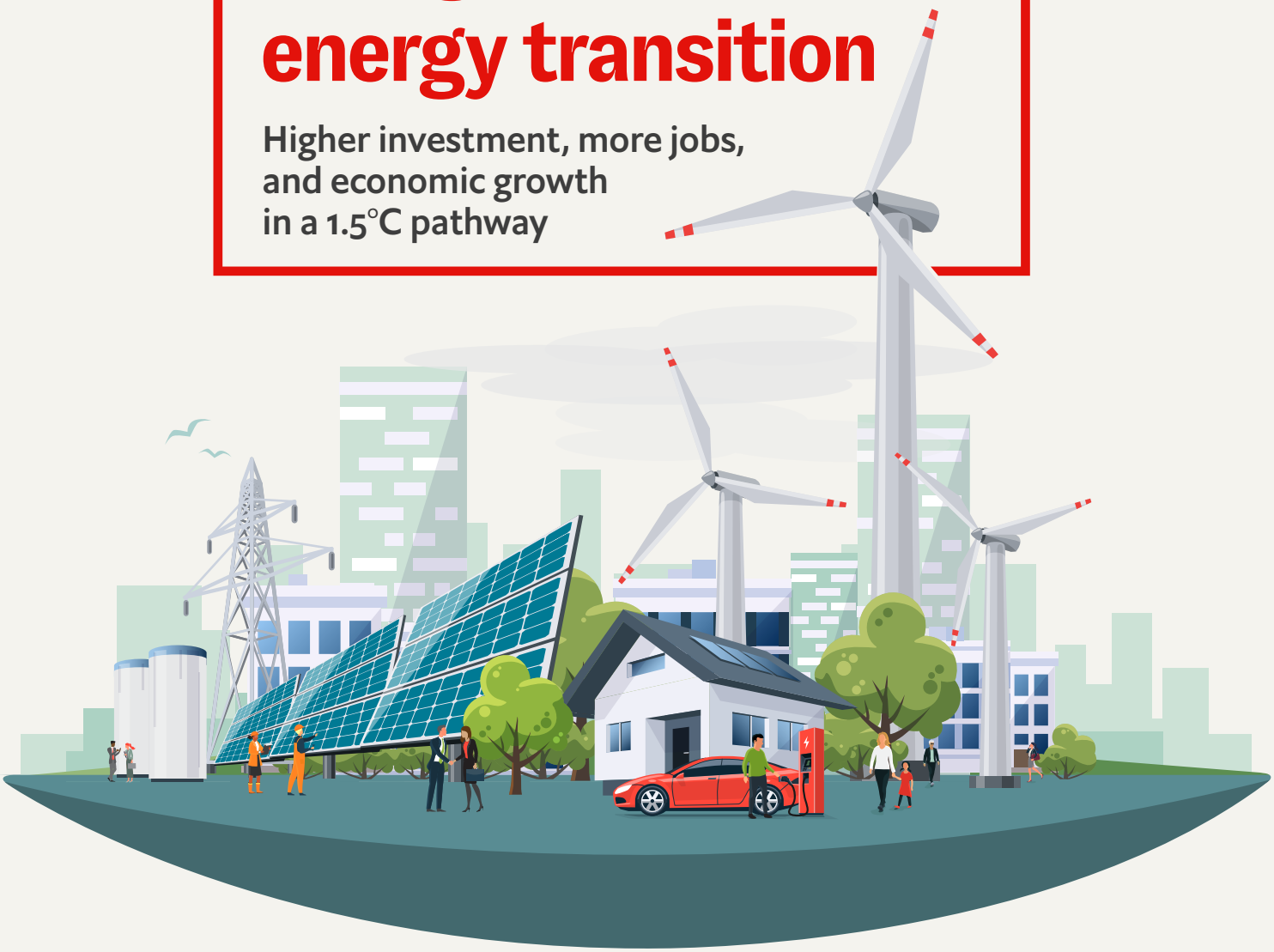
ECONOMIST IMPACT

Sizing the energy transition

Higher investment, more jobs, and economic growth in a 1.5°C pathway



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Foreword

As we look ahead to 2022 there is much to be optimistic about in this report from Economist Impact - a treasure trove of data points and supporting evidence highlighting the size of the economic opportunity from a 1.5 degree aligned clean energy transition. In just four sectors (clean power, green steel, electric vehicles and clean hydrogen), delivering net-zero commitments can support more than 20 million jobs and add more than 4% to global GDP by 2030. These are unprecedented opportunities for businesses and workers to benefit from clean energy technologies and markets.

As the COP26 Presidency, the UK Government has been highlighting the importance of international collaboration to accelerate and scale the benefits that this report makes so clear. Research has shown that costs will be lower and timelines faster if countries collaborate on the energy transition, which is why new global clean energy initiatives were launched at COP26, and existing ones strengthened. These will help unleash the benefits laid out in the pages ahead, for example – the Zero Emissions Vehicle Transition Council, The Global Energy Access Partnership for People and Planet, and the Green Grids Initiative - One Sun, One World, One Grid. Another, The Energy Transition Council, which the UK co-chairs, is already coordinating assistance to multiple developing countries, so that the commitments made at COP26 are implemented in this crucial decade of climate action. International collaboration is also key to ensuring these transitions are just and inclusive, so that no one is left behind.

As the UK continues to seek 1.5 degree aligned ambition in its Presidency year, now in partnership with Egypt which is taking on the COP27 Presidency, we look forward to doing even more to support global collaboration on the energy transition and reporting back on progress, in particular on the Breakthrough Agenda for faster climate action, agreed in Glasgow by 45 governments. The data in this report helps to highlight the Paris-aligned pathway we need to follow in order to achieve the Glasgow Breakthroughs in power, road transport, steel and hydrogen, and the size of the economic prize for all if we do. So, a big thank you and congratulations to the Economist Impact team. I encourage all readers of the report to use the findings to act and advocate for a deeper, just and more rapid clean energy transition.

The Rt Hon Alok Sharma MP
COP President
January 2022

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About the research

Sizing the energy transition is a research programme, conducted by Economist Impact and sponsored by the Climate Emergency Collaboration Group, studying the potential economic impacts to 2030 of energy transition pathways consistent with limiting global temperature rise to 1.5C. This report is the product of Economist Impact calculations and research which draw on existing projections from the IEA, the European Commission, the Net Zero Steel Project and others to determine sector-level impacts across major economies.

We would like to extend our thanks to all those colleagues who provided advice and review, particularly Dan Hamza-Goodacre and Stephen Devlin at the UK Department of Business, Energy & Industrial Strategy.

The report was produced by a team of in-house researchers, writers, editors and designers, including:

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Executive summary

As countries look beyond the pledges made at COP26 in Glasgow to commit to urgent global climate action and build back better, the size of the economic opportunity posed by the clean energy transition is becoming clearer.

All 197 UNFCCC members (including 192 states) have pledged to pursue efforts towards limiting global temperature rise to 1.5°C above preindustrial levels, the hallmark of the 2015 Paris Agreement. Energy (including industry, buildings, transport and electricity) accounts for around three-quarters of global greenhouse gas emissions, meaning that international actions to keep the 1.5°C target alive have the potential to drive a clean energy transition that is unprecedented in scale and opportunity.[1]

Economist Impact calculates that 1.5°C-compatible investments into sectors including clean power generation, electricity grids, electrified road transport, green steelmaking and clean hydrogen could support more than 20 million jobs and add more than 4% to global GDP by 2030. The markets expected to grow the quickest and attract the most investment are those with clear, ambitious and supportive policies.

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Government-backed collaborations such as the Energy Transition Council, Powering Past Coal Alliance, Green Grids Initiative, One Sun One World One Grid and the Zero Emissions Vehicle Transition Council are co-creating transformative solutions, agreeing shared targets and facilitating the global transfer of technology and knowledge. Such groupings are critical, as the International Energy Agency (IEA) found that the transition to net-zero could be delayed by decades without international collaboration.

[1] According to climatewatchdata.org data.

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By aligning global efforts, we can quickly cross tipping points where clean solutions become the most affordable, accessible and attractive options in each greenhouse-gas emitting sector of the global economy—helping to meet the UN Sustainable Development Goals, as well as avoiding catastrophic climate change.

The good news is that feasible pathways with a high probability of staying within 1.5°C have been fleshed out. Ambitious global action to achieve net-zero emissions as outlined by the IEA's "Net-Zero Emissions by 2050 scenario" (NZE) could put the world on a trajectory to 1.5°C as identified by the International Panel on Climate Change (IPCC)—namely, to decrease net anthropogenic carbon dioxide (CO_2) emissions[2] by about 45% from 2010 levels by 2030, and to reach net-zero by around 2050.[3,4] Proliferating national and multinational commitments to achieve net-zero emissions by 2050 across sectors, countries and the global economy are broadly consistent with these 1.5°C pathways, but mean acting together and acting now.

Measures to achieve net-zero are not without significant challenges, but the perceived dichotomy between protecting either the economy or the climate is a false one. On one hand, the real economic costs of inaction and delay are enormous—The Economist Intelligence Unit estimates that global GDP could be 3% smaller by 2050 due to the impacts of climate change.[5] On the other hand, realising the massive investments necessary to transition to a cleaner economy also portend significant economic benefits.

While such benefits are uneven both within and across national economies, countries committed to a 1.5°C-compatible trajectory will not only see net gains in terms of jobs and economic growth, but will also participate in global technological and infrastructure shifts that risk leaving the less ambitious behind.

[2] In this report, the terms of "anthropogenic CO_2 emissions", "CO_2 emissions", and "emissions" (unless specified otherwise) are used interchangeably.

[3] IEA (2021a), "Net Zero by 2050 A Roadmap for the Global Energy Sector". Available at: https://www.iea.org/reports/net-zero-by-2050

[4] IPCC (2018), "Special Report on Global Warming of 1.5°C". Available at: https://www.ipcc.ch/2018/10/08/summary-for-policymakers-of-ipcc-special-report-on-global-warming-of-1-5c-approved-by-governments/

[5] The Economist Intelligence Unit (2019), "Resilience to climate change? A new index shows why developing countries will be most affected by 2050". Available at: https://www.eiu.com/public/topical_report.aspx?campaignid=climatechange2019

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Introduction

Sizing the economic impacts of energy transition investments

The benefits of energy transition investments are myriad in a cleaner economy, which, under the IEA's NZE scenario (consistent with limiting the temperature rise to 1.5°C), continue to grow at a healthy clip. In 2030 the global economy will be some 40% larger than today, while using 7% less energy; meanwhile, job creation and investments translate to a 4% net addition to global GDP by the end of the decade.[6,7]

In 2030 the global economy will be some 40% larger than today, while using 7% less energy; meanwhile, job creation and investments translate to a 4% net addition to global GDP by the end of the decade.

According to the IMF, by boosting demand and increasing productivity in low-carbon private sectors, green public policies suggested by the NZE (ie, public spending to support the expansion of clean energy) could raise net employment by nearly 1% by 2030.[8] That equates to nearly 30 million new jobs.[9,10]

New and protected direct and indirect jobs are those in the energy sector itself, as well as employment resulting from knock-on effects throughout the economy, such as increased spending on intermediate goods and services. GDP is also bolstered through exporting advanced technologies, systems, energy and consumer products, particularly among countries with major energy and manufacturing export capacities such as China, France, Germany, Japan, the UK and the US.

For example, in the case of solar photovoltaic (PV) energy, sector expansion boosts local employment for installation and maintenance as well as among major manufacturers like

6 IEA (2021a)

7 Economist Impact estimates use Economist Intelligence Unit data suggesting 52% growth in 2030.

8 IMF (2021), "Reaching net zero emissions". Available at: https://www.imf.org/external/np/g20/pdf/2021/062221.pdf

9 References in this paper to "additional jobs" or "new jobs" refer to total new job-years created rather than net employment effects.

10 While the analysis of this report is limited to four key sectors (power, road transport, steel and hydrogen) IEA's NZE considers the job creation in major industrial sectors, the building sector, and all power and transport sectors.

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China (which accounted for 71% of solar PV module production in 2019). Indeed, net-zero pathways see major employment gains from wind and solar, where generation capacity increases more than sevenfold by 2030. Not only do these sectors produce more jobs per dollar of investment or per megawatt installed, but the jobs are also good ones. Two-thirds of such workers are highly skilled, requiring substantial training and commensurate salaries.[11]

New jobs by 2030 in advanced vehicle technologies and green steel are created largely within existing companies, but start-ups threaten incumbents that are slow to change, and those jobs are supplemented by new supporting industries for charging infrastructure, batteries, ICT systems, iron transformation, and clean energy inputs. Employment in the clean hydrogen sector is created in production, storage, transport and end-uses, as well as in producing energy inputs.[12]

Amid such change, there will be losers. Governments that depend on rents from hydrocarbon extraction or consumption will see revenue shrink. Jobs that rely on servicing traditional technologies such as internal combustion engines (ICEs) will be less secure. And fossil fuel industries, starting with coal companies, will decline.

Indeed, under the NZE, almost 4.3 million jobs in the fossil fuel sector would be at risk globally as a result of the energy transition.[13] In many cases, existing professional skillsets can be transferred across industries, but a successful and just energy transition will require intensive vocational training and upskilling of vulnerable workers. Skill mismatches and geographic differences mean that social safety nets and direct fiscal support are critical elements to mitigating the impacts on at-risk communities.[14]

By boosting demand and increasing productivity in low-carbon private sectors, green public policies suggested by the NZE could raise net employment by nearly 1% by 2030, equivalent to nearly 30 million new jobs.

[11] IEA (2021a)
[12] Economist Impact estimates do not count energy inputs.
[13] IEA (2021a)
[14] Ibid

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Even after accounting for the need to protect vulnerable communities and ensure a just transition to a clean economy, the investment needed to implement such sweeping change yields overwhelming economic benefits in aggregate, not just by limiting the costly impacts of climate change itself, but also in the relatively short term to 2030.

The sheer scale of capital reallocation associated with mitigating climate change and transforming the energy sector represents "the biggest economic transformation since the industrial revolution" as described by US special presidential envoy for climate John Kerry.[15]

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Energy transition economics to 2030: An Economist Impact analysis

This paper assesses the economic impacts in ten specific focus countries across four key sectors resulting from action that must be taken in the 2020s to remain consistent with net-zero targets and the 1.5°C limit.

To remain aligned with such a trajectory, investment must focus on industries that will most affect emissions, starting with the energy sector. The **power sector** is by far the largest CO_2 emitter, and also among the lower-hanging fruit.[16,17] Achieving very high shares of zero-emission generation is possible with existing technologies, requiring massive deployment of variable wind and solar PV generation as well as dispatchable sources such as hydroelectric and nuclear power. Intermittent generation also requires enabling investments and technologies to enhance grid flexibility, including efforts to scale up **clean hydrogen** technologies for energy storage, in addition to direct use in transport and industry.[18]

Indeed, wholesale transformation is also necessary on the power demand side. The **electrification of road transport** is necessary to eliminate the sector's CO_2 emissions, which in 2018 accounted for 18% of global fossil-fuel carbon emissions,[19] with a particular emphasis on proliferating EVs for light duty vehicles (LDVs). The tougher challenge will be transforming hard-to-abate industrial sectors such as **steelmaking** with new low-carbon production methods and technologies (eg, green steel), which are still nascent or costly.

The power, road transport and steel sectors contributed about two-thirds of global CO_2 emissions in 2020,[20] while clean hydrogen acts as an enabling technology that can improve performance across all three.

[15] La Repubblica (2021), "John Kerry: 'The world is at a turning point for a cleaner future'". Available at: https://www.repubblica.it/esteri/2021/07/22/news/climate_interview_kerry-311213656/

[16] IEA (2019a), "World Energy Outlook 2019". Available at: https://www.iea.org/reports/world-energy-outlook-2019

[17] According to IEA (2021a), combustion activities (ie, energy-related activities, such as those from the power sector and final consumption categories including transport-related and industrial) account for nearly 95% of total global CO_2 emissions.

[18] IEA (2019b), "The Future of Hydrogen". Available at: https://www.iea.org/reports/the-future-of-hydrogen

[19] IEA (2019a)

[20] Economist Impact estimates based on IEA (2021a) and IEA (2019a).

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Research methodology

This paper conducts a meta-analysis by systematically synthesising and/or merging the results of existing projections and scenarios that are consistent with net-zero development pathways, to better understand the economic impacts to 2030 that stem from transforming four target sectors that are critical to mitigating global climate change.

For each sector, the analysis explores needed investment, expected market growth, and subsequent employment creation and GDP expansion. A special focus is placed on the G7 advanced industrialised economies (Canada, France, Germany, Italy, Japan, the UK and the US), plus three major emerging markets (China, India and South Africa). Together, these ten countries account for almost two-thirds of global emissions, with the US, China and India responsible for over half.[21]

As a primary reference, this paper remains consistent where possible with the IEA's NZE scenario.[22] However, it also draws on a variety of sectoral and country-level scenario modelling exercises, while attempting to adjust for consistency across countries and sectors.

Our data analysis draws primarily from IEA projections for clean power and road transport; from the Net Zero Steel Project for low-carbon steel; and from the EU Fuel Cell and Hydrogen 2 Joint Undertaking (FCH 2 JU), the Hydrogen Council, and national government sources and announcements for clean hydrogen.

Limitations

Because our estimations are based on sector-specific investment requirements implied by existing sources, and employ job multipliers derived from the literature, they are limited in their reflection of unique national circumstances or dynamic economic relationships. They also describe total gains rather than net gains; we do not attempt to estimate concurrent sectoral losses, or the complex relationships between these sectors and possible job losses or investment declines in other parts of the economy. Any references to additional jobs or employment refer to total jobs added or saved. Estimates are also limited in their accounting of trade, and generally assume demand to be met with domestic supply. As a result, any original economic estimates contained herein should be understood as indicative figures that convey potential gains rather than projections based on current policy, capital stock, or sector trajectories. Lastly, the indicators analysed in this work do not aim to account for the indirect (and substantial) social, environmental and economic benefits of averting climate impacts.[23]

[21] IEA (2019a)

[22] Our paper recognises that the strategies for economic transformation under the IEA's Sustainable Development Scenario (SDS) and NZE pathways (which in some cases yield a "well-below" 2°C or 1.7°C long-term temperature rise) broadly overlap in the near-term to 2030, with the most significant deviations stemming from uncertainties in the 2030-50 and post-2050 periods.

[23] Previous Economist Intelligence Unit research in 2019 studied the economic impacts of unabated climate change effects, and can be accessed here: https://www.eiu.com/n/global-economy-will-be-3-percent-smaller-by-2050-due-to-lack-of-climate-resilience/

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Power: The largest low-hanging fruit

Achieving a net-zero emissions economy will require major electrification, contributing to a 40% increase in global power demand by 2030.[24] In major emerging markets it grows even faster—China and India account for 50% of global demand growth in the next decade, jumping 52% and 100% respectively under the NZE scenario. At the same time, today's power sector is the source of over a third of global emissions.[25] As such, the electricity sector is the prime locus for achieving deep decarbonisation of the economy and, fortunately, is also where this is feasible using existing technology.

With power demand increasing on the back of growth in emerging economies, and with ageing plants reaching their operational limits in advanced economies, a tremendous opportunity exists for drastically changing the global power generation mix. Ever-cheaper new renewable energy will undercut regular operational costs at existing fossil fuel plants in more and more cases, potentially stranding major generation assets. The breath-taking cost declines of renewable, especially solar, power give electricity the edge in achieving net-zero, and drive a sevenfold increase in installed solar

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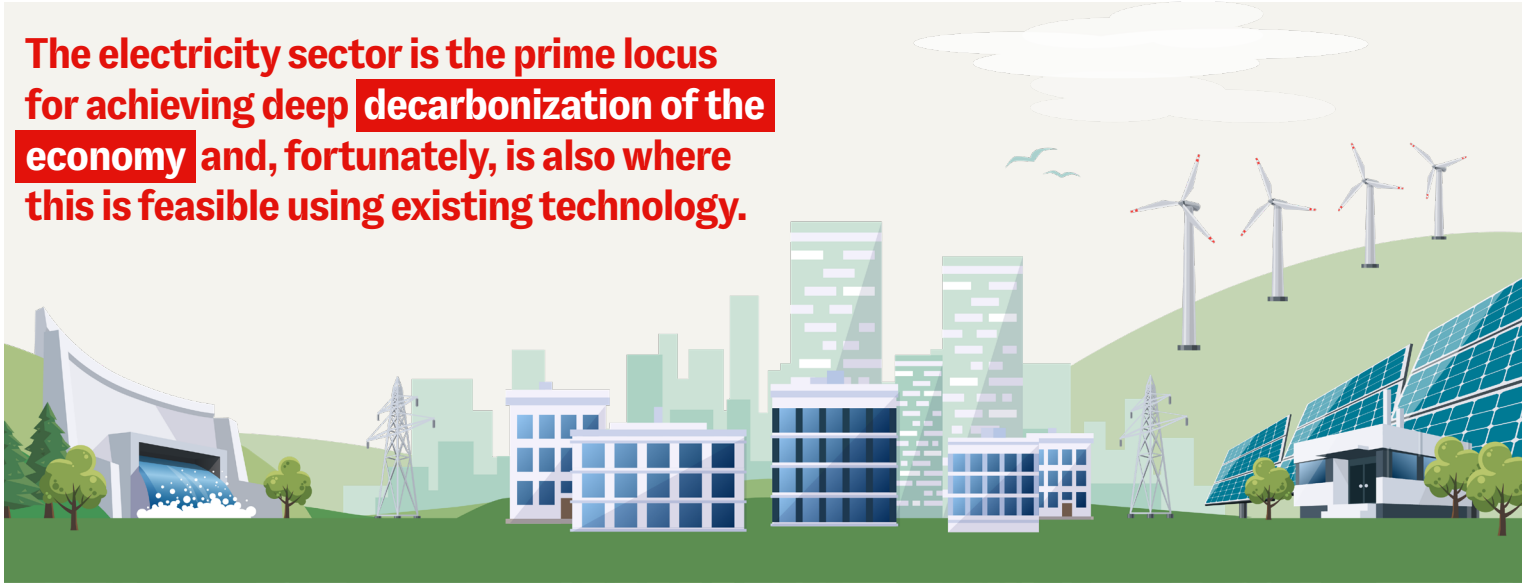

[24] IEA (2021a)
[25] Ibid

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PV and wind capacity by 2030 under the NZE. Such growth in variable power generation should be complemented with dispatchable clean energy sources such as hydropower and nuclear, and necessitates concurrent investments in power grid flexibility. Annual grid investments in storage, transmission and digitalisation are especially marked to 2030 because they lay the groundwork for integrating clean generation.

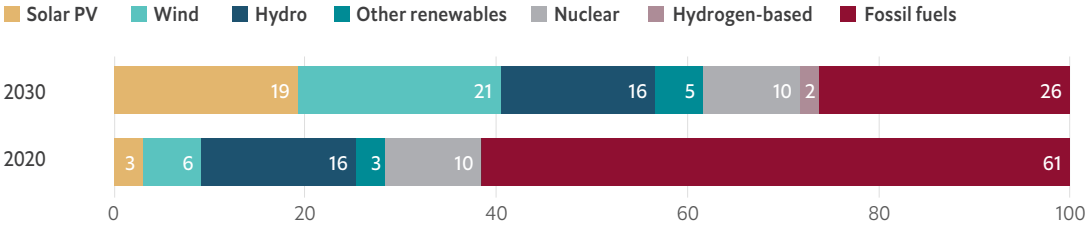
Investment, jobs and growth in a 1.5°C-compatible power sector

The renewable industry is already the major employer in the power sector, and will grow to represent about 60% of energy-related employment by 2030. In 2020 the renewable-energy value chain totalled 12 million jobs globally, with solar PV and wind power accounting for about 5.3 million jobs.[26] Most of the new renewable energy jobs will be created in emerging economies, which produce and deploy the vast number of solar PV modules and wind turbines needed to enable the global energy transition.

Under the IEA's NZE, capital investment in energy rises from 1.8% of GDP in recent years to 2.7% by 2030. By that year, global annual energy investments will jump to US$5trn, with about half in the electricity sector. The share of clean energy (ie, non-fossil fuel based) in the global power system rises from 39% in 2020 to more than 71% in 2030. Renewable energy will account for most of this growth, rising from about 29% in 2020 to 61% in 2030. Solar PV and wind together surge to 40% by the end of the decade.[27] Hydropower and nuclear also play an important role and provide an essential foundation for the energy transition, but their share in total power supply remains mostly stable, at 16% and 10% respectively (Figure 1). Still, keeping up with demand means growing their combined installed generation by 40%.

Figure 1. Power generation by energy type, worldwide, 2020 vs. 2030 (NZE)

%



Source: IEA (2021a).

[26] IRENA (2021), "Renewable Energy and Jobs – Annual Review 2021". Available at: https://irena.org/publications/2021/Oct/Renewable-Energy-and-Jobs-Annual-Review-2021

[27] Economist Impact estimates based on IEA (2021a).

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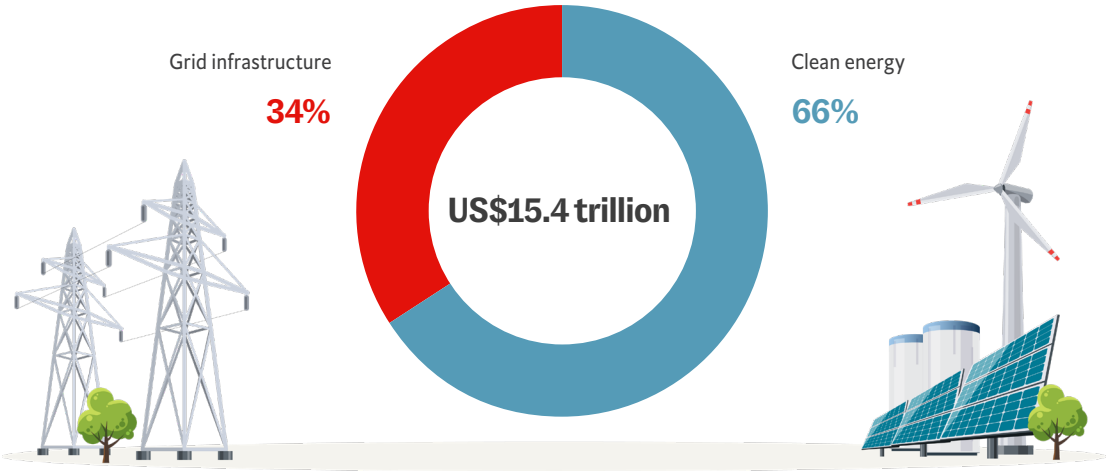
As sources of power generation become less emissions-intensive, the concurrent effects on employment are significant. Renewable energy employs more people than fossil fuels do, both per unit of investment and per unit of generated electricity. An input-output analysis found that, on average, spending US$1m on renewables creates 7.5 full-time equivalent (FTE) jobs, almost threefold the 2.7 FTE jobs in fossil fuels.[28] In the US, every US$1m spent on clean energy generates more than twice as many jobs as the same amount spent on fossil fuels in the short to medium term.[29] On top of that, a US study found that hourly wages in clean energy production and energy efficiency far surpass average wages across the whole economy,[30] if still marginally less on average than wages in the fossil fuel sector.[31]

Yet not all clean energy sources, or even renewables, are equal when it comes to employment effects. New renewable energy sources, like solar and wind, generate more jobs than well-established ones. For instance, the hydropower sector, despite being the largest source of renewable electricity in the world (accounting for 44.6% of total capacity in 2019), employs about half as many people as the solar sector.[32,33]

More than a third of clean power investments will go to electricity networks rather than panels or turbines, with annual investments in enabling grid infrastructure technologies more than tripling to US$822bn in 2030. Two-thirds of network investments will take place in developing economies.[34] On a cumulative basis to 2030, we calculate that US$15.4trn will be needed in clean energy investments, of which US$5.2trn goes to grids and networks (Figure 2) and underpins up to 5 million jobs globally.

Figure 2. Cumulative investments in clean power by 2030, worldwide



Source: Economist Impact estimates.

[28] Garrett-Peltier (2017), "Green versus brown: Comparing the employment impacts of energy efficiency, renewable energy, and fossil fuels using an input-output mode". Available at: https://www.sciencedirect.com/science/article/abs/pii/S026499931630709X

[29] Climate Analytics, World Resources Institute (2021), "Closing the gap: the impact of G20 climate commitments on limiting global temperature rise to 1.5°C". Available at: https://www.wri.org/research/closing-the-gap-g20-climate-commitments-limiting-global-temperature-rise

[30] Muro et al. (2019), "Advancing inclusion through clean energy jobs". Available at: https://www.brookings.edu/research/advancing-inclusion-through-clean-energy-jobs/

[31] Saha and Jaeger (2020), "America's New Climate Economy: A Comprehensive Guide to the Economic Benefits of Climate Policy in the United States". Available at: https://files.wri.org/d8/s3fs-public/americas-new-climate-economy.pdf

[32] IRENA (2020), "Renewable Energy and Jobs – Annual Review 2020". Available at: https://www.irena.org/-/media/files/IRENA/Agency/Publication/2020/Sep/IRENA_RE_Jobs_2020.pdf

[33] IRENA (2021)

[34] IEA (2021a)

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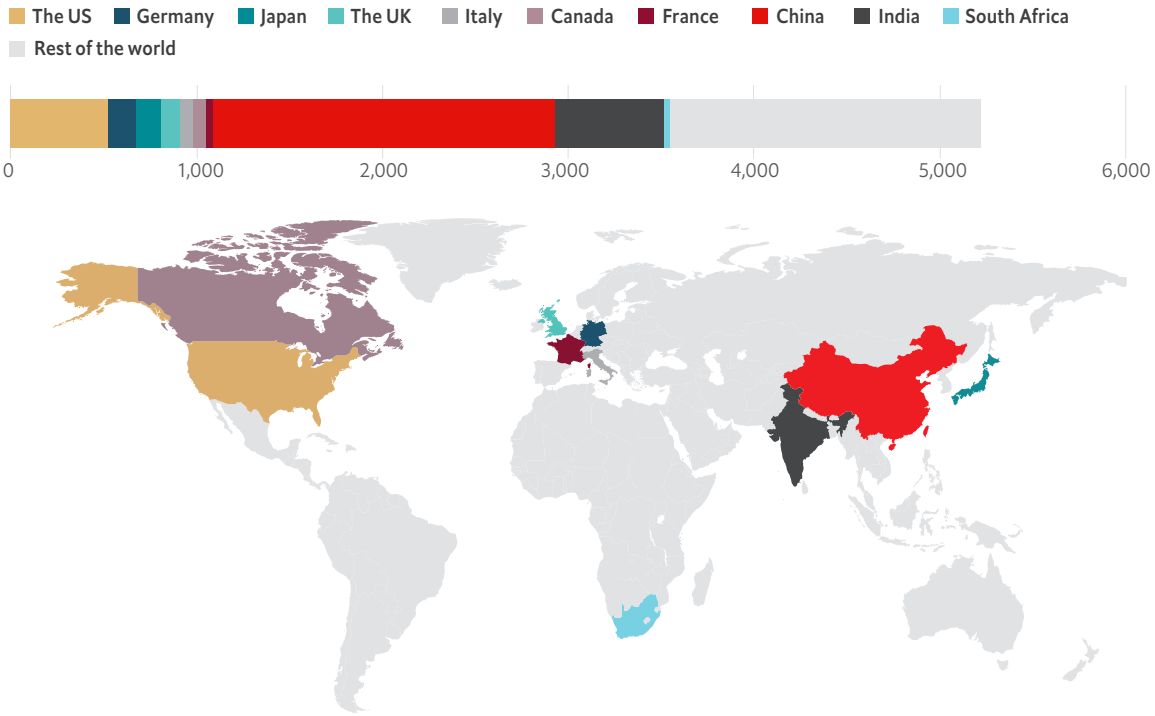
Regional gains from clean power investments

When it comes to employment and growth, the gains from electricity sector investment accrue both to advanced G7 economies, where infrastructure upgrades are needed to accommodate new resources and enable new business models, and emerging economies where demand growth necessitates capacity additions as well as access to renewable resources (Figure 3).

In the US, Economist Impact calculates that putting the power sector on to a net-zero trajectory represents US$1.5trn in cumulative investment to 2030, with significant investments in clean energy generation and transmission to create a more integrated, smart and flexible grid. These investments are expected to be kick-started with federal funding through existing programmes as well as new spending from the Infrastructure Investment and Jobs Act (signed into law by president Joe Biden on November 15th 2021),[35] but will require permitting and regulatory streamlining to deliver such ambitious build-out so quickly. If they materialise, by 2030 the US could lead in solar PV investments among advanced economies, complementing the EU's leadership in wind investments (especially offshore).[36]

Figure 3. Cumulative investments in grid infrastructure by 2030, by country

US$, millions



Source: IEA, with Economist Impact estimates by country.

[35] Reuters (2021), "U.S. Democrats pass $1 trillion infrastructure bill, ending daylong standoff. Available at: https://www.reuters.com/world/us/bidens-sweeping-infrastructure-social-spending-bills-finally-get-vote-2021-11-05/

[36] IEA (2019a)

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The UK government expects offshore wind to create 60,000 jobs by 2030,[37] while the National Grid projects that the UK's energy sector will need to recruit more than 117,000 people in direct employment, including in areas such as data analytics and engineers with renewables expertise.[38] Smart systems technologies, including energy storage and demand-side response, will be critical to integrating renewables into the system, and as a result network investment in this decade could reach US$97bn (more than £71bn). Based on IEA figures and including indirect employment, we estimate that investment into the British clean energy sector could help create up to 500,000 direct and indirect jobs and add 2.8% to GDP by 2030.

In 2030 the EU and the UK together will lead with the highest combined shares of clean energy generation, jumping from today's 59% to over 96%.

European clean energy investments create jobs in similar sectors, as France pursues a carbon-free energy system by 2050 and Germany aims to build a flexible grid to connect northern renewable resources with southern demand centres. The EU stands to gain around 1.7 million jobs across clean energy and power grids, where 1.5°C-compatible power sector investments can add around 2% to German and Italian GDP over a decade. In 2030 the EU and the UK together will lead with the highest combined shares of clean energy generation, jumping from today's 59% to over 96%.[39]

Clean Energy Canada projects the country's clean energy sector to grow by an impressive 58% to 2030, reaching $107.4bn, at which point it will make up 29% of Canada's total energy GDP (up from 22% in 2020).[40] Canada's "New Climate Plan", which is consistent with its net-zero ambition, projects that by 2030 some 111,100 new clean energy jobs will be created. The Economist Intelligence Unit calculates that almost 190,000 direct and indirect jobs could result. Over $69bn of investment will be required in the power grid, in part to connect renewable energy resources in central and northern Canada to southern and coastal cities, creating almost 30,000 direct jobs (and some 68,000 in total).

When it comes to clean power, arguably the greatest economic impacts are concentrated in Asia. In China and India, the share of renewable energy generation will expand rapidly to reach about two-thirds by 2030 (from less than a third today). China remains the world's largest energy consumer, with India the largest source of electricity demand growth.[41]

Under IEA projections, consistent with China's net zero commitment to 2060, annual energy sector investment in 2030 reaches US$640bn.[42] We calculate cumulative power network investments in this decade to top US$1.8trn to build new lines and storage, as well as to retool fossil fuel plants to serve as back-up generators. Seven new long-distance high-voltage lines will be constructed over the next five years to connect western regions (where hydro, wind and solar are plentiful) to population centres in the east. By 2030 six to eight more lines could be needed to develop

[37] GIR (2020), "The Ten Point Plan for a Green Industrial Revolution Building back better, supporting green jobs, and accelerating our path to net zero". Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/936567/10_POINT_PLAN_BOOKLET.pdf

[38] National Grid (2020), "Building the Net Zero Energy Workforce". Available at: https://www.nationalgrid.com/stories/journey-to-net-zero/net-zero-energy-workforce

[39] Economist Impact estimates based on IEA (2019a), IEA (2021a) and IFRI Centre for Energy (2017), "Landscape of Renewable Energies in Europe in 2030". Available at: https://www.ifri.org/sites/default/files/atoms/files/the_landscape_of_renewable_energies_in_europe_in_2030.pdf)

[40] Clean Energy Canada (2021), "The future of Canadian energy looks bright, with clean energy job growth projected to outpace losses in fossil fuels amid a shifting global landscape". Available at: https://cleanenergycanada.org/wp-content/uploads/2021/06/Report_CEC_CleanJobs2021.pdf

[41] Economist Impact estimates based on IEA (2019a) and IEA (2021a).

[42] IEA (2021c), "An Energy Sector Roadmap to Carbon Neutrality in China". Available at: https://www.iea.org/reports/an-energy-sector-roadmap-to-carbon-neutrality-in-china

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"renewable energy bases" on which its net-zero plans are based. China will also benefit from a continued expansion of nuclear power in the next decade, following the resumption of approvals in 2019, and could build as many as 6-8 reactors per year.[43] This would lead China to surpass France's installed capacity in 2022 and America's in 2026, with each new reactor creating about 50,000 jobs.

In China's clean energy generation, we estimate that 3.6 million total direct and indirect jobs could be added by 2030. Large increases in renewable power are driven by their cost advantage over other technologies and policy support, including power market and carbon price signals, to reach around 60% of total generation in 2030. The recent switch to renewable auctions in China is expected to further drive down prices with improved design and operation. As a result, cumulative GDP additions by 2030 could reach over 5.8%.

As of 2020 Japan's cumulative solar PV capacity was the third largest after China and the US.[44] Because of the scarcity of suitable land in Japan, most of this growth came amid a shift from large-scale solar to rooftop assemblies.[45] Achieving its 2030 net-zero compliant non-fossil energy targets (60% of the power mix) will not be easy. Unlike many other countries, Japan does not have an abundance of renewable energy resources, and its high population density, mountainous terrain and steep shorelines represent serious barriers to scaling up the ones it does have. Nonetheless, we estimate that an ambitious net-zero compliant clean energy investment programme could imply over US$250bn in cumulative clean power investments by 2030, plus US$130bn for power grid and flexibility upgrades.

In Africa, rapid economic growth in this decade will require major investments and capacity additions to meet rising demand for power.

When it comes to clean power, arguably the greatest economic impacts are concentrated in Asia. In China and India, the share of renewable energy generation will expand rapidly to reach about two-thirds by 2030 (from less than a third today).

[43] Reuters (2020), "China to build 6-8 nuclear reactors a year from 2020-2025". Available at: https://www.reuters.com/article/china-nuclearpower-idINKBN24A0DL
[44] IRENA (2021)
[45] IRENA (2020)

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Population growth, changing lifestyles and the need for reliable modern energy access will double demand across the continent, and power demand multiplies at least threefold under a net-zero compatible scenario. Renewable energy will be key. Based on IEA's "Sustainable Development Scenario" projections, we estimate that in South Africa alone renewable generation grows from 8 GW in 2018 to nearly 60 GW in 2030, a significant increase with the potential to add 88,000 jobs across both clean generation and power networks.

Opportunities and challenges in clean power

In its size and contribution to emissions, the power sector presents arguably the greatest economic opportunity and challenge for limiting global temperature rise. The financial savings and additional profits pose significant opportunities, while the uneven distribution of costs within and between countries poses a major challenge.

Energy efficiency: Reducing power intensity and creating economic value

Although we do not explicitly estimate the value of **energy efficiency** in this paper, the sector will play a major role in emissions reductions, and will also create significant employment opportunities across both the appliances and building sectors. Due to its cost-effectiveness, employment effects and attractive payback, energy efficiency is the "clean technology" of choice for stimulating the economy in a 1.5°C-compatible transition.

Global spending on energy efficiency nearly doubles by 2030 under net zero scenarios, with almost half allocated to reducing wasteful consumption in buildings (resulting in 40% less emissions in building energy by 2030).[48]

Box 1: Key supporting actions to decarbonize the power sector[46]

- Commitment to 2030 unabated coal phase-out in OECD countries; commitment to halt new coal projects in emerging economies (especially China and India) with targeted financial support from developed countries for early coal retirement (eg, in India)[47]
- Immediate commitments by financial institutions not to finance new coal power plants, new coal mines or coal mine extensions, and to cease financing companies in coal mining during the 2020s
- Government-set quantitative targets for growth of zero-carbon generation and reduction of grid carbon intensity; corporate commitments to increased procurement of renewables (for example, through RE100)
- Introducing and extending effective carbon pricing
- Immediate end to fossil fuel subsidies

[46] Energy Transitions Commission (2021), "Keeping 1.5°C Alive: Closing the Gap in the 2020s". Available at: https://www.energy-transitions.org/publications/keeping-1-5-alive/#download-form

[47] The COP26 Coal to Clean Power Transition statement (signed by several countries including Canada, France, Germany and the UK) commits to transition away from unabated coal power generation in the 2030s (or as soon as possible thereafter) for major economies and in the 2040s (or as soon as possible thereafter) globally.

[48] IEA (2021a)

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However, energy efficient white goods and consumer products for cooling, lighting, washing and cooking play a significant role as well. In both developed and developing markets, appliance replacements in the next decade will on average be more energy efficient due to strengthened performance standards and labelling, and also because efficient appliances are often price-competitive with alternatives.

Under the NZE scenario, energy efficiency delivers the second-largest contribution to bringing down CO_2 emissions by 2030, after variable renewables like solar PV and wind. The fast deployment of efficient technologies results in the primary energy intensity of global GDP improving by an average of 4% through 2030, or about three times the average pace of improvement over the past two decades. The IEA projects global investment in efficiency in end-use sectors to be about US$1trn per year between 2020 and 2030, contributing to a fall in global energy demand by about 7% from 2020 levels.[49]

Under the NZE scenario, energy efficiency delivers the second-largest contribution to bringing down CO_2 emissions by 2030, after variable renewables like solar PV and wind.

Efforts to reduce energy use in buildings, cities and transport are also labour intensive, meaning that energy efficiency can be one of the largest employers in the energy sector. As much as 60% of expenditure on home energy efficiency retrofits could go towards labour, activating local value chains and boosting the economy.[50] Meanwhile, the need to reduce energy usage in heating, ventilation and air conditioning (HVAC) systems and household appliances can mean significant additional investment and job creation in the manufacturing sector.

While estimates vary due to differing definitions of energy efficiency jobs, in 2019 they included about 2.5 million jobs in the US, 1-3 million in Europe, 730,000 in China and 472,000 in Canada.[51]

Because of high labour intensity, energy efficiency investments can generate 6-15 jobs for every US$1m spent, depending on the sector, compared with 1-5 jobs for power grids and less than two jobs for hydro-electric, nuclear or wind projects. Due to the possibility for quick mobilisation, they are one of the most attractive investments in the energy sector for governments seeking to protect existing jobs or generate new jobs. Globally, the NZE projects 5.9 million new energy efficiency jobs in 2030—more than the gains from new power grids.[52]

In Europe, the updated EU Directive on Energy Efficiency, which forms part of the package of proposals for delivering on the European Green Deal, lays out plans to achieve the goal of 32.5% reduced energy use by 2030. That includes a new framework for heating and cooling, which accounts for 80% of energy use in buildings. In

[49] IEA (2021a)

[50] SAEI (2011), "Economic Analysis of Residential and Small-Business Energy Efficiency Improvements". Available at:https://www.seai.ie/publications/Economic-Analysis-of-Residential-and-Small-Business-Energy-Efficiency-Improvements.pdf

[51] Sources as cited by the IEA: NASEO and EFI (2020), The 2020 U.S. Energy & Employment Report; Wang Qingyi (2019), 2019 Energy Statistics; BPIE (Unpublished), Working Paper: Examining the impact of Covid-19 on building efficiency employment in Europe; ECO Canada (2019), Energy Efficiency Employment in Canada; EEC (2019).

[52] IEA (2021a)

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the US, the government has announced plans to develop new performance standards for federal buildings and to establish new Energy Star standards. In China, a reorientation of the economy towards services, combined with tighter efficiency regulations, helped to slow energy demand growth in recent years, and reducing energy intensity has been a consistent target in past five-year plans. Under the IEA's carbon neutral pathway for China, energy consumption in buildings falls 1.4% per year to 2030 from gains in heating, cooking and electrification. In developing countries, where energy demand growth is highest and energy efficiency tends to be lower, improving efficiency can be a critical tool for financial viability and energy security.

Box 2: Key supporting actions to improve energy efficiency[53]

- Regulatory actions to "raise the floor" of efficiency of new equipment and construction
- Market priming to pave the way for new technologies and thereby "raise the ceiling" of the market
- Strengthen appliance performance standards and labelling
- Integrated planning to prioritise energy efficiency in national economic and environmental policies

[53] USAID (2020), "Scaling Up Energy Efficiency in Developing Countries". Available at: https://pdf.usaid.gov/pdf_docs/PA00X3PS.pdf

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Hard as steel: Greening the sector

Steel is a critical component of modern development, a key material for construction and manufacturing, and a major input into future technologies of the low-carbon economy like wind turbines, rails, building retrofits and energy-efficient appliances. The direct effects of steel production globally amount to US$500bn in added value, and more than 6 million jobs around the world. Counting effects throughout the steel supply chain adds an additional US$1.2trn in added value and 40 million more jobs.[54]

However, steel production is also extremely polluting. Nearly 1.9 billion tons of annual steel production contributes to about 7% of global CO_2 emissions, and even under a low-carbon scenario steel demand will increase over the next few years. A sectoral pathway consistent with net-zero commitments and a 1.5°C limit will need to address the fact that steel is the greatest industrial coal consumer—with coal currently providing 75% of the industry's energy as the main source of fuel for blast furnaces. Although emissions are considered hard to abate in this sector, there must be a reduction of 25-30% in the steel industry's emissions intensity by 2030 to meet the 1.5°C target.[55]

Steel is the greatest industrial coal consumer—with coal currently providing 75% of the industry's energy as the main source of fuel for blast furnaces.

Decarbonising the steel sector will need a combination of technological approaches. The industry is already changing significantly to meet this challenge, employing greater recycling of scrap steel and continued process efficiency. Yet those improvements can only achieve so much. Although steel recycling requires only around a tenth of the energy of primary steel production, many countries would not have enough scrap steel availability to keep up with increased demand of secondary steel producers. Ultimately, it is investments in new forms of low-carbon steel production, or green steel, that will close the gap. That means the widespread use of various approaches, such as replacing coal with green hydrogen as a reducing agent, natural gas with carbon capture and storage (CCS), and eventually direct iron electrolysis.

[54] World Steel Association (2020), "Setting the course for a healthy steel industry". Available at: https://www.steelforum.org/stakeholders/gfsec-march-2020-worldsteel.pdf

[55] Climate Action Tracker (2020), "Paris Agreement Compatible Sectoral Benchmarks". Available at: https://climateactiontracker.org/documents/753/CAT_2020-07-10_ParisAgreementBenchmarks_FullReport.pdf

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These solutions are being championed by a number of high-ambition steel producers, many of which have united under the Net Zero Steel Initiative and announced commitments to net-zero steelmaking. The ambition of major producers is particularly important due to the industry's concentration. The top ten producers represent 85% of global production, and China alone accounts for 52% of the world's total. The sector's second-largest player, India, accounts for barely an eighth of that (6.2%). Other big producers include Japan (5.2%) and the US (4.6%).[56]

Country-specific strategies will depend on scrap steel availability, demand, existing stock, carbon storage possibilities and power sector outlook.[57] Strong industrial policy coupled with industry buy-in will be key to commercialising low-carbon processes within the decade, and R&D spending will be needed to lay the groundwork for a low-carbon trajectory after 2030.

Investment, jobs and growth in a 1.5°C-compatible steel sector

To estimate jobs and growth in a net-zero steel sector, our calculations draw directly from national investment and production levels projected by the Net-Zero Steel Project,[58] which has simulated pathways for each country based on demand, production capacity, recyclable scrap availability, CCS availability (ie, access to CO_2 pipelines), and expected turn-over of steel facilities to low-emissions technology. Those pathways see more than a doubling in recycled steelmaking and depend on a 25-year furnace relining schedule (longer schedules would jeopardise a net-zero trajectory).

Material efficiency measures introduced in the steel industry's supply chain have already achieved significant gains and could reduce global steel demand by around 20% by 2050, easing the industry's burden to shift to lower-carbon technologies such as hydrogen and CCS.[59] In addition to more advanced materials, growth in building material use overall should slow as economies (particularly China) become more saturated with infrastructure. Therefore, despite the global economy being 52% larger by the end of the decade,[60] steel demand under a 1.5°C-compatible scenario may only increase 4% with respect to 2020 levels (to nearly 2 billion tons per year).[61]

By 2030 China will still be the largest steel producer, with nearly 46% of the market (Figure 4), a slight drop from today's share of 52%. India's second-place share grows to 7.4% by 2030 (although it is expected to grow to account for 20% of global steel production

[56] World Steel Association (2021), "World Steel in Figures 2021". Available at: https://www.worldsteel.org/media-centre/press-releases/2021/world-steel-in-figures-2021.html
[57] Climate Action Tracker (2020)
[58] Net Zero Steel Project (2021), "Global facility level net-zero steel pathways: Technical report on the first scenarios of the Net-zero Steel Project". Economist Impact figures draw from the "Medium Demand / 200km CO_2 pipeline" scenario. Available at: https://www.netzerosteel.org
[59] IEA (2020a), "Iron and Steel Technology Roadmap". Available at: https://www.iea.org/reports/iron-and-steel-technology-roadmap
[60] Projection by The Economist Intelligence Unit
[61] Net Zero Steel Project (2021)

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by 2050), while other relevant players like Japan and the US would see total output and market share mostly unchanged.

The reallocation of steel sector market share, and the fact that some countries will have to take more drastic action to retire coal-intensive blast furnace technologies, will shape how sector-wide decarbonisation investments are distributed to 2030. As a result, China and India would take on the largest share, or nearly 57% of global investments.

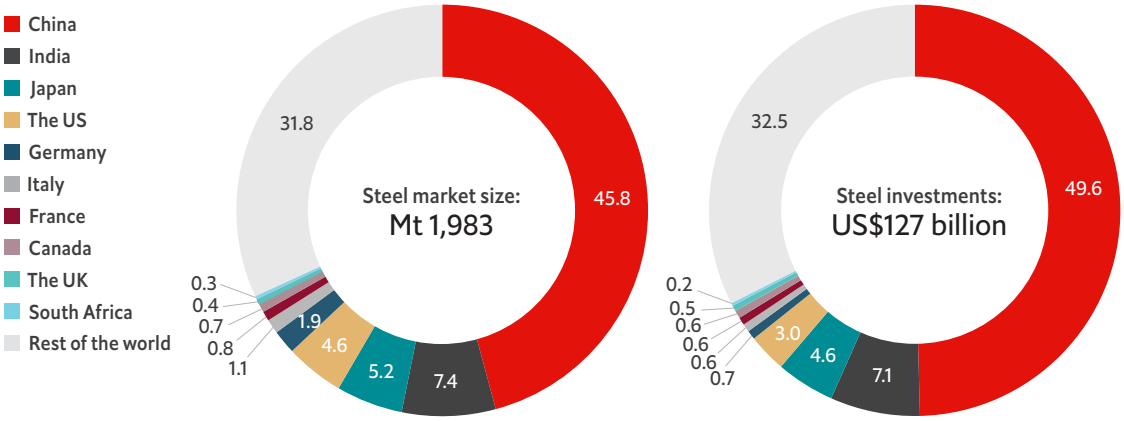
Job creation under a decarbonising steel scenario is generally more concentrated in top producer countries, and especially in those countries leading the transition to a net zero pathway.

In total, the steel sector would help create 1.3 million new (direct and indirect) jobs by 2030, with China and India accounting together for nearly 750,000 jobs (Figure 5). However, because green steel is still a relatively specialised area, and because upgrades and investments will likely take place within existing companies and industries, direct employment gains from green steel are significantly lower, accounting for only 141,000 jobs worldwide, and less than 1,000 direct jobs each in Canada, France, Germany, Italy and the UK.

Worldwide, new expenditure in reconfiguring the steel industry could boost the global economy by up to US$60bn over the next decade, as a result of beneficial spill-overs and multiplying effects across the steel value chain and related sectors.

Figure 4. Global steel market and cumulative investments by 2030 on a net-zero pathway

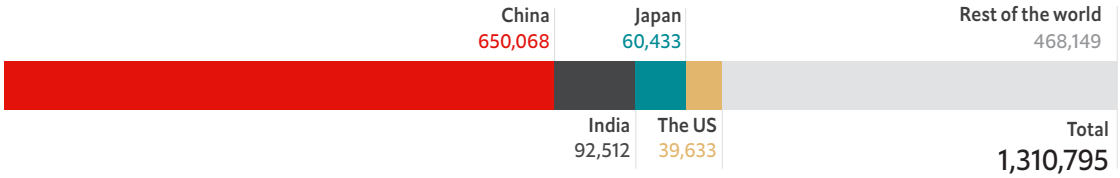
%



Sources: Net Zero Steel Project (2021); Economist Impact estimates.

Figure 5. New jobs created by investments in green steel by 2030 on a net-zero pathway

Thousands of jobs



Source: Economist Impact estimates.

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Regional gains from green steel

Green steel will be of critical importance between 2030 and 2050. However, green steel is still largely at the demonstration stage and requires significant policy support and investment to be commercialised.

So far, the story of green steel has been concentrated in Europe (including the UK), where 38 out of 59 projects are based, and where German firms alone have already committed approximately US$800m in 11 projects.[62] Plans also exist to build green steel plants in Canada, China, the US and Japan, as well as in South Korea and Australia.[63] Overall, seven out of the ten biggest steel producing countries have initiated at least one green steel project, although with different expected completion times.[64] In the US, up to 6% of steel plants could switch to a hydrogen-blend feedstock by 2030.[65]

Green steel is still largely at the demonstration stage and requires significant policy support and investment to be commercialized.

Nine companies representing around 20% of global steel production, including the five largest producers, have set firm net zero emissions commitments. However, these remain concentrated in Europe and Asia, reflecting national and regional net zero pledges and existing regulation. ArcelorMittal, the world's second-largest steel producer, began construction of three pilot plants in 2021, and plans a demonstration plant by 2025 and two-full scale plants by 2026.[66]

Sweden has emerged as an early leader in green steel commercialisation. SSAB, which aims to offer the first fossil-free steel to the market in 2026, plans large investments with its partners, miner LKAB and energy company Vattenfall, and will also seek public funding. Its Hydrogen Breakthrough Ironmaking Technology pilot and hydrogen-based plant costs about SEK1.5bn-2bn (US$180m-US$240m), split between the three owner companies and the Swedish energy agency, while the planned demo plant may cost almost tenfold. The project alone will cut about 10% of the total CO_2 emissions in Sweden and around 7% in Finland.[67]

As green-steel technologies proliferate, where investments take place will depend largely on where the current capital stock is in the overall equipment life-cycle, and particularly on the furnace relining dates. In more mature sectors like Europe and the US, furnace replacement and relining will come up in the middle of this decade, whereas many Asian facilities are coming to their furnace relining dates only in 2025-35. At these points, the core process equipment must be essentially torn down and rebuilt, providing a critical opportunity for substituting in low-emitting iron reduction and smelting.

The key to the sector's decarbonisation will be in China, where so far government efforts to reduce emissions from the industry (which account for 15% of China's total) have included heavy-handed efforts to reduce production, with limited success. In January 2021 the government released a draft five-year roadmap for the industry, calling for more scrap use, expanded electric arc furnace

[62] Green Steel Tracker (2021a), "Tracking announcements of low-carbon investments in the steel industry". Available at: https://www.industrytransition.org/green-steel-tracker/
[63] Green Steel Tracker (2021b), "Green steel production: How G7 countries can help change the global landscape". Available at: https://www.industrytransition.org/insights/g7-green-steel-production/
[64] Green Steel Tracker (2021a)
[65] Fuel Cell & Hydrogen Energy Association (2021), "A Road Map to US Hydrogen Economy". Available at: https://www.fchea.org/us-hydrogen-study
[66] Green Steel Tracker (2021a)
[67] S&P Global Platts (2021), "Feature: Green steel: who's paying?". Available at: https://www.spglobal.com/platts/en/market-insights/latest-news/metals/012121-feature-green-steel-whos-paying

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production capacity and more Chinese ownership of iron ore supplies. The country's carbon emissions trading scheme that launched in July 2021 could eventually drive increased scrap use at the expense of iron ore and coke as mills reduce carbon emissions. However, China's industry is dominated by blast furnaces, and would require widespread introduction of hydrogen and CCS, but neither of which is likely to spread significantly until later in the decade due to economics. Yet, with Chinese efforts to curb production and limit emissions driving steel prices up significantly, the industry will be incentivised to refit plants to meet strict government requirements, avoid further curtailments and meet rising market demand.

Opportunities and challenges: A question of policy

A sustainable transition for the steel sector will not come about on its own. The commercialisation of green steel technology faces systemic barriers such as a lack of infrastructure and unclear demand. Government policy will play an important role. Policy portfolios must be diverse and include solutions such as creating a market for near-zero emissions steel, supporting the demonstration of (and creating the supporting infrastructure for) the required technologies, accelerating material efficiency and increasing international co-operation.

In Europe, where the commercialisation of green steel is most advanced, the EU emissions trading system has not sufficiently supported the transformation of energy-intensive industries. Spurred by the European Green Deal, and recognising that green steel is simply not competitive, the EU has sought to introduce active policy incentives for green steel production.

The principal approaches for active industrial policy include both demand-side market creation, and direct production subsidies through carbon contracts for difference. While subsidies can more effectively enable the realisation of primary green steel production, poor design can skew the distribution of energy transition costs to vulnerable regions or consumers. Parallel programmes such as electricity price guarantees and transitional assistance policies for disadvantaged regions can improve fairness and

The principal approaches for active industrial policy include both demand-side market creation, and direct production subsidies through carbon contracts for difference.

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effectiveness. A complementary use of market creation policy instruments can also reduce the production subsidy volumes needed and aid the global diffusion of new production methods.[68]

Market creation will help to solve demand uncertainty, a major structural challenge. Recent initiatives, such as the First Movers Coalition spearheaded by Mr Kerry, can raise commitments from large corporate consumers to buy green steel.

Carbon pricing, and especially the cost of carbon border taxes in the EU and potentially in the US, will also have a significant impact on steel as a major traded commodity.

Fortunately, the vast majority (85%) of the sector's emissions reductions by 2030 can be delivered through market-ready technologies, such as energy and materials efficiency improvements and fuel switching. Of all steelmaking emission reductions by 2050, only 30% would come from technologies that are at the demonstration or prototype stages today.[69] The bottom line is that until 2030, cleaning the steel industry is largely a commercialisation and industrial policy problem; but the R&D that is invested now will ultimately determine whether the industry keeps to a net-zero pathway by mid-century and plays its part in limiting global temperatures.

Box 3: Supporting actions to accelerate the decarbonization of steel[70]

- Co-ordinate policies to create markets for green steel, including demand-side policies underpinned by standardised procedures and emissions reporting
- Pool and scale-up investments in R&D
- Deploy and scale-up green steel projects
- Increase investment in multilateral funds dedicated to industrial decarbonisation

[68] Vogl, Ahman and Nilsson (2020), "The making of green steel in the EU: a policy evaluation for the early commercialization phase". Available at: https://www.tandfonline.com/doi/full/10.1080/14693062.2020.1803040

[69] IEA (2020a)

[70] Green Steel Tracker (2021b)

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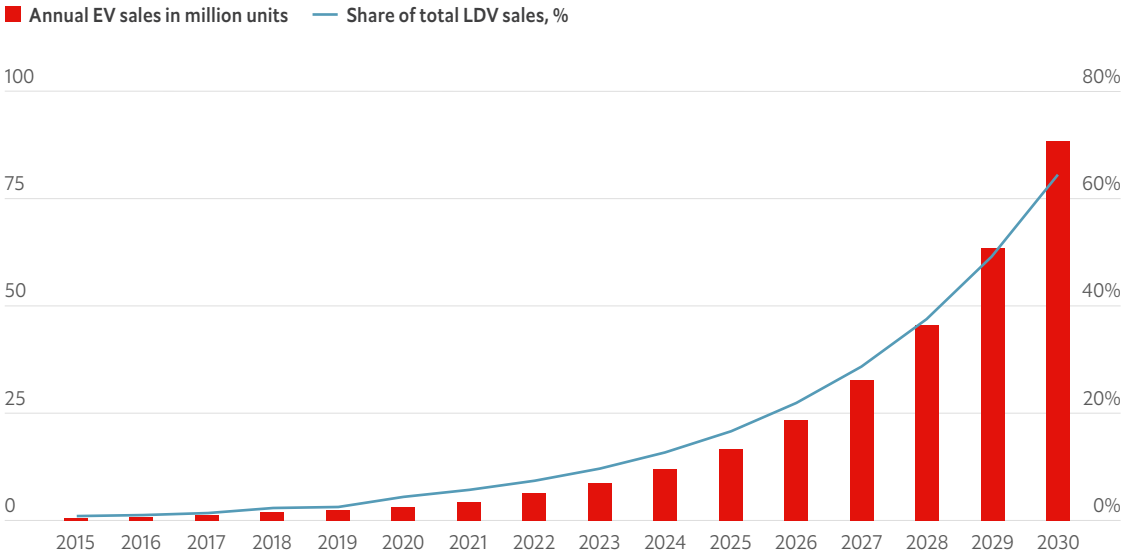
Driving decarbonization: Road transport electrification

Global emissions from road transport were 5.5 $GtCO_2$ in 2020 and will be impacted by ongoing growth in the global vehicle stock.[71] Over half of those emissions come from where electric vehicle (EV)[72] demand is booming: in Europe, China and the US.

At the end of 2020 there were 10 million EVs on the world's roads following a decade of rapid growth. Last year also marked the first year that Europe overtook China as the world's largest EV market.[73] Despite the pandemic-related worldwide downturn in car sales of around 20% in 2020, electric car registrations increased by 41%, with around 3 million electric cars sold globally (or 4.3% share of car sales, up from 2.3% just two years ago) (Figure 6). In 2021 sales are on pace to more than double, to a record 6.2 million units.[74]

Figure 6. Global LDV Electric Vehicles sales, 2015–2030



Source: Economist Impact estimates.

[71] IEA (2021a)

[72] This report considers battery-electric vehicles, plug-in hybrid electric vehicles (PHEVs), and fuel cell electric vehicles as EVs. ZEVs, consisting of BEVs and FCEVs, account for over 70% of today's EV market and about 90% of EV sales by the end of the decade.

[73] IEA (2021b), "Global EV Outlook 2021". Available at: https://www.iea.org/reports/global-ev-outlook-2021?mode=overview

[74] S&P Global Market Intelligence (2021), "EV Impact: Electric vehicle surge resonates across global economy". Available at: https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/ev-impact-electric-vehicle-surge-resonates-across-global-economy-66518519

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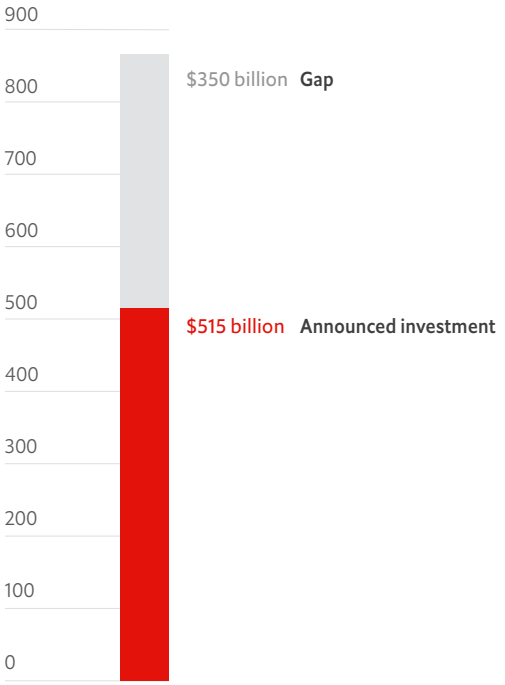
Increasing sales are largely the result of falling prices. Steep cost declines for critical components in EVs (especially batteries), and much lower fuel costs compared with ICEs, mean that EVs are becoming increasingly competitive on a total cost of ownership basis. Those costs will continue to decline through the 2020s, thanks to massive investments to further develop EV technology and scale production across the industry.

Amid such momentum, a number of car manufacturers have raised the bar and declared electrification targets for 2030 and beyond, with some planning to reconfigure their product lines to produce only EVs. In early 2021 these announcements included Volvo (Geely Group, to sell only EVs from 2030); Ford (to sell only EVs in Europe from 2030); General Motors (to offer only electric LDVs by 2035); Volkswagen (to aim for 70% electric car sales in Europe, and 50% in China and the US by 2030); and Stellantis (to aim for 70% electric car sales in Europe and 35% in the US).[75] Commitments have also been announced by Daimler, PSA, Changan, SAIC and others, as well as by individual subsidiaries and brands of these various manufacturing groups.

Only two years ago, no automaker had formally made an announcement around phasing-out ICE vehicles. Automakers with a phase-out pledge before 2040[76] now represent just under 32% of global passenger vehicle sales.[77,78] Overall, current electrification targets by car manufacturers translate to estimated cumulative sales of electric LDVs (mostly passenger cars) of 55-72 million units by 2025.[79]

Figure 7. Cumulative investment needed for EV development and production by 2030 on a net-zero pathway versus announced investments as of November 2021

US$, billions



Sources: S&P Global Market Intelligence (2021); Economist Impact estimates.

In the run-up to COP26, announced investments in EVs and hybrids by major automakers to 2030 already exceed US$500bn.[80] After COP26, Reuters estimated this number to have risen to US$515bn.[81] A net-zero pathway implies that almost US$350bn more may be necessary to transform the global automotive sector to advanced vehicles and mobility (Figure 7).

[75] IEA (2021b)
[76] Pledges to phase out ICE vehicles include ceasing production of PHEVs, but not of FCEVs or BEVs.
[77] BloombergNEF (2021a), "Zero-Emission Vehicles Factbook". Available at: https://assets.bbhub.io/professional/sites/24/BNEF-Zero-Emission-Vehicles-Factbook_FINAL.pdf
[78] BloombergNEF (2021b), "Annex to the Zero-Emission Vehicles Factbook". Available at: https://assets.bbhub.io/professional/sites/24/BNEF-Zero-Emission-Vehicles-Factbook_Annex_FINAL.pdf
[79] IEA (2021b)
[80] S&P Global Market Intelligence (2021)
[81] Reuters (November 2021)

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Indeed, the industry will be disrupted in the coming decade by various concurrent trends, only one of which is electrification. Diverse mobility, autonomous driving and connectivity will also have transformative effects. A McKinsey study estimates that the automotive revenue pool will significantly increase and diversify toward on-demand mobility and data-driven services. This could create up to US$1.5trn in additional revenue potential in 2030, up 30% compared with about US$5.2trn from traditional car sales and aftermarket products and services (already 50% higher than 2015 revenue).[82]

Investment, jobs and growth in a 1.5°C-compatible road transportation pathway

In a NZE economy, the global EV fleet will comprise over 300 million vehicles in 2030 (excluding two/three-wheelers), with EVs representing nearly two-thirds of new car sales and accounting for 19% of the existing stock. An expanding fleet of EVs would continue to reduce well-to-wheel emissions, with the net savings relative to ICE vehicles increasing as a consequence of more decarbonised electricity. In 2030 EVs produce two-thirds less well-to-wheel emissions compared with equivalent ICEs, resulting in a 41.3% reduction in emissions from LDVs overall.[83,84]

A shift from ICEs to EVs at the rates required under a net-zero scenario have significant implications for manufacturing employment. Economist Impact estimates that cumulative investments of US$855bn in EV production by 2030 can create or save 4 million direct and indirect jobs globally (Figure 8), including jobs in traditional manufacturing as well as in electric battery assembly and software engineering. In today's automotive industry, non-software engineers outnumber software engineers nearly 11:1. According to estimates by McKinsey, the value composition of vehicles will significantly change, with software components increasing their share of vehicle value by 4 times and electronics by 1.5 times. In Europe, that implies about 400,000 new jobs in that specialty alone.[85] In addition, battery assembly and manufacturing will be a

On a net-zero pathway, in 2030 the global EV fleet accounts for 19% of existing car stock and reduces emissions by more than two-thirds compared with an equivalent ICE vehicle fleet.

[82] McKinsey & Company (2016), "Automotive revolution - perspective towards 2030". Available at: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/disruptive-trends-that-will-transform-the-auto-industry/de-DE

[83] IEA (2021a)

[84] IEA (2021b)

[85] McKinsey & Company (2019), "Race 2050: A Vision for the European Automotive Industry". Available at: https://www.mckinsey.com/~/media/mckinsey/industries/automotive%20and%20assembly/our%20insights/a%20long%20term%20vision%20for%20the%20european%20automotive%20industry/race-2050-a-vision-for-the-european-automotive-industry.pdf

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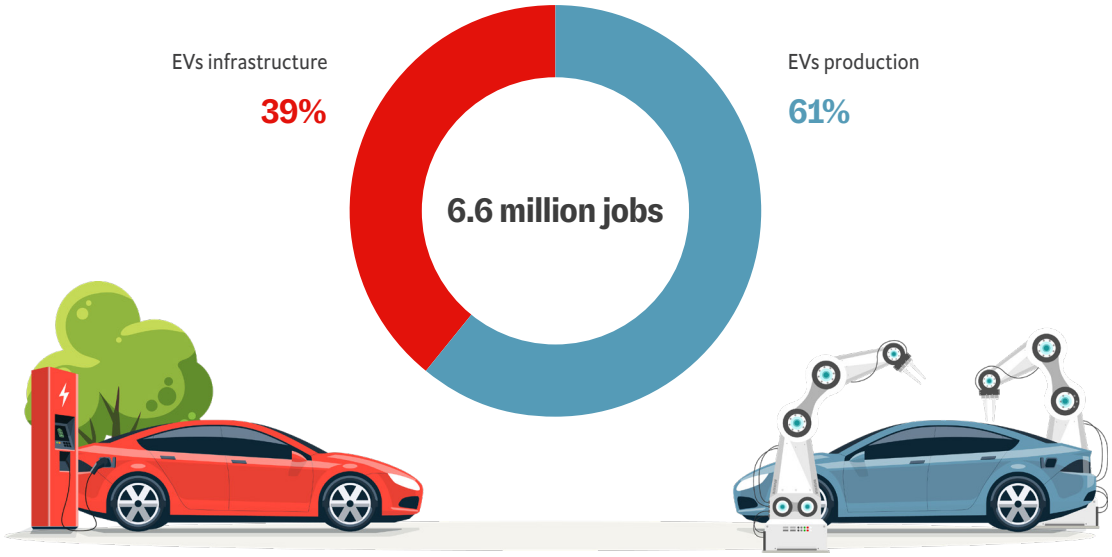
significant source of growth, with EVs accounting for 90% of battery demand. Wood Mackenzie projects that about 119 battery manufacturing sites will be operational by 2030, with Asia-Pacific comprising 80% of global manufacturing capacity and European producers growing their share.[86]

Supporting infrastructure (such as charging capacity) is also an important enabling element to massive EV adoption. In a 1.5°C-compatible pathway, cumulative installed charging power capacity for electric LDV chargers would increase more than 30-fold to over 2.73 TW in 2030, with public chargers accounting for about two-thirds of it. Moreover, even though EV infrastructure would account for a little over a fifth of the EV sector's investments by 2030, this labour-intensive industry would represent nearly 40% of the 6.6 million jobs created globally by the sector.

However, some traditional manufacturing and engineering jobs will also be at risk, partly due to the fact that EVs have about 100 less moving parts and require 30% fewer labour hours to build.[87,88] Over time, the transition to electrification is expected to mean fewer jobs assembling powertrain components and less work for dealership service departments and auto repair shops.

Figure 8. Employment opportunities created by investment in the EV sector by 2030 on a net-zero pathway



Source: Economist Impact estimates.

[86] Wood Mackenzie (2020), "Global energy storage capacity to grow at CAGR of 31% to 2030". Available at: https://www.woodmac.com/press-releases/global-energy-storage-capacity-to-grow-at-cagr-of-31-to-2030/

[87] RethinkX Sector Disruption Report (2017), "Rethinking Transportation 2020-2030, The Disruption of Transportation and the Collapse of the Internal-Combustion Vehicle and Oil Industries". Available at: https://www.wsdot.wa.gov/publications/fulltext/ProjectDev/PSEProgram/Disruption-of-Transportation.pdf

[88] Ford Motor Company (2017), "CEO Strategic Update". Available at: http://s22.q4cdn.com/857684434/files/doc_presentations/2017/CEO-Strategic-Update-12.pdf

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Regional gains from electrified road transportation

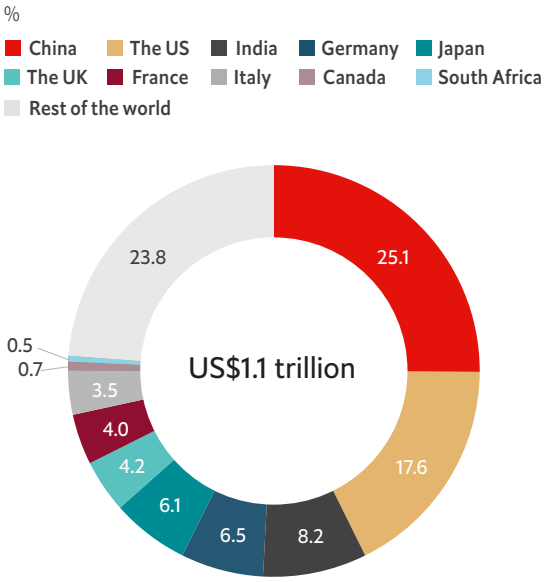
Most of our focus countries feature large automotive industries, including the US, Germany, Japan, China, France, Italy, the UK and India (Figure 9). The potential impacts on employment and growth are especially significant in these countries, but will depend on their companies' acceptance of new technologies and fostering the necessary skills and expertise to compete in the EV sector, particularly in software and battery engineering.

Prior to COP26, 45 governments had announced 100% zero-emission vehicle targets or the phase-out of ICE vehicles through 2050, including 18 national governments and 27 regional and municipal authorities.[89] France was the first to put this intention into law, with a 2040 timeframe.[90] By early 2021 nine countries urged the European Commission (EC) to accelerate an EU-wide phase out of petrol and diesel cars to support national efforts, and by summer the EC's "Fit for 55" package proposed a *de facto* phase-out by 2035.[91] Cars are responsible for 12% of all CO_2 emissions in Europe, and policies to disincentivise fossil fuel inputs have a role.[92] At COP26, over 100 national governments, cities, states and major businesses signed the "COP26 Declaration on Accelerating the Transition to Zero-Emission Cars and Vans", a pledge to phase out new ICE vehicles by 2040 worldwide and by 2035 in "leading markets".[93]

A net-zero pathway for electric road mobility offers an opportunity to leverage Europe's traditional position as a global export champion in the automotive space. Manufacturers should build on the continent's strengths in technology, talents and skills to construct a new automotive ecosystem of holistic and optimised mobility services and solutions. Europe's automotive sector employs 3.5 million workers,[94] and transitioning away from fossil-fuel vehicles will require a significant shift in manufacturing-related employment.

Japan announced that by the mid-2030s it aims for all new passenger cars to be electrified,[95] but the industry is not universally supportive. The head of the national automaker's association and Toyota's

Figure 9. Breakdown of cumulative investment for EV production and infrastructure by 2030 on a net-zero pathway by country



Source: Economist Impact estimates.

[89] BloombergNEF (2021a)
[90] IEA (2020b), "Global EV Outlook 2020". Available at: https://iea.blob.core.windows.net/assets/af46e012-18c2-44d6-becd-bad21fa844fd/Global_EV_Outlook_2020.pdf
[91] Council of the EU and the European Council (2021), "Fit for 55". Available at: https://www.consilium.europa.eu/en/policies/green-deal/eu-plan-for-a-green-transition/
[92] European Commission (2021), "CO_2 emission performance standards for cars and vans". Available at: https://ec.europa.eu/clima/eu-action/transport-emissions/road-transport-reducing-co$_2$-emissions-vehicles/co$_2$-emission-performance-standards-cars-and-vans_en
[93] UN News (2021), "Era free of fossil-fuel powered vehicles comes into focus at COP26; draft outcome is met with calls for more ambition". Available at: https://news.un.org/en/story/2021/11/1105462
[94] European Parliament's committee on Industry, Research and Energy (2021), "The Future of the EU automotive sector". Available at: https://www.europarl.europa.eu/RegData/etudes/STUD/2021/695457/IPOL_STU(2021)695457_EN.pdf
[95] Under the Japanese target, hybrid electric vehicles will continue to be produced. Japanese Ministry of Economy, Trade and Industry (2020), "Green Growth Strategy Through Achieving Carbon Neutrality in 2050". Available at: https://www.meti.go.jp/english/press/2020/1225_001.html

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CEO Akio Toyoda claims that such an aggressive push could cost manufacturing jobs on a net basis if Japanese firms relocate ICE production abroad due to government policy.[96] However, we estimate that, in the presence of necessary investment, Japan could potentially gain or save more than 245,000 new jobs as a result of the shift to EV manufacturing, but the scale of concurrent losses will depend on industry decisions.

In North America, Canada has set zero-emission vehicle (ZEV) targets of 10% of LDV sales by 2025, 30% by 2030 and 100% by 2040.[97] Meanwhile, in the US, an executive order aimed at making EVs account for half of all new vehicles sold in 2030 was signed in August 2021, but the government has resisted calls for a full phase out of new ICE cars.[98] Under a net-zero scenario, the US would need to invest more than US$40bn in charging infrastructure by 2030 to add millions of workplace and public chargers, including direct current fast chargers. We estimate that, across the charging and automotive sector, the US could save or create over 1 million jobs by 2030, but it will require concerted government action. Research by the Economic Policy Institute shows that in the absence of sufficient support for domestic production, the US could see net job losses as the locus of advanced automotive production shifts to Asia.[99]

China targets 20% of vehicle sales to be ZEVs by 2025, and 40% of sales to be new energy vehicles (which include battery electric vehicles, plug-in hybrid-electric vehicles and fuel-cell electric vehicles) by 2030.[100] By 2030 China will continue to lead in EV production and sales. Under a net-zero scenario, it achieves 43% EV sales, hitting the government's 2030 target and remaining on track to achieve China Society of Automotive Engineers' 2035 goal.[101] Chinese manufacturers are even more bullish, with BYD Ltd. predicting 70% EV penetration in 2030 and Nio's founder expecting 90% of new sales to be EVs.[102] Together with Europe, China will lead EV four-wheeler deployment globally, with policies to promote both EV sales and electrification.[103,104] We estimate that as many as 1 million jobs could be gained or saved as a result of Chinese EV expansion.

96 Inside EVs (2021), "Toyota CEO: Going All-EV Could Cost Japan Millions Of Jobs". Available at: https://insideevs.com/news/534262/all-ev-plans-threaten-japan/

97 IEA (2021b). ZEVs do not include PHEVs (hybrid-electric vehicles).

98 The White House (2021), "Executive Order on Strengthening American Leadership in Clean Cars and Trucks". Available at: www.whitehouse.gov/briefing-room/presidential-actions/2021/08/05/executive-order-on-strengthening-american-leadership-in-clean-cars-and-trucks/

99 Jim Barrett and Josh Bivens (2021), "The stakes for workers in how policymakers manage the coming shift to all electric vehicles". Available at: https://www.epi.org/publication/ev-policy-workers/#

100 Institute for Governance & Sustainable Development (2021), "Briefing: China Details Plans for Achieving Carbon-Peaking and Carbon-Neutrality Goals". Available at: https://www.igsd.org/briefing-china-details-plans-for-achieving-carbon-peaking-and-carbon-neutrality-goals/

101 IEA (2019a)

102 CNBC (2021), "China's electric car leaders predict new energy vehicles will dominate the local market by 2030". Available at: https://www.cnbc.com/2021/06/15/chinas-top-ev-car-makers-predict-new-energy-vehicles-will-dominate.html

103 IEA (2020b)

104 Electric micro-mobility options, which are not assessed as part of this analysis, are also popular and expanding rapidly in China, which currently accounts for the majority of the global stock of 350 million electric two/three-wheelers.

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In India, achieving net-zero will require recognising electric mobility as a priority sector for both economic recovery and sustainable growth. By signing the "COP26 Declaration on Accelerating the transition to Zero-Emission Cars and Vans",[105] India has joined the world's leading countries in pledging to globally phase out new ICE vehicles by 2040—unlocking opportunities for increasing domestic value-added in manufacturing, reducing oil import bills, and improving environmental and health conditions. We estimate that the country could stand to gain or save over 530,000 jobs across both manufacturing and charging infrastructure build-out to 2030, far outweighing the expected loss in value from the petroleum and automotive sectors.

Opportunities and challenges of decarbonising road transportation

Even with recent successes, electrifying road transport on a trajectory consistent with 1.5°C climate goals will be a formidable endeavour. It requires stronger commitment and action from all countries together with advances in battery technology and mass manufacturing to continue driving down the cost of EVs. Transport electrification is interlinked with clean power; progress on decarbonising electricity generation is necessary for EVs to attain their full emissions mitigation potential.

The rapid increase in EV sales requires an immediate scale up of new supply chains for batteries and charging infrastructure. In the NZE, battery production capacity increases more than 30-fold, reaching 6.5 TWh by 2030.[106] Any delay in expanding battery manufacturing capacity would not only have a detrimental impact on EV roll-out, but could also slow cost reductions for other clean energy technologies that could benefit from more efficient and affordable energy storage systems.

Some national and state governments would face revenue losses from fossil fuel taxes, posing a structural political-economic challenge to advancing EVs. Governments should therefore plan to diversify their revenue sources while promoting electrification. In the longer run, despite risks to current revenue streams, reduced reliance on fossil fuels will increase the energy security of net oil importers and help improve their trade balances.

Box 4: Key supporting actions to decarbonize road transport[107]

- Light-duty ICE vehicles sales and production bans by 2035 among countries and manufacturers
- Corporate commitments to 100% new EV purchases in corporate and mobility fleets by 2030 at the latest
- Commitment to stringent fleet-wide fuel efficiency standards for cars and vans
- Remove subsidies for petrol and diesel; maintain or increase taxation on petrol and diesel
- Commitments to EV charging infrastructure rollout with clear international standards and expanding number of hydrogen refuelling stations
- Bans and restrictions on use of ICE LDVs in major cities; aim for comprehensive bans in most major cities

[105] UK-COP26 (2021), "COP26 Declaration on Accelerating the transition to Zero-Emission Cars and Vans". Available at: ukcop26.org/cop26-declaration-on-accelerating-the-transition-to-100-zero-emission-cars-and-vans/

[106] IEA (2021a)

[107] Energy Transitions Commission (2021)

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Clean hydrogen: An enabler of the energy transition

Hydrogen is currently enjoying unprecedented political and business momentum, with a rapidly expanding number of projects and policy commitments. Today, dedicated global production of hydrogen amounts to around 130 million tons per year, mainly in the refining and chemicals sectors. However, to significantly contribute to the clean energy transition, hydrogen must be adopted much more widely in sectors where it is almost completely absent at the moment, such as transport, buildings and power generation.[108]

Hydrogen is light, storable, reactive, has high energy content per unit mass and can be readily produced at industrial scale. It can also be made from a diverse range of energy sources. In recent years, a colour system has emerged to refer to different forms of hydrogen production.[109] "Black", "grey" or "brown" refer to hydrogen produced from coal, natural gas and lignite respectively. "Blue" is when hydrogen comes from fossil fuels (primarily natural gas) offset by emissions mitigation measures, such as CCS; there are currently seven such plants in operation globally. "Green" hydrogen is made using clean energy sources.[110]

To significantly contribute to the clean energy transition, hydrogen must be adopted much more widely in sectors where it is almost completely absent at the moment, such as transport, buildings and power generation.

The hydrogen sector is scaling up and green hydrogen might become cost-competitive by 2030, by which time the IEA estimates the cost of producing it could fall by 30%.[111] Today, approximately 95% of global dedicated hydrogen production uses either natural gas or coal (due to its dominant role in China) as a primary feedstock, with the former accounting for roughly three-quarters. This use represents 6% of total natural gas demand and 2% of total coal demand worldwide, making the sector responsible for 2.4% of global emissions.[112]

[108] IEA (2019b)
[109] Ibid
[110] World Economic Forum (2021), "Grey, blue, green – why are there so many colours of hydrogen?". Available at: www.weforum.org/agenda/2021/07/clean-energy-green-hydrogen/
[111] IEA (2019b)
[112] Ibid

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Investment, jobs and growth in the emerging clean hydrogen sector

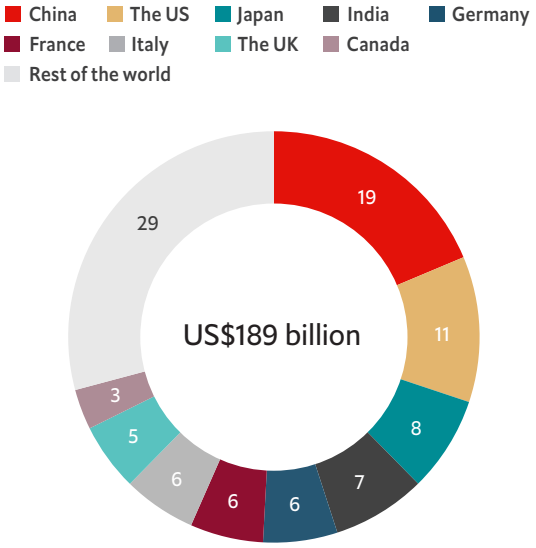
The hydrogen sector's principal contributions to reducing emissions will happen post-2030. In the NZE, three-quarters of hydrogen-related cumulative emissions reductions by 2050 are delivered by technologies that are today only at the demonstration or prototype stage (such as those for green steel production).

Innovation over the next ten years will require public support to leverage private R&D investment to successfully demonstrate and deploy these technologies by the end of the decade. Such efforts should also be accompanied by the large-scale construction of hydrogen transport and electrolyser infrastructure, and will be spearheaded by countries including China, the US, Japan, India and the four largest European economies, where ambitions are particularly strong and billions of dollars are earmarked for hydrogen development (Figure 10).

A tally of project announcements, investments required to reach government production targets, and spending projections across the value chain adds up to more than US$300bn through 2030.[113,114] Given the industry's early stage, the vast majority (73%) of these investments involve announcements but not committed funding. To date, the Hydrogen Council estimates US$80bn of mature investments until 2030.[115] These include US$45bn in the planning phase, which means companies are spending sizable budgets on project development. Another US$38bn involves either committed projects or those under construction, commissioned or already operational.

Figure 10. Breakdown of cumulative investment for clean hydrogen production by 2030 on a net-zero pathway by country

%



Source: Economist Impact estimates.

As a cross-cutting technology, hydrogen will be a key enabler for tackling various critical decarbonisation challenges, including in steelmaking, where it will play a principal role in meaningful reductions. In the power sector, hydrogen can play a key role in grid flexibility, which will be increasingly necessary due to rising shares of variable renewables and growing power demand. For gas producing countries facing declining demand for fossil fuels, hydrogen production with CCS offers a new source of value. Hydrogen is also one of the leading options for storing renewable energy, and during

[113] Hydrogen Council and McKinsey & Company (2021), "Hydrogen Insights Report 2021". Available at: https://hydrogencouncil.com/wp-content/uploads/2021/02/Hydrogen-Insights-2021-Report.pdf
[114] Economist Impact estimates for global cumulative investments by 2030 (US$189bn) are limited to the following clean hydrogen categories: electrolysis, distribution, and refuelling stations.
[115] Hydrogen Council and McKinsey & Company (2021)

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the 2030s it promises to be especially cost competitive for storage, allowing for weekly or even monthly supply and demand imbalances to be met. Its unique energy storage capacity could open possibilities for long-distance transport and export of renewable energy.[116]

Correspondingly, the prospect of green hydrogen production implies huge amounts of dedicated renewable electricity sources to produce it. Most of the employment potential posed by green hydrogen production is in creating this clean power supply, which accounts for about 60% of such jobs.[117,118] Many jobs stemming from the expansion of clean hydrogen are also linked to its applications, as opposed to production, distribution or storage. Hydrogen used in the power sector, rather than as industrial feedstock, leads to more job creation; and even more jobs result from applications in transport and buildings.[119] Our calculations, which are limited to new jobs from clean hydrogen production and distribution (not including power generation or end-uses) to 2030 (when clean hydrogen is expected to have just become commercially viable) reach only 200,000 globally.

Hydrogen used in the power sector, rather than as industrial feedstock, leads to more job creation; and even more jobs result from applications in transport and buildings.

Regional gains from clean hydrogen

Europe (including the UK) currently leads globally in the number of announced hydrogen projects, followed by Japan, China and the US, as well as South Korea and Australia. In future hydrogen demand centres like Europe and Japan, the focus is on industrial and transport application projects.

Europe (including the UK) has 105 announced projects, or 46% of the global total, that cover the entire hydrogen value chain including midstream and downstream.[120] These include multiple integrated projects featuring close cross-industry and policy co-operation, such as the Hydrogen Valley in the northern Netherlands.

In 2020 the EU hydrogen strategy was released as part of the European Green Deal and commits to increasing the production of green hydrogen to 1 million tons per year by 2024 with 6 GW of electrolysers and 10 million tons by 2030 (roughly equivalent to current European production with fossil fuels).[121] The EU hydrogen strategy has particularly strong support from the Netherlands, which is looking to repurpose its natural gas infrastructure as the Groeningen field declines; and from Germany, which presented its own national strategy in June 2020 committing €7bn to domestic production. The EU has set up a "Hydrogen Energy Network" as a platform for discussing hydrogen among EU member states, as well as the "Hydrogen Initiative", which promotes co-operation on sustainable hydrogen technology

[116] IEA (2019b)

[117] Economist Impact estimates based on FCH 2 JU (2020), "Opportunities for Hydrogen Energy Technologies Considering the National Energy & Climate Plans". Available at: https://www.fch.europa.eu/sites/default/files/file_attach/Final%20Report%20Hydrogen%20in%20NECPs%20%28ID%209501746%29.pdf

[118] In order to avoid double counting jobs already estimated in other sections of this paper, investment and employment calculations for the hydrogen sector do not include those from renewable electricity production or end-use applications. Our figures account for direct jobs from clean hydrogen production (including electrolysis), refuelling stations, and distribution, representing between 25% and 30% of total jobs in the hydrogen sector by 2030.

[119] Catrinus Jepma, New Energy Coalition, as quoted in Energy Monitor "Hydrogen tests climate policymakers with its job potential" (May, 2021) https://energymonitor.ai/tech/hydrogen/hydrogen-tests-climate-policymakers-with-its-job-potential

[120] Hydrogen Council and McKinsey & Company (2021), "Hydrogen Insights Report 2021". Available at: https://hydrogencouncil.com/wp-content/uploads/2021/02/Hydrogen-Insights-2021-Report.pdf

[121] European Commission (2020), "A hydrogen strategy for a climate-neutral Europe". Available at: https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf

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with businesses and organisations.[122] While the EU hopes for upwards of 1 million indirect jobs from the hydrogen economy in 2030, we estimate direct jobs from production and transport alone to number in the tens of thousands.

The UK is a world leader in R&D for using hydrogen in heating as a substitute for fossil fuels like natural gas.[123] In August 2021 the British government released its own hydrogen strategy targeting 5 GW of clean hydrogen production capacity by 2030, by which time it expects hydrogen to unlock £4bn of investment and support more than 9,000 jobs.[124] Unlike the EU strategy, the UK's includes a specific track on blue hydrogen. With ambitions to be a global leader in hydrogen development evidenced in its commitment to a £100m low-carbon hydrogen fund, the UK has significant commercial opportunities for hydrogen production and investment.

The US is a leader in producing and distributing gaseous and liquid hydrogen, generating about 11.4 million tonnes per year, with an estimated value of about US$17.6bn.[125] Shifting to a broader use of hydrogen provides opportunities to extend that leadership, according to a report by the Fuel Cell & Hydrogen Energy Association that includes a roadmap for US hydrogen consistent with the 1.5°C pathway. They estimate that reaching the report's targets could drive about US$140bn per year in revenue and support 700,000 direct and indirect jobs across the value chain by 2030.[126]

Japan and South Korea are strong in road transport applications, green ammonia, LH2 and LOHC projects. Japanese companies are leading technology development to control combustion of flammable hydrogen in turbines, and Japan also built one of the world's largest water electrolysers.[127] The country is especially bullish on hydrogen; the government already subsidises 135 hydrogen refuelling stations around the country (the largest number in the world) and is actively encouraging its use for green steel. However, Japan's production strategy relies on significant hydrogen imports from places like Australia, with transport technology pioneered by Kawasaki Heavy Industries, limiting domestic employment impacts from renewable power inputs.

China also has strong ambitions for clean hydrogen—the central government has included hydrogen among six "industries of the future" in its 14th Five-Year Plan. It is currently the world leader in hydrogen production, with its annual output of 20 million tons (produced mostly with coal for industrial and chemical processes) accounting for around a third of global production. The China Hydrogen Alliance, a government-supported industry group, predicts that by 2025 the output value of the country's hydrogen energy industry will reach Rmb1trn (US$152.6bn) and that by 2030 China's demand for hydrogen will reach 35 million tons, accounting for at least 5% of China's energy system. New projects, including a Sinopec plant to produce 500,000

[122] IEA (2019b)
[123] GIR (2020)
[124] HM Government (2021), UK Hydrogen Strategy. Available at: https://www.gov.uk/government/publications/uk-hydrogen-strategy
[125] Fuel Cell & Hydrogen Energy Association (2021), "Roadmap to a US Hydrogen Economy". Available at:https://static1.squarespace.com/static/53ab1feee4b0bef0179a1563/t/5e7ca9d6c8fb3629d399fe0c/1585228263363/Road+Map+to+a+US+Hydrogen+Economy+Full+Report.pdf
[126] Fuel Cell & Hydrogen Energy Association (2021)
[127] Japanese Ministry of Economy, Trade and Industry (2020), "Green Growth Strategy Through Achieving Carbon Neutrality in 2050". Available at: https://www.meti.go.jp/english/press/2020/1225_001.html

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tonnes of hydrogen a year from renewable energy by 2025, are indicative of Chinese efforts to dominate the global green hydrogen market. We expect the country to account for the largest share of green hydrogen production, storage and transport investment to 2030.

Opportunities and challenges to rapidly scaling up clean hydrogen

The rapid scaling up of clean hydrogen, through both demand creation (by encouraging the purchase of products made with lower emission hydrogen-enabled processes) and support for demonstration projects and production investment, has the potential to create jobs and economic activity across a small but growing hydrogen economy.

While the momentum behind hydrogen is strong, infrastructure and market development must accelerate to facilitate widespread adoption within the outlook period. A number of important barriers to catalysing a virtuous investment cycle still need to be addressed. Among them are uncertainties surrounding the climate ambition of national governments, which increase the risk of investing in clean (and particularly green) hydrogen technologies, raise capital costs and reduce the allocation of funds towards its expansion.[128]

Other barriers include near-term technological risks to certain uses of hydrogen (such as for long-distance trade) and atomised value chains that limit major sector players from scaling at sufficient pace. Additionally, a number of restrictive regulations should be updated to allow the use of hydrogen in market-ready applications. For example, modifying regulations in some countries that limit hydrogen concentrations in the natural gas network can stimulate higher levels of hydrogen blending.[129] Finally, a lack of globally accepted standards hinders the advancement of trade, the development of safety measures and consistent life-cycle analyses of the environmental impacts.[130] Both demand-side and supply-side policy support, including government investment in early-stage manufacturing capacity, can help to realise the significant employment and growth potential of hydrogen after 2030.

Box 5: Key supporting actions to accelerate clean hydrogen[131]

Demand-side support

- Carbon pricing
- Mandates or product standards
- Voluntary green premium
- Public procurement
- Contracts for difference
- Updated regulations for blending and other end uses

Supply-side support

- Targets for electrolyser capacity to be achieved by specific dates, underpinned by credible commitments
- Initial public investment in electrolyser manufacturing capacity and in hydrogen production assets, in the form of de-risking mechanisms that will crowd-in private capital
- Co-ordinate with a significant build-out of variable renewable energy generation

[128] IEA (2019b)
[129] Ibid
[130] Ibid
[131] Energy Transitions Commission "Making the Hydrogen Economy Possible" (2021) https://energy-transitions.org/wp-content/uploads/2021/04/ETC-Global-Hydrogen-Report.pdf

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Conclusion

In the wake of the covid-19 pandemic and widespread economic recession, the global economic recovery is likely to be volatile and uneven. Public spending and support, together with dedicated policy and private sector commitment to long-term value, provide an opportunity to put the world on a more sustainable growth trajectory. Solutions to decarbonise large parts of the economy have the potential to invigorate economies, present major investment opportunities, create jobs and enable a green recovery.

But a serious commitment to limit the global temperature rise to 1.5°C requires a scale of investment and economic change that goes far beyond the recovery, requiring sustained government action to mobilise trillions of dollars in private investment and new economic activity while protecting consumers and vulnerable workers.

In just four key sectors, the energy transition will require global investments of US$16.8trn by 2030. Governments need to work with businesses, financial institutions, individual investors and civil society to enable market and demand development for clean industries, while disincentivising short-term focused investments in polluting technologies.

The economic impacts of such massive investments necessary to transition to a cleaner economy are overwhelmingly positive. They include nearly 22 million new jobs worldwide across the four key sectors, and a 4.6% boost to global GDP by 2030. Beyond creating new economic opportunities worldwide, they contribute to mitigating the effects of climate change that could otherwise cause a 3% reduction of global GDP by 2050.

Reaping the benefits of necessary actions to 2030 relies mostly on the widespread deployment of available low-carbon technologies, but concerted R&D to develop technologies necessary after 2030 is also good for the economy. Major R&D efforts needed to bring new low-carbon technologies to market over this decade can boost productivity and create entirely new industries, benefiting countries that prioritise low-carbon innovation.

In its size and contribution to emissions, the power sector is the low-hanging fruit for limiting global temperature rises. The technology to transform it is already cost-competitive and quickly undercutting traditional fossil fuels. Cumulative global investments in new clean power generation, including both renewables and advanced nuclear power, would

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amount to over US$10trn by 2030 and boost global GDP by 2.8%. New renewable projects produce more than threefold more jobs than fossil fuels per dollar invested, and investments in clean power generation add or save around 8.7 million jobs by 2030, including almost 4.7 million in the G7.

Investments in an expanded, smarter, more flexible and more resilient electricity grid underpin the energy transition and deliver over 1 million jobs among G7 countries. To cope with a 40% increase in electricity demand by 2030, and deep penetration of variable renewable energy generation, US$5.2trn in worldwide power network and grid investments will be necessary over the decade, creating over 5 million jobs and almost 1.8 million in China alone.

Electrifying road transport has a severe impact on traditional automotive jobs, but creates 4.4 million new jobs among G7 countries in charging infrastructure, electric battery assembly, and software engineering, while wider industry trends like automated driving point to new value streams. With 350 million LDVs in 2030 under a 1.5°C trajectory, EVs represent nearly two-thirds of new car sales and 19% of the car stock, as well as reducing sector-wide emissions by more than 40%. The US$1.1trn of cumulative investments in electrified road transport to 2030 creates or saves 6.6 million jobs globally, while the industry expands to on-demand mobility and data-driven services.

The steel sector will need to reduce its emissions in 2030 by at least 25%, and 85% of these reductions can be delivered through market-ready technologies. A number of high-ambition steel producers are championing the use of these technologies and have set firm net zero emissions pledges. However, government support will be necessary for the successful commercialisation of green steel processes within the decade. Decarbonising the steel sector by mid-century will require cumulative investments of US$127bn by 2030, creating or saving over 1.3 million jobs.

In order to make a significant contribution to limiting global warming to below 1.5°C, hydrogen must be widely adopted in sectors where it is almost completely absent today, such as transport, buildings and power generation. Three-quarters of hydrogen-related emissions reductions by 2050 are delivered with technologies that are currently at the demonstration or prototype stage, making the sector one of the most challenging. Accelerated innovation will require public support to leverage private R&D and successfully demonstrate and deploy clean hydrogen technologies.

Governments must ensure that the 1.5°C trajectory takes into account the social and economic impacts on individuals and communities. Although job creation and environmental improvements provide widespread benefits, decision-makers will have to pay close attention to consumer prices and employment dynamics in order to provide direct support to adversely affected communities.

Crisis creates opportunity. The energy transition will require massive investment and cause economic disruption for some, but it carries enormous economic potential in new industries, employment and innovation. The countries poised to gain will be those willing to rise to the challenge, seize the opportunity and lead the transition.

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Technical Annex: Sizing the energy transition

Here, we explain the methodology used by Economist Impact to estimate the data point values used in the *Sizing the energy transition* report. Values were estimated to the year 2030, presuming consistency with a 1.5°C and/or net-zero pathway.

1. Clean power sector

1.1 Clean energy generation

Clean energy generation investments were estimated using a "generation capacity gap" approach, which estimated country-specific clean energy generation capacity needed for each technology (by 2030) under a 1.5°C pathway. Generation capacity gaps were estimated as the difference between country-specific capacity levels for 2018 with their respective capacity levels by 2030 compatible with the IEA's Net Zero Emissions by 2050 (NZE) scenario. Once technology-specific gaps were determined, needed investments by 2030 and employment creation were estimated using technology-specific multipliers (US$/kW and jobs/US$, adjusted from the underlying multipliers used by the IEA's NZE). Added GDP levels by 2030 were estimated using the NZE's implicit "investments-vs-GDP multiplier", which was calculated as a function of the relationship between added global GDP under the NZE (+4% by 2030, as determined by the IMF)[132] and the total cumulative investment levels calculated by Economist Impact.

Although this approach is likely to underestimate the needed capacity investments for clean energy generation given that some existing clean energy capacity might be retired in the coming years, it captures the unique country-specific electricity demand changes in 2018-30 (as each country faces different demand growth, electrification rates and particular starting points for grid emission factors). Moreover, as global clean-energy installed capacity would increase nearly fourfold under a 1.5°C pathway, the impact of retiring clean energy power plants may be considered negligible as a share of total investments.

Similar to other sectors, the use of a single generic employment creation multiplier (jobs per investment levels in dollars) for all countries fails to take into consideration how labour costs and/or productivity levels might vary considerably across countries. This concern is furthered by the fact that investment costs (construction, logistics, capital, etc) per output unit can also vary significantly between countries.

[132] IEA (2021a), "Net Zero by 2050 - A Roadmap for the Global Energy Sector", page 22: "Total annual energy investment surges to USD 5 trillion by 2030, adding an extra 0.4 percentage point a year to annual global GDP growth, based on our joint analysis with the International Monetary Fund. (...) All of this puts global GDP 4% higher in 2030 than it would be based on current trends."

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1.2 Grid infrastructures

Using the relationship between grid infrastructure and total power annual investments in 2030 under the IEA's NZE, we estimated global cumulative investments in grid infrastructure by 2030. To determine country-specific cumulative investments and job creation, we used each country's shares in clean energy investments as multipliers (assuming a stable relationship between those shares and grid infrastructure shares).

This approach, which uses a standard ratio between added clean energy capacity and grid investments, has several limitations. For instance, this relationship is likely to vary largely between countries due to their differences in domestic and international logistic costs (due to country-specific demographic distribution, geographic position, topography and weather) and in the adopted mix of clean energy technologies. However, for simplicity and keeping a consistent methodology across countries, we chose to use a standard multiplier rule.

Similar to other sectors, added GDP levels by 2030 were estimated using the IEA's NZE implicit investments-vs-GDP multiplier.

2. Low-carbon steel sector

Country-specific investments by 2030 (aligned with a 1.5°C pathway) were obtained from the "Medium Demand - 200 km CCS Pipeline" scenario of Net-zero Steel Project's (2021, Bataille et al). However, the approach used by Bataille et al differs from the IEA's NZE, as it only focuses on steel-industry specific changes, while the NZE considers the compounding cross-sector effects of multiple industries. As a result, although global steel output by 2030 under the NZE is 8% bigger than today (with steel demand increasing in the energy sector, rail and others), for Bataille et al the demand is only 4% bigger. Additionally, even though the analysis of Bataille et al considered country-specific technology choices, its resulting mix of steelmaking technologies per country by 2030 is likely to differ from the NZE.

Employment creation for the steel sector was estimated using a multiplier that offered a relationship between investment levels and job creation. However, as the estimation of this multiplier was based only on figures for only one country (the US), employment creation estimates fail to adequately take into consideration the differences in labour costs and/or productivity levels across each steel producer company and/or country. Therefore, employment levels are likely underestimated for less automated and more labour-intensive economies (eg, China and India). For simplicity and keeping a consistent methodology across countries, we chose to use a standard multiplier rule. As for other sectors, added GDP levels by 2030 were estimated using the NZE's implicit investments-vs-GDP multiplier.

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3. Low-carbon hydrogen sector

As the most incipient of the industries analysed here, clean hydrogen is the sector with the least amount of past information and standardised metrics, which can result in significant variations among projections from reputable sources. As such, this sector required the greatest use of assumptions and multipliers, and so figures in this section should be regarded as indicative. In addition, although our analysis used information from sources that considered the ambitious deployment of hydrogen by 2030 (and are, generally speaking, aligned with the IEA's NZE scenario), these sources did not specifically consider a 1.5°C pathway.

Employment creation, total hydrogen industry cumulative investments by 2030 and specific low-carbon hydrogen cumulative investments by 2030 for France, Germany, Italy and the UK are based in calculations from the EU Fuel Cells and Hydrogen Joint Undertaking. Those investments include R&D, CAPEX and OPEX expenditure for production, distribution and refuelling stations, but we have removed investments and jobs related to clean power production to avoid double counting with previous sections. Using this information, two multipliers were calculated - one capturing the relationship between investment levels and employment creation, and the other between total and low-carbon specific hydrogen investments.

For estimating other country-specific cumulative investments and therefore employment, we used the specific market shares of each country in the global electrolyser market in 2016 as a proxy to understand which countries were "early", "moderate" or "late" adopters of low-carbon hydrogen technologies. This helped us to understand the differences in the investment and market growth dynamics of each of the three categories (information for Germany, Italy and the UK served as the basis for calculating the multipliers, which were then applied to Canada, China, Japan and the US). For India, values were estimated using the country's expected market size by 2030 (in tonnes) and multipliers between it and other variables. Similar to other sectors, added GDP levels by 2030 were estimated using the IEA's NZE implicit investments-vs-GDP multiplier.

Investments, job creation and GDP impact analysis in the low-carbon hydrogen sector assumes that all demand is met with domestic production. Although the cost of transporting hydrogen could represent a large share of its full cost (eg, between 30% and 45% when transporting between Australia and Japan), imports could still be cheaper than domestic production.[133]

4. Electrified road transportation

4.1 Electric vehicles[134]

EV investments were calculated with an "annual EV production gap" approach. Production gaps were estimated as the difference between annual country-specific EV sales by 2030 (under a 1.5°C pathway) and annual country-specific EV sales levels in 2020. Once annual EV production gaps were

[133] IEA (2019b)

[134] Our calculations for EVs and overall car sales/stock considered all light duty vehicles (LDVs), including personal and light commercial vehicles. Throughout this work, the definition of EVs includes battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell electric vehicles (FCEVs

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determined for each country, needed investments by 2030 were calculated using an estimated investment/production multiplier. As the estimation of this multiplier, which is based on figures for only one manufacturer (ie, Ford), it does not adequately account for the differences in capital and labour costs and/or productivity levels across each manufacturer and/or country. For simplicity and keeping methodology consistent across countries, we chose to use a standard multiplier rule.

Country-specific investments for France, Italy, Germany and the UK were obtained by multiplying each country's share in European car sales (2019) by the overall estimated investments needed for EU-28. For Canada and South Africa, country-specific investments were obtained by multiplying each country's share in global car sales (2019) by the overall estimated global investments needed.

For employment creation, we used multipliers (adjusted by the underlying NZE multipliers) to convert country-specific cumulative investment levels into jobs. Similar to other sectors, a generic employment creation multiplier (jobs/investment US$) fails to take into consideration how labour costs and/or productivity levels might vary considerably across countries. This concern is furthered by the fact that investment costs (construction, logistics, capital, etc) per output unit can also vary significantly between countries. Added GDP levels by 2030 were estimated using the IEA's NZE implicit "investments vs GDP multiplier".

Due to a lack of better understanding of the future global dynamics of car production/trade (particularly for EVs), this methodology for estimating employment creation assumes that all country-specific sales are met with domestic production. However, given that LDVs are highly tradable goods, this approach is likely to underestimate job creation in countries with significant automotive exports (eg, China, Japan, Germany and the US).

4.2 EV charging infrastructure

EV-charger investments were calculated using an "EV-charger gap" approach. Gaps were estimated as the difference between country-specific cumulative installed charging power capacity (TW) in 2030, under a 1.5°C pathway, and country-specific cumulative installed charging power capacity (TW) in 2020. Country-specific cumulative installed charging power capacity (TW) in 2030 was estimated assuming a stable relationship between each country's shares of EV sales by 2030 and their demand of EV installed charging power capacity.

Once EV-charger gaps were estimated, needed investments by 2030 were calculated using a multiplier that captured the relationship between investment in dollars and charging capacity (US$/kW). For employment creation, we used multipliers (adjusted by the underlying IEA's NZE multipliers) to convert country-specific cumulative investment levels into jobs. Similar to other sectors, a generic employment creation multiplier (jobs/investment US$) fails to consider how labour costs and/or productivity levels might vary considerably across countries. This concern is furthered by the fact that investment costs (construction, logistics, capital, etc) per output unit can also vary significantly between countries. Added GDP levels by 2030 were estimated using the IEA's NZE implicit investments-vs-GDP multiplier.

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