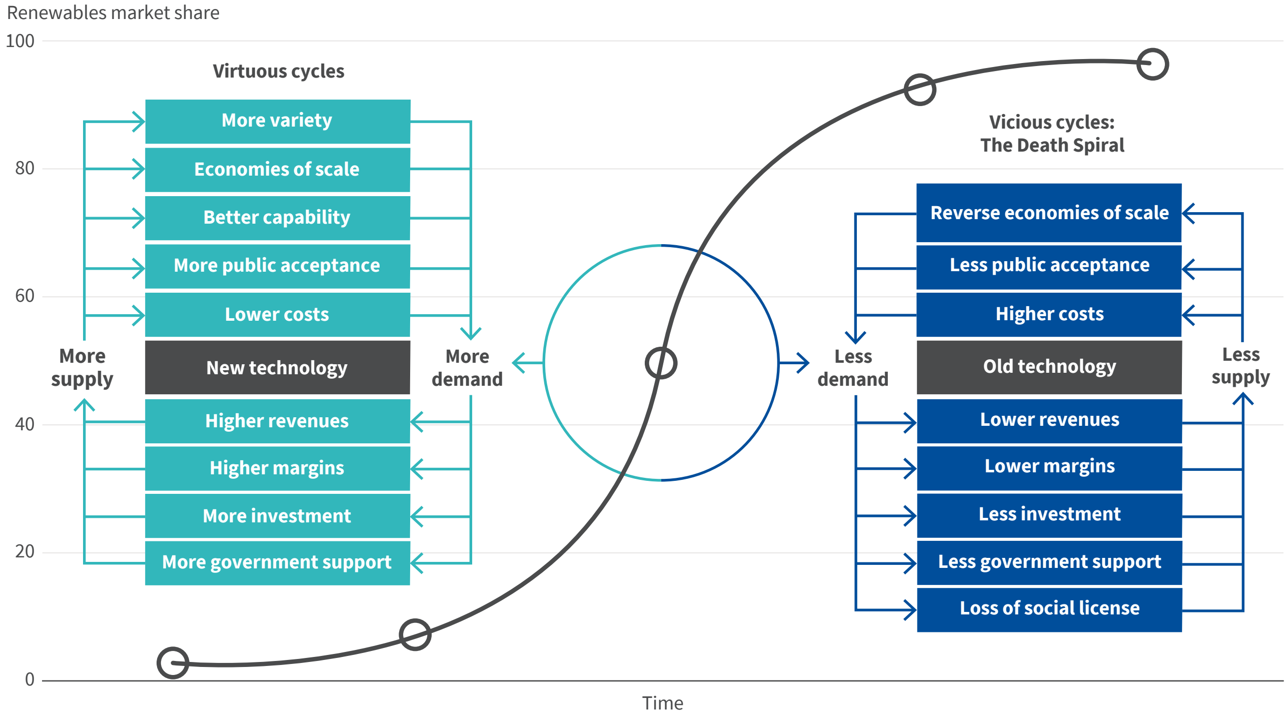
Disruption could happen fast

Combined with high power prices and potential new contract-for-difference models, improving LCOEs of renewables mean this could be the right time to wean investors off subsidies and increase their allocations.

In a 2021 report, think-tank RethinkX contended this was just the beginning of an unavoidable disruption that could see renewables displace fossil fuels much faster than anticipated. Now the economics are in place (i.e., more efficient energy sources at the right price), the transformation cannot be stopped, even though some hurdles could slow adoption, for example political challenges or lobbying by incumbents. The report argues causal feedback loops will increasingly drive disruption of the energy system.[46]

45. 'Making clean electrification possible – 30 years to electrify the global economy', Energy Transitions Commission, April 2021.
46. James Arbib, et al., 'Rethinking climate change: How humanity can choose to reduce emissions 90% by 2035 through the disruption of energy, transportation, and food with existing technologies', RethinkX, August 2021.

Figure 11. **Feedback loops drive disruption (Market share, per cent)**



Source: James Arbib, et al., August 2021.[47]

Adam Dorr, director of research at RethinkX, also says continued innovation means that, by the time current renewable models' EROIs plateau, we will already have new and better ones.

"The disruption will not simply swap in new technologies for old ones, but will create an entirely new energy system, with new properties that require new business models and metrics," he says. "The optimal solar, wind and batteries system that meets all of today's electricity demand will have three to five times as much generating capacity as our existing grid, because it must be sized for the most challenging times of year. Throughout the rest of the year, the system will produce what we call super power – an abundance of zero-carbon energy at near-zero marginal cost. That's revolutionary. It's a complete game-changer."

> *"The disruption will create an entirely new energy system"*
>
> **Adam Dorr**
> Director of Research, RethinkX

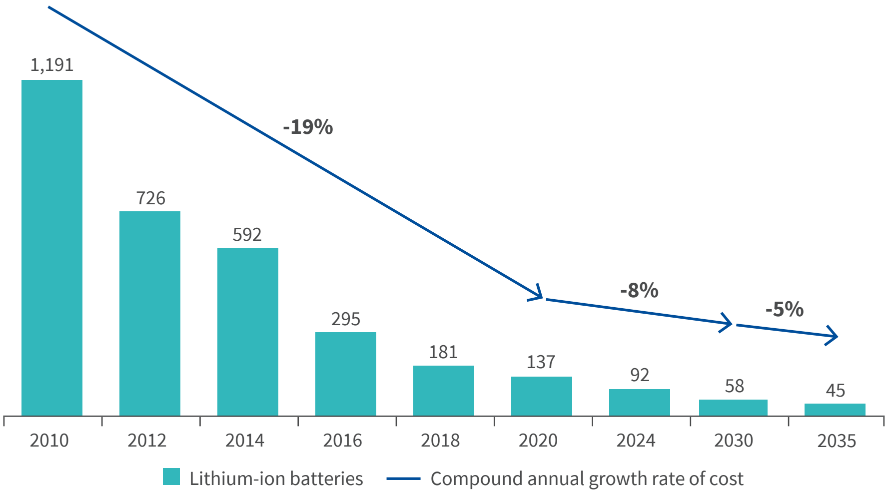
47. James Arbib, et al., 'Rethinking climate change: How humanity can choose to reduce emissions 90% by 2035 through the disruption of energy, transportation, and food with existing technologies', RethinkX, August 2021.

We may not need as much storage as we think

This also means battery storage may not be as big an issue as many models anticipate.

From a cost perspective, battery economics become less attractive as duration increases. This makes lithium-ion batteries an unlikely solution for long-duration and seasonal storage, although they are projected to be increasingly effective for daily balancing (Figure 12).

Figure 12. **Lithium-ion batteries increasingly cost-effective for daily balancing (S/kWh)**



Source: Energy Transitions Commission, April 2021.[48]

From a technology standpoint, the only long-term storage solution proven at scale is pumped hydro, which involves pumping water upstream in periods of excess electricity in the grid to release it and generate power when needed. This has land and environmental implications, but other technologies (e.g., compressed air, vanadium flow batteries, gravity batteries and hydrogen) are economically unproven.[49]

However, long-term storage capacity will not be needed until renewables make up most of the energy system, giving technologies time to mature. Long-duration energy storage start-ups received over $1 billion of investment in 2021, and grid operators have raised the issue. This increases the likelihood technology will be ready in time to meet demand, although Mulley says there must be stronger market signals to ensure long-term storage is available when needed.[50]

Long-term storage capacity will not be needed until renewables make up most of the energy system

In addition, as the costs of building wind and solar capacity continue to fall, it may become cheaper to build large excess capacity, further reducing the need for long-duration storage.[51]

48. ‘Making clean electrification possible – 30 years to electrify the global economy’, Energy Transitions Commission, April 2021.
49. Luke Mulley, ‘ESG thematic: Grid-level battery storage’, Aviva Investors ESG Research, October 17, 2022.
50. Luke Mulley, ‘ESG thematic: Grid-level battery storage’, Aviva Investors ESG Research, October 17, 2022.
51. M. Diesendorf and T. Wiedmann, ‘Implications of trends in energy return on energy invested (EROI) for transitioning to renewable electricity’, Ecological Economics, volume 176, October 2020.

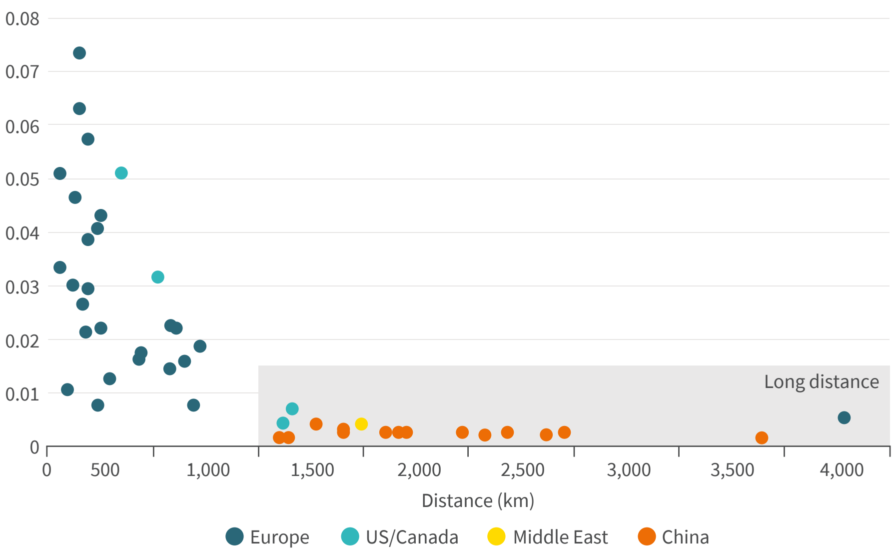
"Storage gets talked about a lot, but it's actually not such a prominent part of the solution," says Timmons. "It can be less expensive to use a different energy source that can produce at the time you need it than to invest a lot in batteries."[52]

Long-distance transmission lines could also be important, smoothing energy production by transporting it from sunny and windy places to where it is needed, particularly as HVDC costs decline with distance, since fixed costs are spread (Figure 13).

"In the US, the same solar panel produces a lot more energy in Arizona than it does in Massachusetts. Economically, it would be optimal to develop sunny areas with solar panels, windy areas with wind turbines, then move the energy around," says Timmons.

> *"The same solar panel produces a lot more energy in Arizona than Massachusetts"*
>
> **David Timmons**
> Ecological Economist,
> UMass Boston

Figure 13. **HVDC capex cost of electricity transport ($/(kWh*1,000km))**



Note: Projects in development, excludes financing cost.
Source: Energy Transitions Commission, April 2021.[53]

52. D. Timmons, et al., 'Cost minimisation for fully renewable electricity systems: A Mauritius case study', Energy Policy, Volume 133, October 2019.
53. 'Making clean electrification possible – 30 years to electrify the global economy', Energy Transitions Commission, April 2021.

Government and supranational support

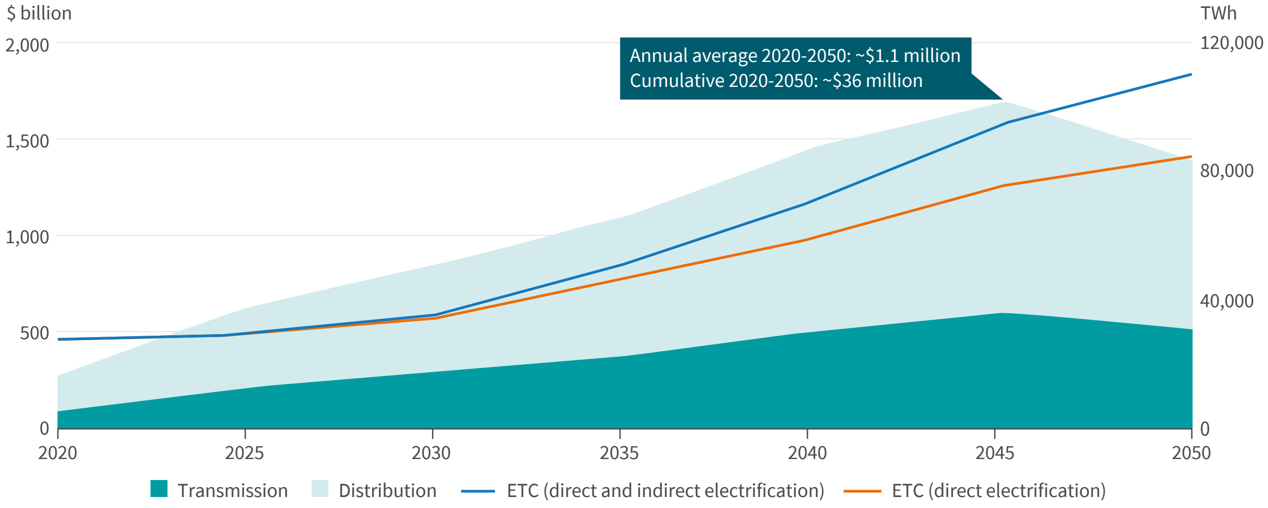
Despite the positive momentum in various areas, a supportive government policy and regulatory environment will be critical to enable the transition to renewable energy. As Timmons puts it, "climate change is an external cost – borne by society rather than energy producers – so market forces alone will not make the transition".

Timmons wrote:

"Besides putting a price on carbon (perhaps with dividends returned to the public), government could make it easier to build the needed infrastructure. And public support is needed: For example, public acceptance of transmission lines to move electricity from the windy Great Plains to city centres is another challenge for an all-renewable grid".[54]

This includes speeding up planning permissions, but also investing in networks to enable the ramp-up of electrification (Figure 14).

Figure 14. **Network investment will be lumpy and front-weighted**



Source: Energy Transitions Commission, April 2021.[55]

A realistic carbon price is also necessary to tilt the system away from fossil fuels, although whether this will happen at a global scale remains debatable.[56]

According to research by Nick Robins, professor in sustainable finance at the Grantham Research Institute for Climate Change and the Environment, while over 90 per cent of global emissions are covered by net-zero policy commitments, the failure to price carbon gives fossil fuels a subsidy equivalent to seven per cent of global GDP.[57]

Actual subsidies also need to end to level the playing field; policymakers could go even further by capping fossil-fuel extraction.

54. David Timmons, 'How to have an all-renewable electric grid', The Conversation, August 22, 2019.
55. 'Making clean electrification possible – 30 years to electrify the global economy', Energy Transitions Commission, April 2021.
56. 'Pricing carbon: Taxing polluters is the only way forward', Aviva Investors, August 26, 2021.
57. Nick Robins, 'Investing in a just transition to net-zero', Grantham Research Institute on Climate Change and the Environment, Centre for Climate Change Economics and Policy, June 7, 2022.

"At some point, we have to be more serious about stopping the use of fossil fuels and enact policies that will accomplish that," says Timmons. "We need caps on the thing that's causing the problem, as opposed to manipulating prices to cajole people into adopting the new technology."

Governments also need to start looking at other metrics alongside GDP, including decarbonisation, biodiversity and social welfare, to reduce the reliance on fossil fuels and extractive economics (see more in *The levers of change: A systems approach to reconcile finance with planetary boundaries*).[58]

"We want to see a ratcheting up of ambition and more roadmaps on how to get from here to 2050," adds Stathers. "That's where the gaps are. Governments need to be held to account."

There are positive moves, from the UK's net-zero target to the EU's 'Fit for 55' programme, the Inflation Reduction Act in the US, and China leading the world in the rollout of renewables. But, as COP27 demonstrated, many gaps remain, creating incentives to continue with the current energy system rather than establish a new one. These also maintain uncertainty for renewable players and investors.

"There are market and technology risks – the market risk being that consumers aren't willing to pay a premium on a product that would have a huge decarbonisation impact; the technology risk being that carbon capture, utilisation and storage (CCUS) or hydrogen never pan out," says Utzinger. "No company should be shouldering that on its own. There is a role for government and explicit policy intervention to de-risk a lot of these projects and create an even playing field."

> *"There are market and technology risks. No company should be shouldering that on its own"*
>
> **Sora Utzinger**
> Senior ESG Analyst

The ETC is advocating for better power-market design to create the right environment by ensuring predictable and sufficient revenue streams to de-risk renewables projects.

"We are not talking about subsidies anymore," says Pravettoni. "Policy instruments like a symmetric contract for difference can incentivise renewables capacity by creating the right balance between revenue certainty and capping the upside so consumers can benefit from falling costs."

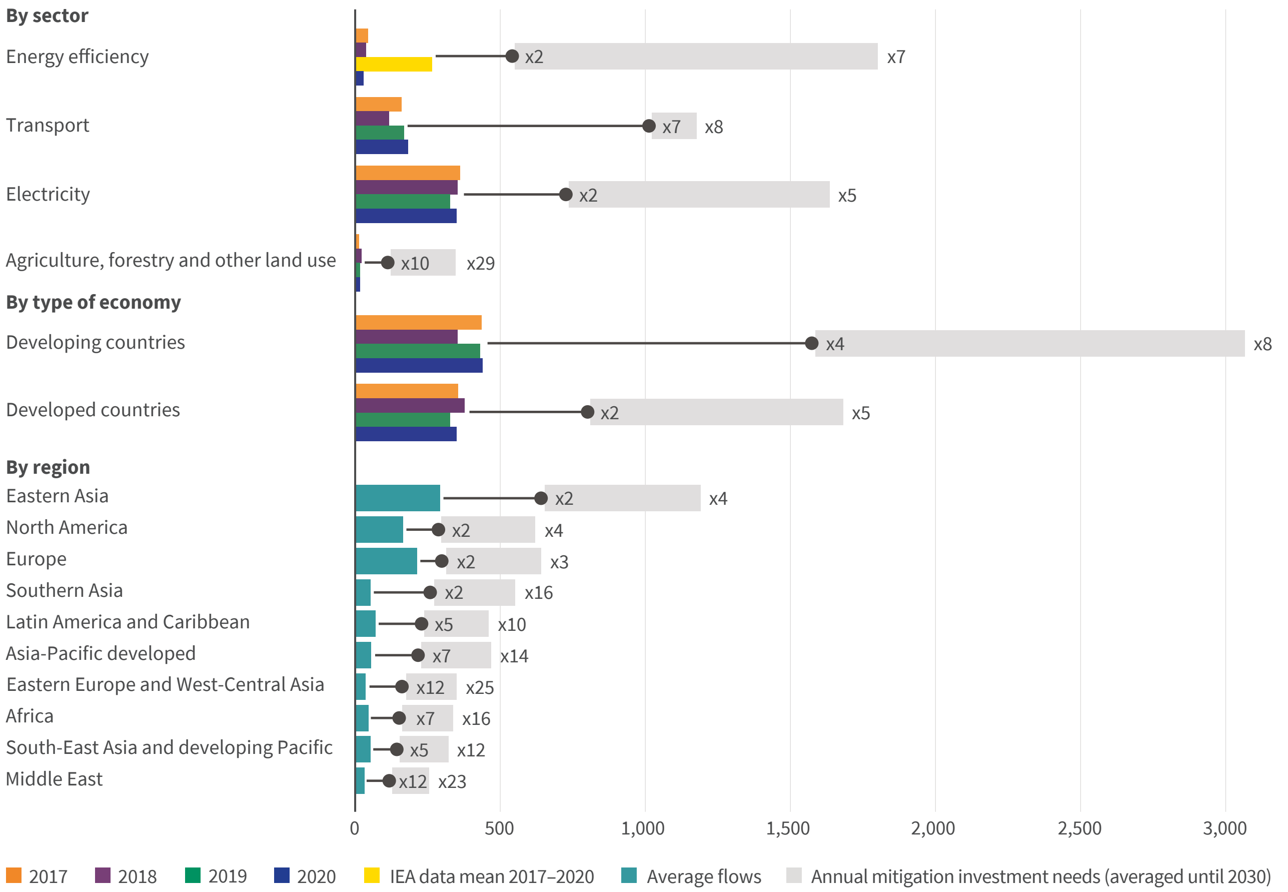
Finally, governments need to manage the transition to avoid stranding workers and communities that rely on carbon-intensive industries today. Choosing the right location for new sites, supporting communities and retraining workers will all play a part. At a global level, it also means investing heavily in climate finance for emerging markets.

58. AIQ Editorial Team, 'The levers of change: A systems approach to reconcile finance with planetary boundaries', Aviva Investors, September 13, 2022.

Financing the transition in emerging markets

COP27 saw developing countries being increasingly vocal in demanding financial support from developed nations. They called for a variety of instruments, from the 'loss and damage' fund, which was finally agreed but remains to be financed, to a redefinition of multilateral institutions' mandates to include environmental sustainability.[59]

Figure 15. **Investment must grow three to six times by 2030, mostly in emerging markets (US$bn)**



Note: Actual yearly flows compared to average annual needs. 2015 yr-1.
Source: IPCC, April 4, 2022.[60]

Huge investments are needed, but it is hard to make the numbers work. Pravettoni says that, for renewables projects, a combination of an unsupportive policy environment, state of transmission networks, creditworthiness of major power utilities, and small size of many projects make it harder to secure low-cost financing.

Linked to these issues is the fact most emerging markets are considered high risk, leading to a much higher cost of capital than in developed countries. This is a significant barrier because renewables mostly require upfront investment before they can start making money.

59. Simon Mundy, 'Climate finance: How would you raise $2.4tn a year?', Financial Times, November 16, 2022.
60. 'Sixth Assessment Report', IPCC, April 4, 2022.

"You don't have to buy all the gas you're ever going to burn at the same time you build a natural-gas-fired power plant, but you effectively do with wind and solar, so the cost of capital is a big deal," says Timmons. "That is a problem for low-income countries with high borrowing costs."

It is also a barrier for institutional investors, whose mandates often don't allow them to take on such levels of risk. This is why the World Bank and other multilateral institutions came under fire at COP27 for being too risk-averse to support emerging markets' transition to renewables.

"To attract private capital, we need de-risking mechanisms, for example from the multilateral development banks," says Pravettoni. "Blended finance vehicles, especially at the early project stage, can aggregate small- or medium-sized projects by bundling them together."

However, she says local governments must also play their part through policy commitments and targets for renewable energy to provide certainty to investors, as well as addressing issues specific to the energy sector, like the creditworthiness of utilities and grid connections.

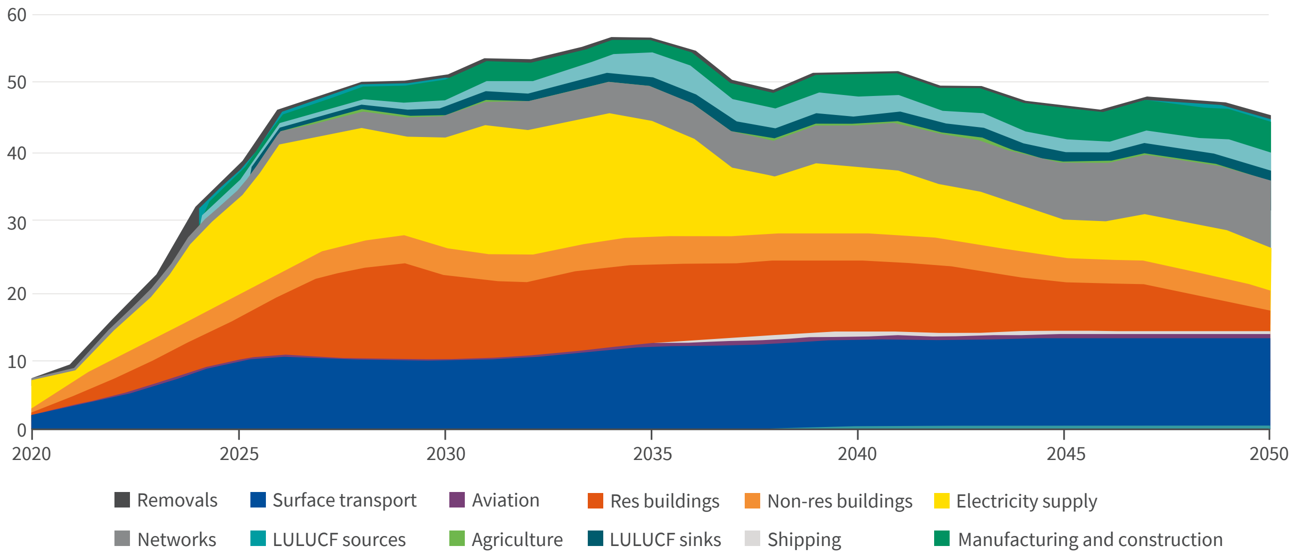
> *"We need de-risking mechanisms, for example from the multilateral development banks"*
>
> **Elena Pravettoni**
> Senior Analyst,
> Energy Transitions Commission

Investment implications: What could 2050 look like?

Opportunities and risks today

The Climate Change Committee, the independent statutory body set up to provide advice to the UK government, estimates net-zero capital investments in the UK need to grow from around £10 billion a year in 2020 to £50 billion by 2030. This should create a wealth of investment opportunities in the short term, particularly if other countries follow a similar path (Figure 16).

Figure 16. **Achieving net zero: Estimated additional annual investment (£bn/year, real 2019 money)**



Source: Climate Change Committee, December 9, 2020.[61]

"Our research agenda reflects the reality this is a large and complex problem," says Utzinger. "We are not in a position to rule anything out given we are still at an early stage of decarbonising the energy system. We need to try everything; that could mean nuclear, renewables, battery storage, hydrogen and carbon removal and capture, but also looking at the role of natural gas.

"As we are mid-transition, we will probably end up investing in two systems at once: the low-carbon system we need for the future and the fossil-fuel-based system we need today to make it all happen," she adds.

> *"As we are mid-transition, we will probably end up investing in two systems at once"*
>
> **Sora Utzinger**
> Senior ESG Analyst

61. 'Sixth carbon budget', Climate Change Committee, December 9, 2020.

Her research estimates a compound annual growth rate (CAGR) of five to nine per cent in wind over the next 30 years. Original equipment manufacturers (OEMs) have recently borne the brunt of rising costs, and the question remains of when they will become viable. On the other hand, smart developers are benefitting from high investor demand and OEMs tied into low prices. That creates investment opportunities in areas like cable suppliers and wind-focused utilities.

Huge investment is also required to update ageing grids and plug in renewables, not to mention upgrading to smart grids and improving interconnectedness, supporting the outlook for power solutions providers like Hubbell and Quanta Power.

"Although short-term challenges remain around permitting, European renewables are now looking attractive for long-term investors compared to the last two years," adds Mulley. "Their outlook then was hampered by concerns oil and gas companies would come in and massively bid up the space, returns would get compressed, and renewable developers wouldn't make money.

"Oil and gas names only took about 25 per cent of the awards last year, but the share prices of renewable names tanked off that. Orsted is a good example, as it went from around DKK1,400 in January 2021 to DKK620 at the end of November 2022," he adds.[62]

> *"Although short-term challenges remain around permitting, European renewables are now looking attractive for long-term investors compared to the last two years"*
>
> **Luke Mulley**
> ESG Utilities Analyst

With the EU having set its inframarginal price cap at €180 and windfall taxes being set out, there is now more certainty in the sector, while valuations are not pricing in much growth despite strong demand.[63] Mulley says this creates opportunities, as he expects there will be more than enough projects to go round for European developers to meet the EU's 2030 renewables targets.

Recent research Mulley conducted on battery storage also finds opportunities, with global capacity forecast to grow 15 times at a 30 per cent CAGR by 2030, although this varies dramatically between the US, Asia and Europe. Mulley finds the US is currently the largest and most attractive market, while Asia is set to overtake it in the early 2030s, driven mostly by China and India. Europe is a notable laggard, but this leaves it as a potential growth story, with BloombergNEF recently doubling its outlook for the region's energy storage growth to 2030.[64]

The ETC's *Making clean electrification possible* report also found the power sector represents the majority of investments needed to reach net zero, though it also identified opportunities in hydrogen, industry, transport and buildings (Figure 17).[65]

62. Source: Bloomberg, as of November 28, 2022.
63. '6 points for Governments as you implement the EU's new revenue cap on power generation', Wind Europe, October 5, 2022.
64. Luke Mulley, 'ESG thematic: Grid-level battery storage', Aviva Investors ESG Research, October 17, 2022.
65. 'Making clean electrification possible – 30 years to electrify the global economy', Energy Transitions Commission, April 2021.

Figure 17. **Investments to reach net zero across the energy sector**

2050 vision			Key investment needs	Total investment 2020-2050 (US$bn)	Total annualised investment (US$bn p.a.)	Share of GDP per cent
Power	Total power generation 110,000 TWh / year Total capacity required 27.35 TW solar 14-16 TW wind 2-4 TW of hydro, nuclear, othe zero-carbon	Renewables and other zero-carbon	26-34 TW solar 14-15 TW wind 3.5 TW other zero carbon	~46,000-47,000	~1,500–~1,600	~0.8
		Transmission and distribution	~50 per cent of generation, front-weighted	~36,000	~1,100	~0.6
		Battery storage	14 TWh per day (5 per cent of daily generation)	~1,500	~50	~0.03
		Seasonal storage: H2 storage and/or CCS on thermal plants	4 TW thermal capacity equipped with CCS (5 per cent of generation)	~3,800	~130	~0.07
			1.5 TW electrolysis (2 per cent power shifted)	~430	~15	~0.05
Hydrogen in final use	800 Mt/year for final sectoral energy use	Production	7.6 TW electrolysis 0.7 TW blue hydrogen capacity	~1,800	~40	~0.02
		Transport and storage	Salt caverns and other storage Gas pipeline retrofit	~1,100	~40	~0.03
Industry	Steel, cement and petrochemicals industries achieve zero-carbon		CCS application to cement Hydrogen DRI or CCS for steel Multiple forms of changed chemical production process	~1,600	~50	~0.03
Transport	Road charging infrastructure	Total decarbonisation road transport ~2bn electric cars and ~200m electric trucks and buses	~100bn slow residential, 200m moderate speed public and 10 million superfast chargers, + truck and bus chargers	~2,000	~70	~0.04
	Aviation and shipping	All long haul routes running with zero carbon fuels	Aviation and green shipping R&D, SAF plant investment and ship / fuel supply retrofit	~900	~30	~0.02
Buildings Energy efficiency	IEA estimate of additional required investment in better insulation and more efficient lighting and HVAC systems			~12,000–15,000	~400–500	~0.2
Total				**~106–110,000**	**~3,600–3,700**	**~1.8%**

Note: Wind and solar capacity for hydrogen production is included in renewables generation.
Source: Energy Transitions Commission, April 2021.[66]

Looking at hard-to-abate sectors – from steel to cement, plastics to transport – specifically companies taking risks by investing in R&D for unproven technologies that could make a difference from a decarbonisation perspective, Max Burns, global equities portfolio manager and head of equities research at Aviva Investors, says they need to be placed in the context of each investment (see more in *The going gets tough: Can heavy industry decarbonise?*).[67]

66. 'Making clean electrification possible – 30 years to electrify the global economy', Energy Transitions Commission, April 2021.
67. AIQ Editorial Team, 'The going gets tough: Can heavy industry decarbonise?', Aviva Investors, August 23, 2021.

"For a strategy aiming for sustainable outcomes as well as investment returns, for example, we would highlight the decarbonisation perspective and take into account the company's flattish or decelerating returns on investment capital because of what it is doing," he says. "It would be subjective and depend on knowing exactly what companies are doing and giving them credit for it."

Although he says investment opportunities are still rare for solutions like CCUS or hydrogen, it is important to keep abreast of progress.

"We don't want to miss something new, but it is early stage with those technologies, and we have plenty of time to work through that," he says.

Tomorrow

For hydrogen and CCUS, Pravettoni says the focus has to be on building the market. The ETC's vision is for clean electricity to grow from around 20 per cent of final energy demand today to 60 or 70 per cent by 2050, but electricity may simply not work for the remaining 30 per cent.

"That is where we see a role for clean hydrogen, bioenergy and a very limited, but important, role for CCUS," she says. "Alongside clean electrification, these form the key ingredients of the net-zero vision."

Utzinger adds there is a huge soft-power struggle at the core of this, particularly around renewables development in Africa. She expects more competition for deals between China and Europe, which could eventually create investment opportunities too. COP27 saw increased deal-making around hydrogen with Germany leading the way; Scholz announced Germany would increase the budget for its H2Global scheme, accelerating green hydrogen imports from outside the EU from €900 million to €4 billion.[68]

From a real assets perspective, Murphy sees potential opportunities in energy efficiency and long-term storage, though he doesn't think they are investable yet – energy efficiency because it is fragmented, and long-term storage because the technology still needs to be developed.

> *"This is what's interesting for infrastructure; a lot of the technology is still for the future"*
>
> **Darryl Murphy**
> Managing Director
> of Infrastructure

"This is what's interesting for infrastructure; a lot of the technology is still for the future," he says. "The two biggest risks investors dislike are technology risk and long-term revenue risk. In most of these, you have both."[69]

Although energy efficiency and storage, but also circularity, will play a role, Kevis says it is imperative to be nimble, identify the cheaper and most practical options and invest in those at speed.

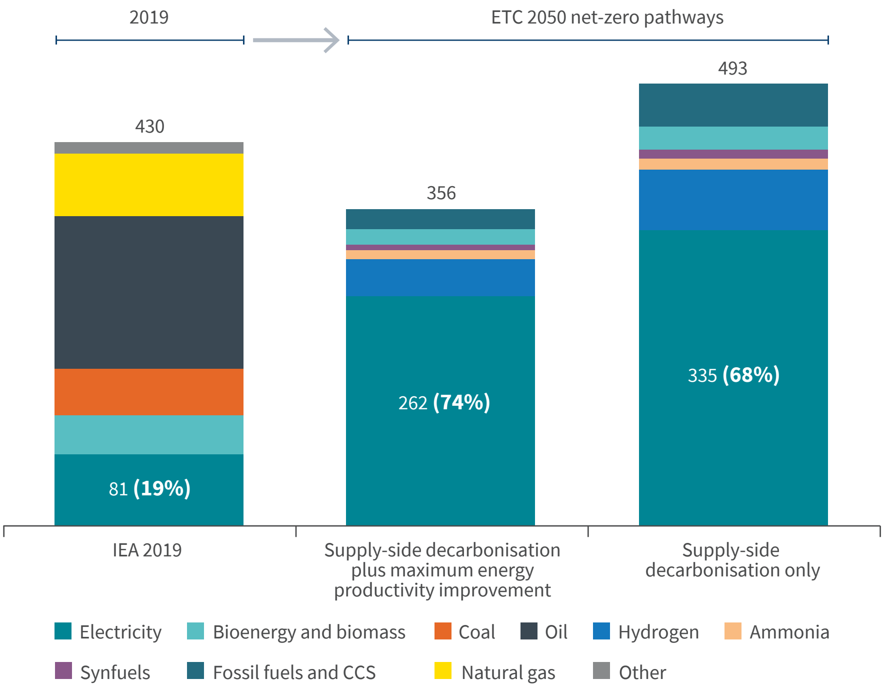
"Companies and governments must learn from each other," he says. "Governments have to work with the private sector, and we must take a longer-term view; that's where we will find the right solutions."

68. Leigh Collins and Agnete Klevstrand, 'COP27 round-up: Green hydrogen takes prime position on global stage, with multiple initiatives and projects announced', Hydrogen Insight, November 21, 2022.
69. Darryl Murphy, 'An investor's perspective on the UK's Net Zero Strategy', Aviva Investors, October 28, 2021.

The long term

Most studies forecast a 2050 energy mix overwhelmingly reliant on renewable electricity, combined with some dispatchable (available on demand) sources such as hydropower or biomass to fill in the gaps (see *Other technologies to complement wind and solar*). They also include some storage, short and long term.

Figure 18. **ETC's indicative final energy mix in a net-zero economy (EJ/year)**



Note: Percent shows difference versus 2019.
Source: Energy Transitions Commission, April 2021.[70]

As the net-zero energy system takes shape, investment opportunities will become clearer in those areas. However, Timmons repeats several factors will influence the need for dispatchable power and storage. Building wind and solar capacity, as well as long-distance transmission lines, to use the seasonal complementarity of the wind and sun is one such factor. Shaping demand to fit the availability of wind, sun, but also rainfall for hydropower, is another, as is using technology to improve efficiency.

"It's clear from the various studies it is absolutely feasible, at costs in line with recent years' energy costs," says Timmons. "But there are so many variables, it's hard to project how it will actually come together."

> *"There are so many variables, it's hard to project how it will come together"*
>
> **David Timmons**
> Ecological Economist, UMass Boston

70. 'Making clean electrification possible – 30 years to electrify the global economy', Energy Transitions Commission, April 2021.

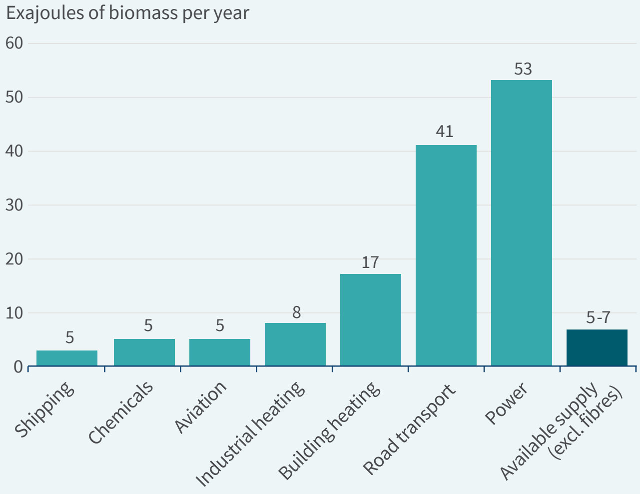
Other technologies to complement wind and solar

Nuclear fusion could be the answer to all our clean energy requirements, but humanity has yet to master it. Until then, wind and solar dominate, generally complemented by hydrogen, nuclear fission (henceforth referred to as 'nuclear'), biomass, and fossil fuels with CCUS to varying levels depending on the models.

Other technologies are sometimes mentioned, such as tidal or geothermal, but are not scalable due to unproven technologies and large externalities for the former and geological constraints for the latter. (Few countries other than Iceland can rely on geothermal for most of their energy needs.)[71]

Biomass features in many transition plans, but a 2021 report from consultancy Material Economics shows, when collating all current policy and corporate climate scenarios for the EU, aggregate demand for it will outstrip available supply by 40 to 70 per cent due to environmental and land-use constraints (Figure 19). Plans must be reviewed to reduce the reliance on future biomass, restricting it to the most productive uses, such as material uses in wood products, fibre and chemicals rather than energy.[72]

Figure 19. **Potential biomass demand per end-use in the EU**



Source: Material Economics, 2021.[73]

Mulley says hydropower is also geographically constrained in that most of the best sites are already in use, while the environmental damage stemming from flooding entire valleys makes new projects increasingly hard to justify – not counting the cost and time needed to build them. In a world with increasing water stress due to climate change, it also makes little sense; even existing hydro is becoming less reliable (see *What about water?*).

Nuclear is threatened by water stress too and by the time and budgets needed to build new plants, not to mention issues of waste management and the social licence to operate. In addition, Timmons says new nuclear is not a necessary part of the future energy mix.

"From my modelling, and from lots of other models in different countries, we don't need nuclear fission in the energy mix to make this work," he says. "We can do this on renewable sources alone."

He adds that, because nuclear plants are slow to power up and down, they are not a good fit to complement renewables at times of peak demand or reduced solar and wind availability.

However, Pravettoni says they could play in important role in countries like China, where new nuclear projects can come online at speed and in a cost-effective fashion. She also thinks that in any geography with existing nuclear, early exits could be cancelled or postponed. "Where we have it, we should absolutely be using it," she says.

Mulley adds certain countries may want to have some nuclear across the mix in terms of security of supply, even where it might not be the most cost-efficient power source.

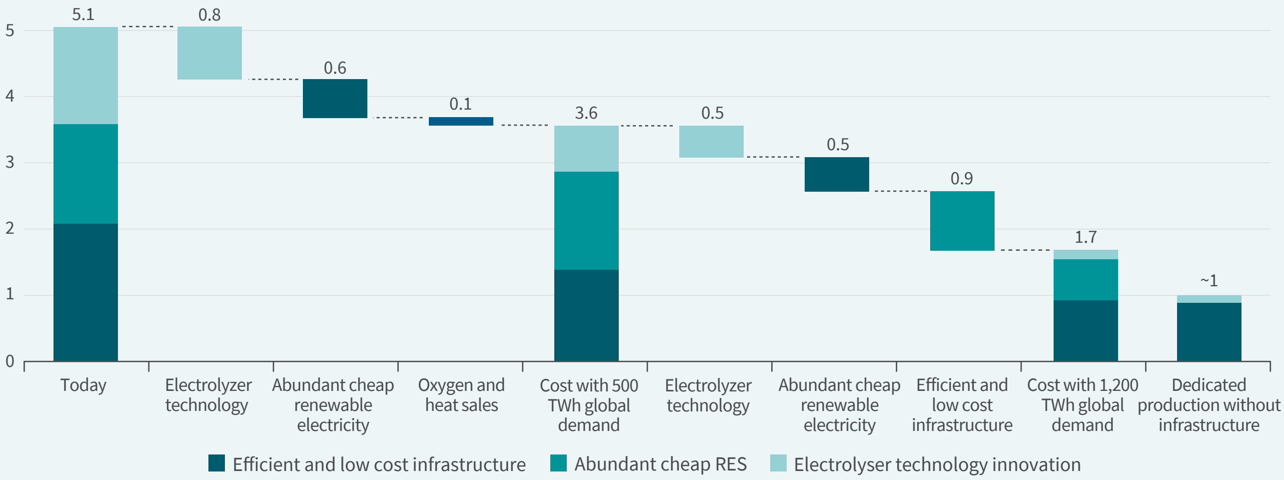
"If the state is willing to fund nuclear and pay a premium for that security of low-carbon generation, it makes sense," he says. "It's not necessarily cost-competitive, but an energy mix is not just a case of getting as much as possible at the lowest cost."

Murphy also notes small modular reactors (SMRs) are more flexible and cheaper to build.

71. David Timmons, et al., 'The economics of renewable energy', Global Development and Environment Institute, Tufts University, 2014.
72. 'EU biomass use in a net-zero economy - A course correction for EU biomass', Material Economics, 2021.
73. 'EU biomass use in a net-zero economy - A course correction for EU biomass', Material Economics, 2021.

Figure 20. **What is needed to get the cost of hydrogen below €2/kg**

Levelised cost of hydrogen production, EUR/kg of H2 delivered



Source: Material Economics, 2021.[74]

"In infrastructure circles, alongside talk about CCUS and hydrogen, we are hearing about SMRs as the future," he says.

In contrast, hydrogen is in the early stages of development, but experts believe it has a niche role to play. Its widespread use would have to include building distribution networks and redesigning engines, as well as using zero-carbon electricity to produce it in vast quantities. Economically, it therefore makes more sense to electrify the economy as much as possible.

"To make clean hydrogen, the main avenue is from renewable electricity through electrolysis, so the hydrogen necessarily ends up being more expensive as an energy source than the electricity was to start with," says Timmons. "But there are some sectors where we can't use batteries.

"Battery-powered aircraft will perhaps never cross the Atlantic, and hydrogen is one of the options. Even if we had to take perfectly good electricity and turn it into liquid hydrogen, it might end up being the least expensive solution as a zero-carbon aviation fuel," he adds.[75]

Hydrogen can also be a solution for heavy road transport and hard-to-abate industries like steel smelting, which requires very high temperatures that are hard to obtain through electric power.[76]

"The key thing to add here is cost," says Kevis. "There is commitment to hydrogen and significant investment set aside in European and US policies, but it's got to be done in the right manner and the costs still have to come down."

According to Material Economics research, costs could fall to low levels, though this would require electrolyser technology innovation, abundant and cheap renewable electricity, and efficient and low-cost infrastructure (Figure 20).

Similarly, CCUS might be used at the margin for hard-to-abate sectors, but the technology remains unproven at scale.

"I'm very sceptical that it will ever be less expensive to dig the carbon out of the ground as coal, burn it, and then put the carbon back into the ground than just using an alternative like solar panels," says Timmons. "My expectation is that hydrogen and CCUS wouldn't be large parts of the renewable energy future, though they might be significant for some of those hard to decarbonise sectors."

74. 'EU biomass use in a net-zero economy - A course correction for EU biomass', Material Economics, 2021.
75. Sylvia Pfeifer, 'Rolls-Royce tests hydrogen-fuelled aircraft engine in aviation world first', Financial Times, November 28, 2022.
76. 'The going gets tough: Can heavy industry decarbonise?', Aviva Investors, August 23, 2021.

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