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AN INTERNATIONAL ASSESSMENT OF FISCAL SPENDING MEASURES TO SUPPORT LOW-CARBON TECHNOLOGIES

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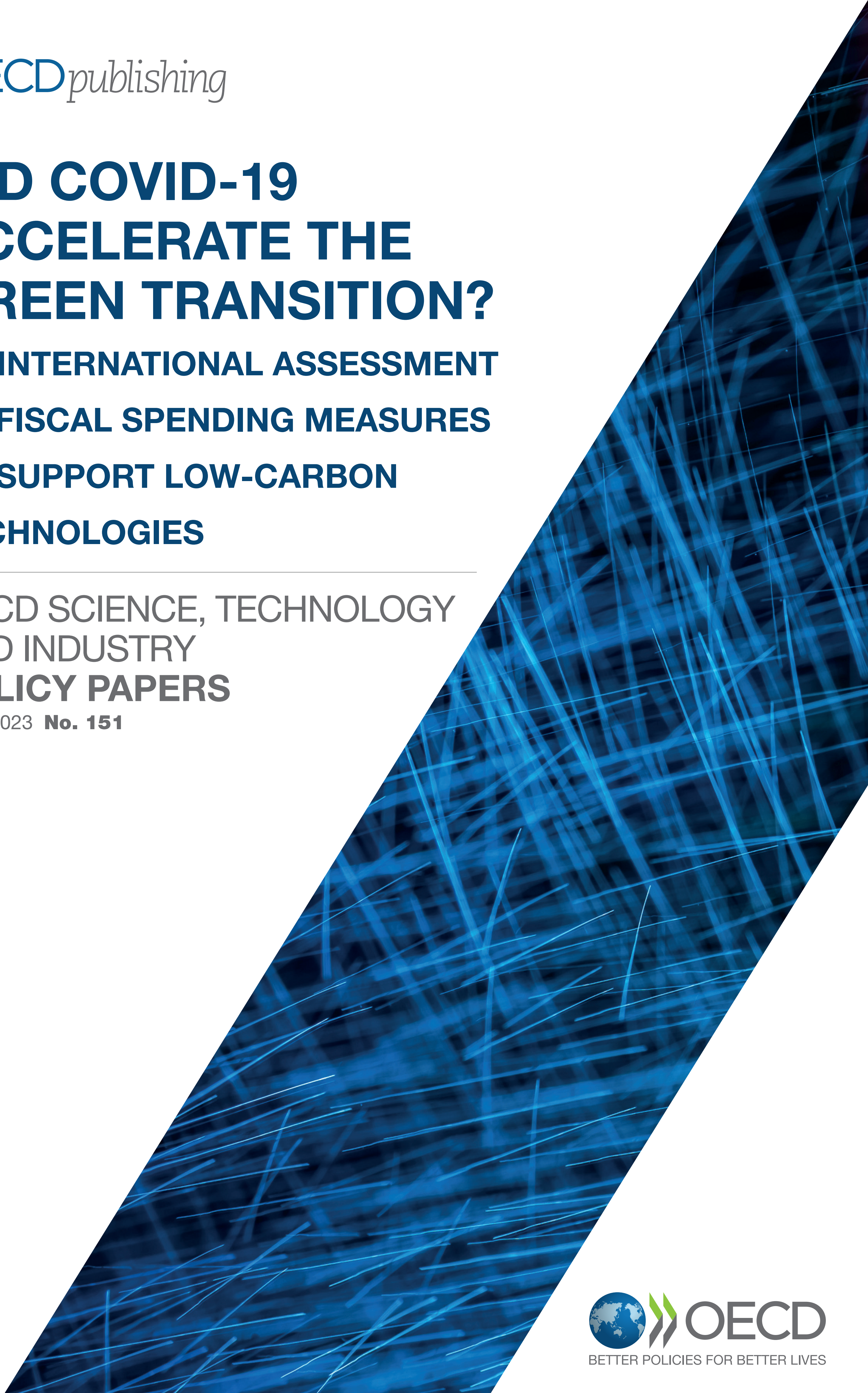

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Did COVID-19 accelerate the green transition? An international assessment of fiscal spending measures to support low-carbon technologies

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Fiscal spending policies adopted in the wake of the COVID-19 pandemic have been presented as a unique opportunity to "build back better" and re-ignite the economy while accelerating the transition to a low-carbon economy. This paper analyses 1 166 funding measures announced by 51 countries and the European Union in 2020-21 to support development and diffusion of low-carbon technologies. These measures – amounting to USD 1.29 trillion – can make an important contribution to filling the climate investment gap, particularly in emerging technologies such as Carbon Capture, Usage and Storage and green hydrogen. A modelling analysis suggests that they could have large impacts on greenhouse gas emissions and bring about significant co-benefits in terms of clean sectors' output growth and reductions in fossil fuel imports.

Keywords: climate change mitigation, low-carbon innovation, technological change, innovation policy

JEL Codes: L52, O38, Q54, Q55, Q58.

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Executive Summary

Fiscal spending policies adopted in the wake of the COVID-19 pandemic have been presented as a unique opportunity to "build back better" and re-ignite the economy while accelerating the transition to a low-carbon economy. This paper analyses the impact of fiscal measures adopted as a response to or in the aftermath of the COVID-19 pandemic on the development and deployment of innovative low-carbon technologies – i.e. innovative technical solutions characterised by a low greenhouse gas emission intensity, compared to existing alternatives.

This work builds on the OECD Low-Carbon Technology Support database (LCTS), a newly developed repository of funding measures announced in 2020-2021 with content fitting such description, encompassing support towards low-carbon technology development, adoption and diffusion. This includes relevant updates to these measures, such as the U.S. Inflation Reduction Act and some EU Member States' Recovery and Resilience Plans. The resulting database comprises initiatives for 51 countries (members of the OECD, the European Union and G20), collectively representing 89% of global GDP and 79% of global annual greenhouse gas emissions. Although coverage may not be complete for all countries, 1166 support measures involving government spending toward low-carbon technologies have been identified, amounting to USD 1.29 trillion.

The analysis shows that around 40% of total low-carbon technology government support has been directed to the energy sector (generation, transmission and distribution), one third to the transportation sector and 14% to the buildings sector. With a mere 4% of the total funding going towards industry – which is responsible for 23% of global CO_2 emissions – appears as the "forgotten" sector of the low-carbon technology public spending measures adopted in the aftermath of COVID-19, although enhanced deployment of renewable electricity may indirectly enable further electrification in the industry sector.

At least 73% of the funding identified is apparently aimed at already mature technologies. Around 7% explicitly targets research and development (USD 54 bn) and demonstration (USD 31 bn), while another 8% targets early-stage technologies. This is a significant contribution towards the development of new technologies that are needed to keep the world on track for net-zero emissions by mid-century. Among early-stage low-emission technologies, hydrogen has been the main priority (especially in the United States, France and Germany), followed by carbon capture utilisation and storage (CCUS) and smart grids. A relatively small part of funding made available through these recovery packages appears to have been dedicated to nuclear innovation, zero-emission buildings and advanced batteries.

Comparing the post-COVID low-carbon technology public funding with estimated additional investment needs to reach net-zero emissions targets by 2050 reveals that the former – while making a welcome contribution to closing the investment gap – falls short of the latter. These measures are not sufficient to put countries on track to meet the net zero target. Assessment at the broad sector level reveals that post-COVID low-carbon technology public funding in OECD countries represents up to 12-14% of the additional annual investment needs in advanced economies in the energy sector and for buildings, up to 5% in road and maritime transport, and up to 9% in industry. This overall shortfall however masks considerable heterogeneity across technologies within each sector. Post-COVID low-carbon technology public funding contributes significantly to closing the investment gap for CCUS, energy efficiency, nuclear power and hydrogen (depending on scenario), but it is relatively smaller in electric vehicles, energy storage, and renewable energy.

A modelling analysis suggests that the measures included in the LCTS database could make an important contribution to GHG emission reductions. In total, GHG emissions are projected to fall by 1150 Mt CO_2-eq in 2030 and by 1400 Mt CO_2-eq in 2050 in OECD and EU countries, compared to a reference scenario in which climate mitigation is limited to pre-COVID climate and energy policies. The introduction of the low-carbon technology support measures captured in the LCTS database is projected to lead to a 12% emissions reduction in 2030 in the EU and North America. Half of this reduction in emissions comes from investments in the power sector, in particular renewable energy. By 2050, 26% of cumulative emissions reductions come from public support to R&D activities conducted between 2020 and 2030. As a consequence, a dollar spent on R&D support induces six times more cumulative emissions reductions by 2050 than the same dollar invested to support adoption. This illustrates the large returns from investing in low-carbon R&D support in the long run and reinforces the case for ambitious innovation policies for the net-zero transition. Low-carbon technology support measures have small positive effects on GDP and employment and trigger significant growth of green sectors such as equipment for wind and solar energy. They also enable significant reductions in fossil fuel imports, especially in Europe, thereby improving energy independence.

In short, government support measures adopted in the wake of the COVID-19 crisis have oriented investment towards sectors and technologies key for the low-carbon transition and could bring about significant emissions reductions. However, they cannot by themselves close the investment gap to reach net zero emissions by mid-century. They must now be accompanied by more ambitious complementary climate policies that would induce private investment and trigger the deeper structural changes made necessary by net zero targets and the current fossil fuel energy price crisis.

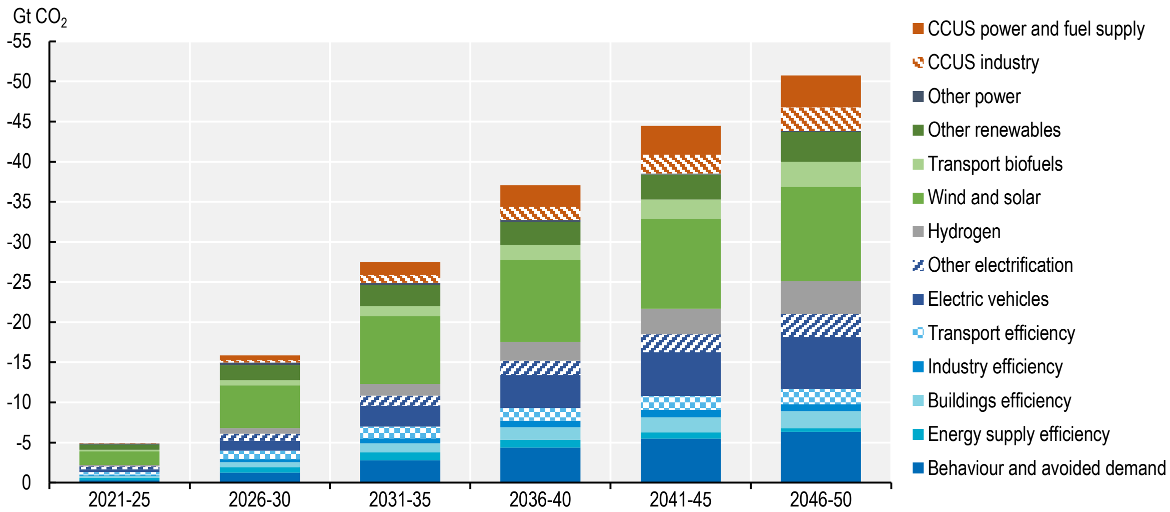
1 Introduction and background

The need for increased investment in low-carbon technologies

Countries representing more than 90% of the world economy have legislated or announced targets of climate neutrality by the mid-century. Reaching this objective requires rapidly adopting zero-carbon energy sources and production processes across all economic sectors (Figure 1) as illustrated by the International Energy Agency's Net-Zero Emissions by 2050 Scenario (IEA, 2021[1]).

Figure 1. The net-zero economy requires system-wide technological change

Average annual CO_2 reductions from 2020 in the IEA's Net Zero Emissions scenario, by source



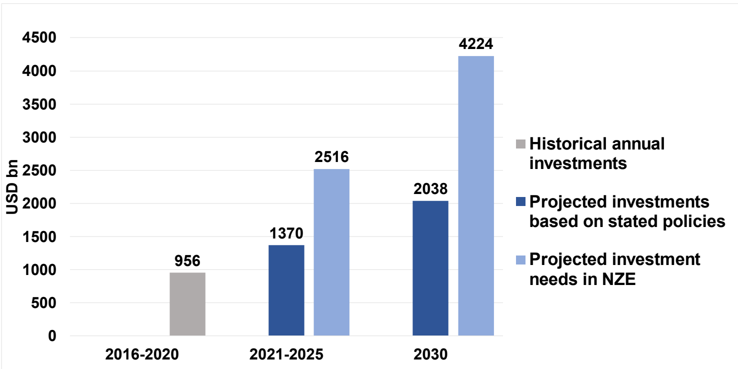
Note: Activity = changes in energy service demand from economic and population growth. Behaviour = change in energy service demand from user decisions, e.g. changing heating temperatures. Avoided demand = change in energy service demand from technology developments, e.g. digitalisation.
Source: (IEA, 2021[1])

Achieving climate neutrality requires both the large-scale deployment of existing low-carbon technologies (such as renewable energy, electric vehicles or insulation material) and the development and adoption of new technologies that are still far from maturity (e.g. green hydrogen, carbon capture and storage). Some of the carbon-free technologies necessary to reach net zero emissions already exist, but their cost needs to be reduced so that they can become fully competitive with carbon-based alternatives and can be deployed rapidly and at scale (IPCC, 2022[2]). Other technologies are still in their infancy (e.g. advanced batteries, hydrogen electrolysers, electrification of production processes, sustainable bioenergy and direct air capture and storage) and need to be further developed.

According to the IEA Net Zero scenario, while most (81 %) of the global reductions in CO_2 emissions through 2030 come from technologies readily available today, nearly half (45 %) of the global reductions in energy-related CO_2 emissions through 2050 will have to come from technologies that are currently at the demonstration or prototype phase (see Figure A A.1). In some sectors like heavy industry and long-distance transport, the share of emissions reductions from technologies that are still under development today is even higher. This requires a very substantive acceleration of the innovation cycle compared to what has been achieved historically for previous waves of low-carbon technologies such as renewable energy or batteries. For example, in the IEA Net Zero scenario, carbon capture, utilisation and storage (CCUS) in cement production is brought to the market by 2024, hydrogen-based steel production and direct air capture by 2026, and most technologies at small prototype stage, such as solid-state batteries, by 2030.

The major emissions reductions implied by the net-zero transition require large investments in the development and deployment of technologies, products, processes and methods that reduce the greenhouse gas (GHG) emissions of production and consumption systems (IPCC, 2022[2]; OECD/The World Bank/UN Environment, 2018[3]). Comparing the IEA's Net Zero Emission 2050 scenario (NZE) to the Stated Policies Scenario (STEPS) – which describes what would happen if all announced policies were actually implemented, but not more – suggests that approximately USD 1.2 trillion average additional annual investments is needed in clean energy investments towards 2025 globally, and USD 2.2 trillion average additional annual investments would be needed by 2030[1] (Figure 2). Power generation represents the largest part of the required additional investments (especially renewable energy). It is followed by end-use technologies (energy efficiency, clean vehicles), alternative fuels (hydrogen-based fuels and biofuels) and electricity networks.

Figure 2. Clean energy investment needs in IEA's NZE scenario compared to foreseen investments under stated policies (IEA's STEPS scenario) and recent investment



Note: These numbers only include clean energy investment, and therefore exclude historical and projected investments in fossil fuels in energy generation without CCUS and coal, oil and natural gas. Also note that for the time periods 2016-2020 and 2021-2025, we display average annual spending *during* the two periods, but for 2030, we only display average annual investments *in* 2030. This is due to difference in data availability.
Source: (IEA, 2022[4]); detailed dataset behind World Energy Outlook 2022 and Box 1.A (IEA, 2022[5])

For research, experimental development and demonstration (RD&D) specifically, the IEA (2021[1]) reports that at least USD 90 billion of public funding needs to be raised by 2026 to complete a portfolio of demonstration projects for technologies that could be commercially ready by 2030 and contribute to achieving net zero emissions by mid-century.

The scale of the transformation needed is such that neither the private sector nor governments will be able to provide the necessary investment on their own. Over the 2016-2020 period, the IEA reports that 63% of the USD 56 billion invested annually globally in energy projects was funded by private actors. This proportion is higher in advanced economies (89%) than in emerging and developing economies (excluding the People's Republic of China – hereafter, 'China' – 54%) (IEA, 2022[4]). Going forward, The Race to Zero coalition suggest that governments or public entities (including sub-national governments and local authorities) would provide around 30% of this financing globally, while private actors would provide the remaining 70% (Vivid Economics, UNFCCC Race to Zero campaign and the Glasgow Financial Alliance for Net Zero, 2021[6])

Governments thus have a dual role to play. First, mobilizing private finance by putting in place the right incentives via climate policy packages that support the rapid and radical transformations required (Fay, 2015[7]). These should involve pricing carbon and removing fossil fuel subsidies, non-market based policies such as emissions standards and regulations and complementary policies to facilitate the reallocation of capital and labour towards low-carbon activities and to offset the adverse distributional effects of reducing emissions (D'Arcangelo et al., 2022[8]). Secondly, directly investing into low-carbon technologies. This includes investment support to research and development – both via public R&D expenditure and support to private R&D activities –, subsidies for demonstration projects, support to scale-up and deployment (via e.g. advanced market commitments, guaranteed public procurement, direct subsidies, etc.) as well as direct funding of low-carbon infrastructure at scale (Cervantes et al., 2023[9]).

Low-carbon technology support policies introduced during the COVID-19 crisis

The COVID-19 crisis and the associated lockdowns across the world led to a massive drop in economic output.[2] Governments responded by implementing rescue and recovery packages and other fiscal measures to support economic activity in addition to protecting public health. In the two years following the start of the COVID-19 pandemic, national governments and the European Union announced up to USD 18 trillion dedicated to rescue and recovery economic stimulus as a response to the COVID-19 crisis, where approximately USD 3 trillion was marked as recovery funding, and the rest as short-term relief rescue (O'Callaghan et al., 2021[10]). Stimulus packages were based on long-term oriented public investment. The Russian Federation's (hereafter, 'Russia') war of aggression against Ukraine and the energy price crisis that followed gave further impetus to expansionary policies: the provision of public funding is particularly important in the context of high economic uncertainty, as it induce firms to reduce or postpone investment and innovation activity as well as to reduce access to financing (Baker, Bloom and Davis, 2016[11]).[3]

This massive intervention by public authorities around the world could give an important impulsion to the development and deployment of low-carbon technologies. Encouraging a low-carbon shift has been a priority in the aftermath of the COVID-19 pandemic, and many governments integrated a significant environmental dimension into their stimulus packages, alongside digitalization, health systems and social infrastructure. The EU, for example, imposed that 37% of the Next Generation EU stimulus package be targeted at supporting the green transition. Recovery packages and post-COVID fiscal stimulus were thus presented as a way to "build back better" and address pressing environmental issues (in particular climate change) at the same time as the economic downturn (OECD, 2022[12]). Evidence shows that green stimulus funding adopted in the wake of the Global Financial Crisis of 2007-08 contributed to generating economic growth and creating jobs while positively impacting the environment, although there are usually trade-offs between those objectives (Agrawala, Dussaux and Monti, 2020[13]). Box 1 summarises the main features of the GFC stimulus and its estimated effect on low-carbon technologies.

Box 1. Lessons from the Global Financial Crisis for a green transition

Key features of the GFC stimulus

- Short-term fiscal stimulus mostly concerned with boosting firm and household spending to provide relief to vulnerable households and SMEs that were most at risk.
- Medium-to-long-term fiscal stimulus concerned with infrastructure investment and technological development, with some environmental focus.
- Existing estimates suggest that 16% of all fiscal stimulus (over USD 500 billion) was directed toward activities with a positive environmental impact, such as renewable energy deployment or subsidies for electric cars and for insulation works (Robins, 2010[14]).

Main take-aways from research concerning the impact of GFC stimulus on low-carbon technologies

- Policies supporting the generation of electricity from renewable energy sources were effective at boosting innovation and deployment and at reducing emissions, but less so at creating jobs. For example, the 2009 American Recovery and Reinvestment Act largely contributed to the 50% reduction in capital costs for solar PV in the period 2008-2014 and saved 8.6 Mt CO_2 annually (Council of Economic Advisors, 2016[15]), the number of renewable energy technology patents issued by the US Patent Office grew from 2009 to 2012 (Mundaca and Luth Richter, 2015[16]). On the other hand, the job effects of renewable energy support were relatively small.
- Subsidies to fuel-efficient vehicles may also have had mixed effects. The U.S. low fuel efficient car scrappage programme (CARS) may have saved 9-28 Mt CO_2 emissions (Mian and Sufi, 2012[17]), but the cost per job created was estimated at USD 1.4 million, which is much higher than alternative fiscal measures (Gayer and Parker, 2013[18]).
- Policies supporting energy efficiency in buildings seem to have been effective at creating jobs in the short run, but their impact on emissions has been small, in particular because of significant rebound effects in energy demand (Agrawala, Dussaux and Monti, 2020[13]).
- Despite the fact that many governments provided support to clean technology development (Pollitt, 2011[19]), support to technology and innovation under the GFC stimulus did not work as well as planned. Among projects supporting R&D and demonstration of CCS technology, only one was eventually completed in the EU (European Commission, 2018[20]), and in the U.S., the US Department of Energy (DOE) returned USD 1.3 billion of the initial CCS project support to the US Treasury Department in 2016, because the projects could not be realised.

Source: The information in this box draws heavily on (Agrawala, Dussaux and Monti, 2020[13]).

Throughout the course of the pandemic and as many countries announced and implemented fiscal stimulus measures, various initiatives by think-tanks, research institutes and international organizations tracked and analysed countries' new fiscal measures, many presented as part of recovery packages. These include Oxford University (together with IMF, UNEP, GFPN, GIZ) (O'Callaghan et al., 2021[10]), the IEA (2022[21]), the OECD (2022[12]), the Wuppertal Institute together with E3G (2021[22]), Vivid Economics (2021[23]), IISD (together with IGES, OCI, ODI, SEI, Columbia University) (Energy Policy Tracker, 2021[24]), Bruegel (Darvas et al., 2022[25]) and Nahm, Miller and Urpelainen (2022[26]).

According to the most comprehensive "recovery trackers", green[4] stimulus funding was higher after COVID-19 than after the GFC. The OECD Green Recovery Database reports that approximately 30% (around USD 1.1 trillion) of "recovery" measures was positively environment-related, and the Global Recovery Observatory (GRO) reports that measures representing approximately USD 1 trillion can contribute to the reduction of greenhouse gas emissions. Nahm, Miller and Urpelainen (2022[26])[5] report similar results. For countries in the European Union, the Green Recovery Tracker (Wuppertal Institute and E3G, 2021[22]) finds a similar percentage of green measures in total COVID-related public spending.

Objectives and outline

The objective of this report is to present evidence on the impact of fiscal measures adopted in response to or in the aftermath of the COVID-19 crisis on the development and deployment of low-carbon technologies across countries, sectors and innovation stages. The analysis is based on a new custom-developed database – the OECD Low-Carbon Technology Support database (LCTS). Created for the purpose of informing these questions, it covers all low-carbon technology support measures announced from February 2020 until December 2021. The new LCTS database focuses on measures with the potential to mitigate climate change via support towards development or adoption of low-carbon technologies. This excludes support for natural resource development activities that, while contributing to net zero objectives, such as reforestation initiatives, fall outside the scope of this exercise. Support measures are broken down by sector (e.g. transport, energy generation), technology (e.g. green hydrogen, solar PV, CCS, etc.) and by the targeted phase of the innovation cycle (research and development, demonstration, deployment) when information is available. The methodology and resulting dataset are described in the next section.

Estimates of public investment in low-carbon technologies are then compared to investment needs and carbon emissions reduction potential as available from existing modelling analyses, such as the IEA's Net Zero Scenario, in order to understand where remaining investment gaps are largest. While these could be filled by future public investment programmes, effective action may also require adoption of complementary policies to incentivise private investment. The potential impact of the measures included in the LCTS database on greenhouse gas emissions is also explored through an additional modelling exercise.

This paper is organised as follows. Section 2 presents the methodology used to create the database constructed for the purpose of the study and provides a descriptive analysis with a detailed breakdown of funding by region, economic sector, technology, and innovation stage. In section 3, announced investment budgets are compared with the investment needs reported in various decarbonisation scenarios. In section 4, results from a modelling exercise are presented, showing potential greenhouse gas emission reductions induced by the measures and macroeconomic impacts on GDP and labour markets. Section 5 offers conclusions and policy recommendations.

2 Methodology and data

Methodology

The construction of the LCTS database focused on identifying fiscal measures, adopted in response to or in the aftermath of the COVID-19 pandemic, with the intention of accelerating the development or deployment of low-carbon technologies across the economy. Box 2 describes in some detail the scope and key characteristics of the database. The LCTS includes measures announced from February 2020 to December 2021, including significant revisions and updates to these measures made after December 2021 where relevant, such as the U.S. Inflation Reduction Act (IRA) or European Union member states' Recovery and Resilience Plans (RRP).[6] While funding announcements made throughout this period may have included recurring investments prior to the COVID-19, they mostly concerned newly purposed resources for green technology. Hence, the focus on "recovery" announcements implies that most baseline government spending in green technology is not captured in the LCTS.

To analyse the impact of post-COVID public spending on low-carbon technologies, the LCTS database builds on two regularly updated green recovery trackers: the OECD Green Recovery Database (OECD, 2022[12]) and the Global Recovery Observatory (GRO) (O'Callaghan et al., 2021[10]), developed by Oxford University's Smith School of Enterprise and the Environment. These two datasets have a similar geographic coverage, focusing on OECD countries and selected large economies.[7] Both distinguish between rescue and stimulus/recovery measures, include some basic binary information on expected environmental impacts of the policies (positive or negative) and information on the type of policy (investment in R&D, adoption subsidies, etc.). However, their level of detail and coverage differs, for example in terms of types of measures, budget allocation, targeted technologies and their innovation stages. From the above sources, recovery measures with a direct or indirect positive environmental impact adopted by OECD, EU and G20 countries were considered for inclusion in the LCTS database when there was sufficient information to indicate that such measures fell within the technology support scope of the LCTS database.[8]

The combination of selected elements from the GRO and OECD Green Recovery databases was complemented by manual cleaning (e.g. to avoid potential double counting of budgets) and extensive information gathering directly from available government sources. 378 measures (out of 1166) were added by collecting information from government sources. Particular attention was paid to identifying the supported technologies, their sector of application and their potential stage in the "innovation cycle". Secondary data sources were used for confirmation and validation. An important element of the exercise focused on contrasting and enhancing the database with information from the "STI policies for net zero portal", a collaborative undertaking between the EC, IEA and OECD providing information on STI policies that explicitly support the transition to net zero. The portal's policy data has been collected via the EC-OECD STIP Survey and the IEA's Policies and Measures Database (PAMS). (EC-OECD, 2021[27])

Each measure in the LCTS database was allocated to a sector of activity: energy, buildings, transport, industry, agriculture, CCUS, water/waste management and other activities. Each measure is also linked with a specific technology, such as renewable energy generation, electric vehicles or energy efficiency in buildings. Finally, the innovation stage of the targeted technology is categorised by reference to guidance elements and definitions in the OECD Frascati Manual (OECD, 2015[28]) (R&D and boundaries), the IEA framework for measuring public support for RD&D (IEA, 2022[29]), the Oslo Manual on measuring innovation (OECD/Eurostat, 2018[30]) as well as academic literature and the IEA Technology Roadmaps[9].

Box 2. Inclusion criteria and key characteristics of the dataset

The Low-Carbon Technology Support (LCTS) database focuses exclusively on fiscal measures (usually adopted as part of COVID-19 recovery packages) whose objective is to support the development or diffusion of low-carbon technologies.

To be included, a measure must imply the use of government spending and have been announced as a reaction to or in the aftermath of the COVID-19 pandemic. Only measures whose aim is to deliver long-term economic or environmental benefits are considered: short-term rescue measures are excluded. Measures also need to be additional with respect to baseline policies, i.e. completely new measures or significant budgetary expansions of pre-existing measures.

Not all measures that contribute to reducing or capturing greenhouse gas emissions (such as reforestation projects) are within scope. The focus is on measures that support the development or adoption of low-carbon technologies, namely ultimately contributing to the adoption and diffusion of state-of-art **technical solutions characterised by a low greenhouse gas emission intensity**, compared to existing alternatives.

The LCTS database includes measures announced **from February 2020 until December 2021 and updates to these measures made after December 2021** where relevant (e.g., the U.S. IRA and some updated EU Member States' Recovery and Resilience Plans). There can be a lag between investment announcement and when these become publicly accessible, which implies that some low-carbon technology measures are not included in the LCTS database.

The LCTS database includes **1166 measures totalling USD 1.29 trillion worth of announced spending (not necessarily actual disbursements)**. The data includes measures adopted by **51 economies,** including members of the OECD, the European Union and G20, (which account for 89% of global GDP and 79% of global annual CO_2-eq emissions) although coverage for non-OECD and EU members is likely to be less comprehensive.

In the final stage of the data construction process, a validation exercise was carried out by delegates to the OECD Committee on Industry, Innovation, and Entrepreneurship (CIIE) and to the Committee on Science and Technology Policy (CSTP). Delegates affiliated with these committees were invited to validate the information collected by the OECD Secretariat. The validation exercise allowed delegates to review the measures listed, add new measures to the database, and, if needed, correct information gathered by the Secretariat. Final adjustments were made to the dataset once comments were received from the OECD member countries.[10]

In total, 1166 measures are included in the LCTS database, including 788 initially extracted from the GRO and OECD databases (for which additional details were added) and 378 measures added (amounting to USD 569 billion, of which USD 412 billion was related to the US Inflation Reduction Act). Examples of measures included in the dataset are shown in Table 1.

Table 1. Examples of low-carbon technology measures in the LCTS database

Description	Country	Sector	Technology	Amount (million USD)
Thermal renovation of public buildings	France	Construction	Energy efficiency in buildings	4731
Electric charging infrastructure development	Italy	Transport	Charging infrastructure for electric vehicles (EV)	875
Promotion of new renewable energy (solar) projects in the amount of 2000 megawatts	Israel	Energy	Renewable energy - Solar PV	2012
Clean Energy Future Fund in Western Australia to invest in clean energy technologies (Strike Energy's Mid-West Geothermal Project)	Australia	Energy	Renewable energy – geothermal	2
Carbon capture and storage project ('Langskip' project), including funding for the transport and storage project Northern Lights.	Norway	CCUS	CCS	1956
Grants for improvements to bus transportation facilities and vehicles, including improved service provision and reduced environmental impact (IIJA)	United States	Transport	Low-emission buses	3161
Improved energy subsidy scheme of the Flemish Region – smart control	Belgium	Construction	Energy efficiency in buildings	24
Limonense Electric Freight Train	Costa Rica	Transport	Rail infrastructure	450
Development of next-generation storage batteries and next-generation motors	Japan	Industry	Advanced batteries and motors	1376

Note: The exchange rates applied in this table correspond to the yearly average of 2021.
Source: OECD Low-carbon Technology Support database (version May 2023).

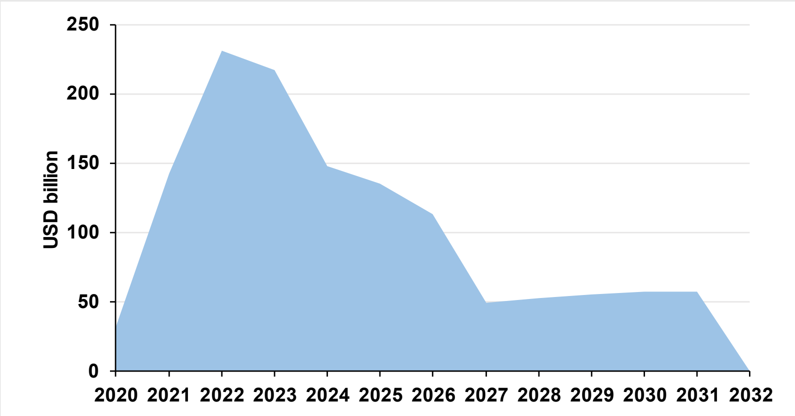
For most measures, the amount of fiscal spending corresponds to the measure's budget as indicated in official documents. For tax credits whose fiscal cost is unknown as it depends on future uptake and no overall budget cap is assigned (41 measures in total), the analysis uses official cost estimates provided by governments. This is especially the case of the US Inflation Reduction Act (25 tax credit measures in the LCTS database), for which the amounts correspond to estimates published by the Joint Committee on Taxation in August 2022.[11]

Data overview

The LCTS database includes measures adopted by 51 countries (members of the OECD, EU and G20) which collectively represent 89% of global GDP and 79% of global annual CO2-eq emissions. The database includes a total of USD 1.29 trillion of announced spending.

The announced measures are intended to be disbursed across several years, with some measures planned all the way until 2032. Figure 3 shows the distribution of this total public spending over time. Most of the public spending (60%) was planned to be disbursed within the years 2020-2024, 30% between 2025 and 2029, and the remaining 10% from 2030 onwards.

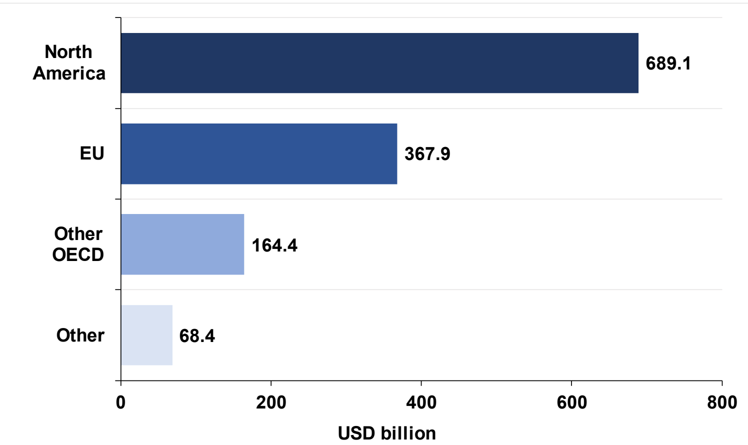
Figure 3. Planned disbursement of post-COVID low-carbon public spending



Source: OECD Low-carbon Technology Support database (version May 2023).

Figure 4 presents the distribution of the total post-COVID low-carbon technology public funding across regions in the LCTS database. 14 countries budgeted over USD 10 billion for low-carbon technology support in fiscal packages adopted during the COVID-19 crisis. Most of the global low-carbon technology funding is budgeted in North America. The investments planned by the United States account for more than 48% of total low-carbon technology public funding (USD 616 billion), the main contributions being the Inflation Reduction Act (USD 412 billion) and the Infrastructure Investment and Jobs Act (USD 199 billion). Italy and the United Kingdom follow, with respectively 8% and 6% of the total investments in the database.

Figure 4. Total public funding by region in the Low-carbon Technology Support database



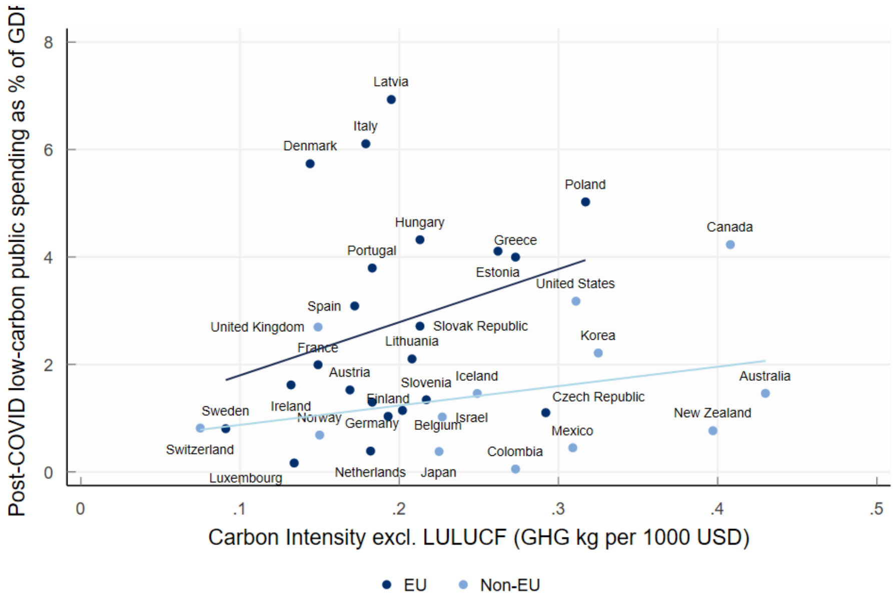
Note: This chart provides a geographical disaggregation of funding for the measures covered in the LCTS database. North America includes Canada, the United States and Mexico. EU includes all 27 EU member states, both OECD and non-OECD members (Bulgaria, Croatia, Cyprus, Malta, Romania). Other OECD includes other OECD member countries (excluding EU countries, Canada, Mexico and the US). “Other” includes selected key partners and G20 economies that are neither member of the OECD nor of the EU (Argentina, Brazil, China, India, Indonesia, Russia, Saudi Arabia and South Africa). Note that this category has less comprehensive coverage of public funding measures and thus is left out of some of the analyses presented in the rest of the report.
Source: OECD Low-carbon Technology Support database (version May 2023).

On average, OECD countries budgeted 2% of one year’s GDP for low-carbon technology support, while the share for non-OECD countries is significantly lower (0.55% of one year of GDP). Out of the 10 countries with the highest planned investment in low-carbon technology (measured as a share of annual GDP), nine countries are members of the European Union. The full list of countries and their low-carbon spending is available in the Annex, Figure A A.2 (amount) and Figure A A.3 (share of GDP).

Figure 5 shows the relationship between post-COVID low-carbon public spending (as a share of one year of GDP) and emission intensity in 2020 (GHG emissions in kg per 1000 USD of GDP). It shows a positive correlation between countries' low-carbon public spending in GDP and emission intensity (with the slope of the relationship greater for EU than for non-EU countries): more emission-intensive countries made greater public investment in low-carbon technologies as part of their post-COVID packages, suggesting these countries used the crisis as an opportunity to catch up with more carbon-efficient economies.

Figure 5. Post-COVID low-carbon public spending in GDP and GHG intensity of the economy

Excluding Land Use, Land-Use Change and Forestry (LULUCF)

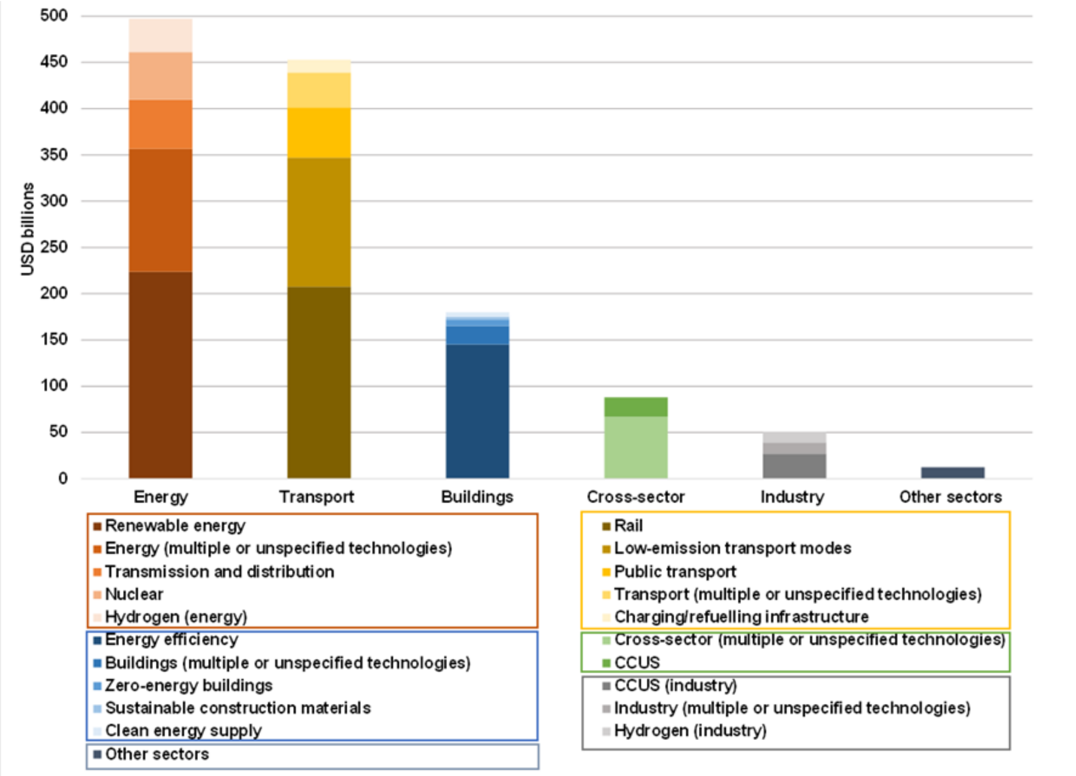


Note: The x-axis shows carbon intensity per country as kilogramme of greenhouse gas emissions per 1000 USD, the y-axis shows low-carbon technology public spending as a percentage of one year of the country's GDP. Greenhouse gas emission numbers are from 2020, GDP numbers are from 2020 for most countries, except for Chile, Colombia, Israel, Korea, Mexico, where GDP numbers are from 2018. Türkiye and Chile are dropped as there are no reported monetary values for these countries in the database.
Source: OECD Statistics: Greenhouse Gas Emissions (OECD, 2023[31]), OECD Statistics: Gross Domestic Products (GDP) (OECD, 2023[32]); OECD Low-carbon Technology Support database (version May 2023).

Support across economic sectors

Figure 6 shows the breakdown of announced funding by sector and technology. In total, around 40% (USD 490 bn) of all low-carbon technology public funding is dedicated to energy generation, transmission, or distribution. Over a third (USD 450 bn) of the funding targeted the transportation sector. The buildings sector represents 14%, while the industry sector is the recipient of a mere 4% of the total funding. Finally, 7% of funding was dedicated to technologies with applications across several sectors (in particular CCUS). Country-specific distribution is available in Figure A A.4.

Figure 6. Post-COVID low-carbon public spending by sector and technology



Note: For each sector, a proportion of spending can be dedicated to multiple technologies within the sector, or to the sector in general but not to specified technologies. Measures amounting to around USD 90 billion target more than one sector ("cross-sector"). These measures target either multiple technologies across multiple sectors, or do not specify the low-carbon technology, such as measures targeting "green/clean/low-emission technologies", "green transition", etc. The category "other sectors" includes agriculture (USD 6.7 bn), water and waste management (USD 3 bn) and education/skills (USD 2.5 bn). Measures not targeting any sector or technology in particular (USD 8.5 bn) are excluded.
Source: OECD Low-Carbon Technology Support database (version May 2023).

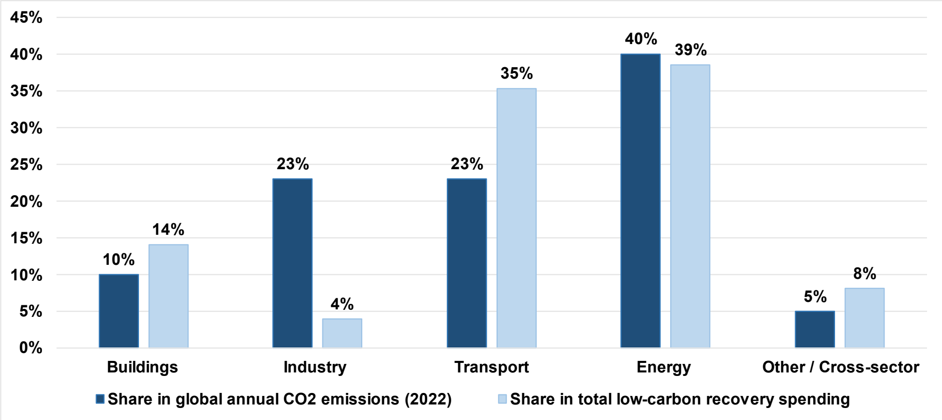
Within energy generation, transmission and distribution, 45% of spending is channelled towards renewable energy, with solar PVs and wind power as the main targeted technologies. 27% of spending targets multiple technologies within the energy sector. The remaining 29% is equally spread between nuclear energy (10%), transmission and distribution of electricity (11%) and hydrogen production (7%).

In the transportation sector, almost half of the spending is channelled towards upgrading, expansion and electrification of railways, followed by support for low-emission transport modes, such as electric vehicles (EVs), hybrid vehicles, hydrogen vehicles and battery production for electric vehicles (31%). 12% of spending targets public transport infrastructure, such as trams, metros and cycling pathways, with the remaining funding targeting charging/refuelling infrastructure and multiple technologies.

Finally, energy efficiency measures, such as insulation and renovation, improved home appliances, lighting, and heat pumps make up most of the low-carbon technology public funding related to buildings (81%). Within industry, measures supporting CCUS and hydrogen for industrial processes stand for 53% and 23% of funding, respectively. The remaining 24% target multiple technologies within the industry sector.

Figure 7 compares the distribution of low-carbon technology public spending with sectors' contribution to global emissions. While both distributions appear to broadly match, a significant gap between the amount of public spending targeting the industry sector and that sector's contribution to global GHG emissions is apparent. As pointed out by the IEA (2020[33]), the industry sector faces several unique challenges when it comes to reaching net zero emission targets, such as long-lived capital assets (30-40 years for plants in heavy industries), high-temperature heat equipment, process emissions (from chemical reactions) and exposure to competitive global markets (e.g. in steel, aluminium, and primary chemicals production). In this respect, post-COVID packages seem to have missed the opportunity to provide support to the industry sector commensurate with its emissions and the specific challenges it faces to decarbonise, even though deployment of renewable electricity and other cross-sectoral improvements may indirectly enable further electrification in the industry sector.

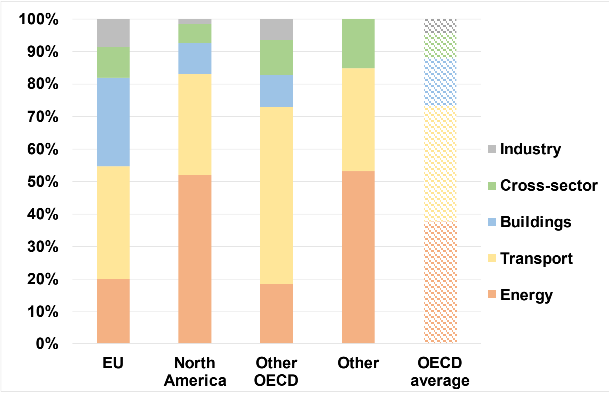
Figure 7. Distribution of global energy-related greenhouse gas emissions and low-carbon technology spending to different sectors



Note: Post-COVID public investments not targeting any sectors or technologies (USD 8.5 bn) are excluded from this graph.
Source: OECD Low-carbon Technology Support database (version May 2023), IEA Global energy-related CO_2 emissions by sector (IEA, 2022[34])

Figure 8 presents the distribution of low-carbon public funding across sectors by region. Transportation and energy received the majority of funding in all regions. North America (Canada, Mexico and United States) allocated over half of government funding to the energy sector (52%). The financing is mainly intended to support energy production, particularly via renewables and nuclear energy. In the European Union, more than a third of the funds (35%) are allocated to the transport sector, in particular rail networks, public transportation and electric vehicles. The EU stands out as the region with the greatest focus on the buildings sector, with 25% of their total funding.

Figure 8. Post-COVID low-carbon technology public spending by sector and region

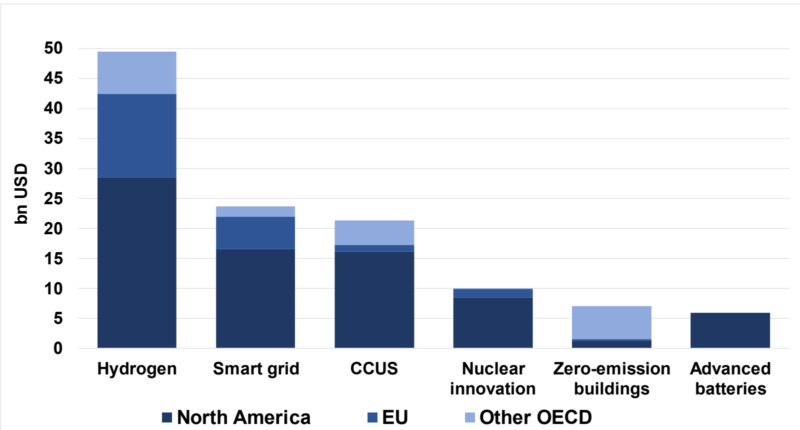


Note: The last column (striped) shows the average percentage of low-carbon technology spending to each sector across OECD countries. Post-COVID public investments not targeting any specific sectors or technologies (USD 8.5 bn) are excluded from this graph.
Source: OECD Low-carbon Technology Support database (version May 2023)

Support to emerging technologies

Funding dedicated to specific emerging technologies amounts to close to 9% of all low-carbon public funding (ca. USD 118 bn). Figure 9 shows that among emerging technologies, hydrogen has been the main priority, with measures amounting to USD 49.5 billion (3.8% of total funding). Approximately 1.8% of low-carbon public funding was channelled to smart grids (USD 23.7 bn), 1.7% to CCUS (USD 21.4 bn) and 0.8% (USD 9.9 bn) to nuclear innovation (Small Modular Reactors, Advanced Modular Reactors). Lastly, 0.5% of funding is dedicated to zero-emission buildings and to advanced batteries.

Figure 9. Post-COVID low-carbon public spending in emerging technologies across regions



Source: OECD Low-carbon Technology Support database (version May 2023)

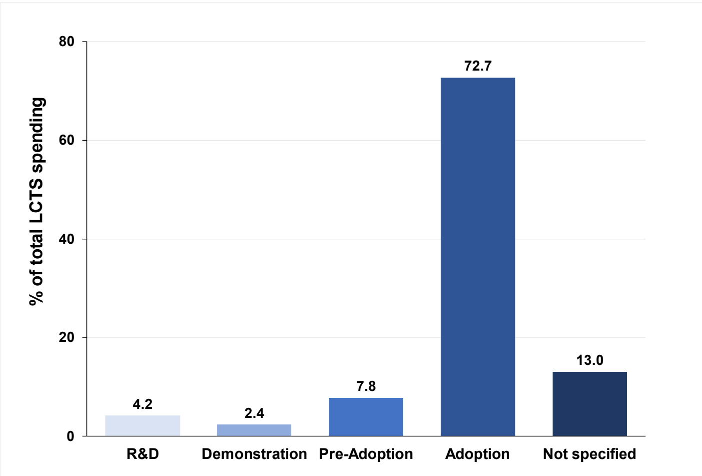
Figure 9 also shows the geographic origin of funding for these low-carbon technologies. In general, most of the funding targeted at emerging technologies comes from North America, with USD 28.5 billion for hydrogen, USD 16.6 billion for smart grids and USD 16.1 billion for CCUS. In percentage terms and relative to other geographies, North America has a strong presence in advanced batteries and nuclear energy, with over 85% of support measures globally. The EU has a strong focus on hydrogen, where it accounts for almost a third of the total funding targeted at emerging technologies (28.1% or USD 13.9 bn).

Looking more closely at how different countries prioritised emerging technologies within their national low-carbon technology measures, hydrogen has been the main priority in Japan and many EU countries (including Belgium, and Germany), while CCUS received priority in Norway, Japan and Denmark. Smart grid technology played an important role in Hungary, Estonia, Italy, and Korea, while low-emission buildings dominate in Korea and the Czech Republic. In contrast to other countries, the United States spread efforts across several emerging technologies, including hydrogen, CCUS, smart grid, nuclear innovation and advanced batteries. See Figure A A.5 for more details[12].

Support for R&D and demonstration activities

Figure 9 show that most of the low-carbon technology public funding has been used to scale up existing technologies, as opposed to targeting technologies at early stages of development, although this focus on deployment of mature technologies varies significantly across countries. Figure 10 shows that overall, roughly 6.5% of total green funding was channelled towards support for R&D (ca 4.2% or USD 53.6 billion) and demonstration projects (ca 2.4% or USD 30.4 billion). An additional 7.8% (USD 100 bn) of low-carbon public spending is channelled at emerging technologies at the pre-adoption stage based on their Technology Readiness Level (TRL)[13], not specifically mentioning R&D or demonstration. In total, therefore, around 14.3% of post-COVID funding targets pre-commercialisation phases, while 72.7% adoption and deployment phases (13% of funding cannot be linked with any innovation stage). Globally, emerging technologies in the research and development, demonstration and pre-adoption innovation stages received USD 184 billion. The trends in distribution of funding channelled to different innovation stages are similar across regions (Figure A A.6). On a country level, focus of low-carbon technology public funding on various innovation stages differs (for further detail see Figure A A.7).

Figure 10. Spending by innovation stage as a percentage of total low-carbon technology support

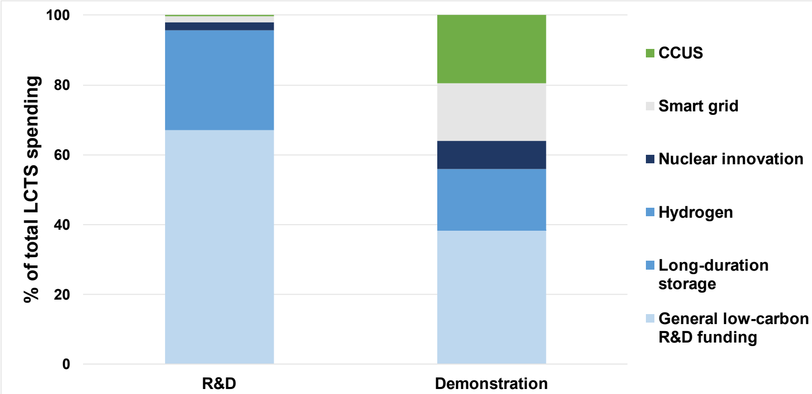


Note: Measures are categorised as "Research and Development (R&D)" if they explicitly mention "R&D" and categorised as "Demonstration" if they explicitly mention "pilot (project)", "prototypes", "limited number of projects", 'trials", "demonstration", "test/testing", or "laboratory for the development of ...". Measures are categorised as "Pre-Adoption" based on the Technology Readiness Level (TRL) or if spending relates to other emerging technologies, not specifically mentioning R&D or demonstration. The remaining funding in the Low-carbon Technology Support database supports measures which target the adoption phase, several phases or for which the innovation stage cannot be specified.
Source: OECD Low-carbon Technology Support database (version May 2023)

Figure 11 shows that most R&D support does not target any specific technology but is instead made available to support low-carbon R&D in general. Examples include the first call for proposals under the EU Innovation Fund for demonstration of innovative low-carbon technologies (USD 1.2 bn), Austria's investment package for R&D innovations in firms in the field of climate protection and future technologies (USD 0.4 bn) and Norway's increase in the budget of the Climate and Energy Fund to support green technology development in areas such as hydrogen, battery technology, offshore wind and green shipping and other renewable energy projects (USD 0.23 bn).

Among technologies specifically targeted, hydrogen ranks first in terms of funding for both R&D and demonstration. For example, the US Infrastructure Investment and Jobs Act included a USD 8 bn measure to finance research that demonstrates the commercialisation of clean hydrogen production and use in the transportation, utility, industrial, commercial and residential sectors. Japan dedicated USD 1.8 bn to research projects related to hydrogen use in steelmaking processes via the Green Innovation Fund. Whereas a large portion of funding at the demonstration stage supports CCUS, nuclear innovation and smart grid technology projects, funding for the R&D stage of the same technologies remains limited.

Figure 11. Distribution of spending across technologies within measures targeting RD&D



Note: The category "General low-carbon R&D funding" includes funding related to measures specifically supporting research and development or demonstration, but that do not target any specific technology. This category includes broader low-carbon measures and sector-specific but not technology-specific measures.
Source: OECD Low-carbon Technology Support database (version May 2023)

There is a negative relationship between countries' spending on R&D as a percentage of GDP and the share of post-COVID low-carbon spending dedicated to RD&D, suggesting that countries with relatively weaker focus on R&D spending may have used the fiscal measures adopted during the COVID-19 crisis as a catch-up opportunity, consistent with the findings presented in Figure 5 on GHG intensity and post-COVID low-carbon technology support in GDP. No correlation is observed between low-carbon innovation performance (measured by the share of patents protecting climate-related technologies in total patenting activity of the country) and the proportion of post-COVID public spending to research, development, and demonstration efforts. (For further details see Figure A A.8).

3 Comparison with investment needs in low-carbon technology to reach climate targets

This section compares funding for low-carbon technologies made available via fiscal measures announced as a response to or in the aftermath of the COVID-19 crisis to global investment needed to reach the carbon neutrality target by mid-century, with the objective to assess the remaining "investment gaps".

Various studies have quantified the investments needed to ensure the deployment of low-carbon technologies at the necessary scale. These models however differ in several respects, for example in the choice of methodology (top-down versus bottom-up approaches), full versus incremental costs and the exclusion or inclusion of consumer-level investments (IPCC, 2022[2]). These differences in methodology can generate diverging investment needs in low-carbon technologies and innovation.

This section relies on IEA estimates for low-carbon investment needs, while acknowledging that other estimates are available. It focuses on two widely used IEA scenarios: the Sustainable Development Scenario (SDS) and the Net Zero Emission 2050 Scenario (NZE). Box 3 gives a brief overview of the various scenarios.

In the SDS and the NZE, USD 3.3 trillion and USD 4.2 trillion, respectively, would need to be invested globally in clean energy annually by 2030. Existing policies are expected to induce USD 2 trillion of annual investments by 2030 (IEA Stated Policies scenario - STEPS), implying that USD 1.3 trillion and USD 2.2 trillion is needed in additional annual investments by 2030 to achieve the SDS and NZE scenarios, respectively, including both private and public financing.

Box 3. IEA scenarios used in this report

This report uses three scenarios from the IEA to benchmark the measures in the LCTS database: the Net-Zero Emissions scenario by 2050 Scenario (NZE), the Sustainable Development Scenario (SDS) and the Stated Policies Scenario (STEPS). These scenarios project GHG emissions from energy and industrial processes, in addition to annual average investments in energy. The scenarios are used to compare annual investments required in clean energy with fiscal spending measures in the LCTS database (Chapter 25), and to compare GHG emissions reductions with modelled impacts of fiscal spending measures (Chapter 4).

The NZE is an ambitious pathway scenario, with the aim to achieving net zero CO_2 emissions by 2050 and a rapid reduction in non-CO_2 emissions, limiting temperature rise to 1.5 °C (IEA, 2021[35]). It describes feasible sector-specific emissions reductions pathways to achieve net-zero CO2 emissions by 2050.

The SDS is also a pathway scenario, but here the aim of reaching net-zero emissions is achieved around 2070. The 1.5 °C target is exceeded in the early 2030s but global warming remains limited to

1.7 °C around 2050 (IEA, 2021[35]). It works backwards from the achievement of energy-related UN Sustainable Development Goals and shows what would be required to meet them (IEA, 2020[36]).

The STEPS is a conservative scenario that incorporates an assessment of all the policy ambitions and targets that have been legislated for or announced by governments around the world (IEA, 2020[36]). It does not have a stated goal or a pre-defined pathway, but instead illustrates the consequences of existing and stated policies for the energy sector.

More detail on the scenarios can be found at:

STEPS: https://www.iea.org/reports/global-energy-and-climate-model/stated-policies-scenario-steps

NZE:https://www.iea.org/reports/global-energy-and-climate-model/net-zero-emissions-by-2050-scenario-nze

SDS: https://www.iea.org/events/introducing-the-sustainable-development-scenario

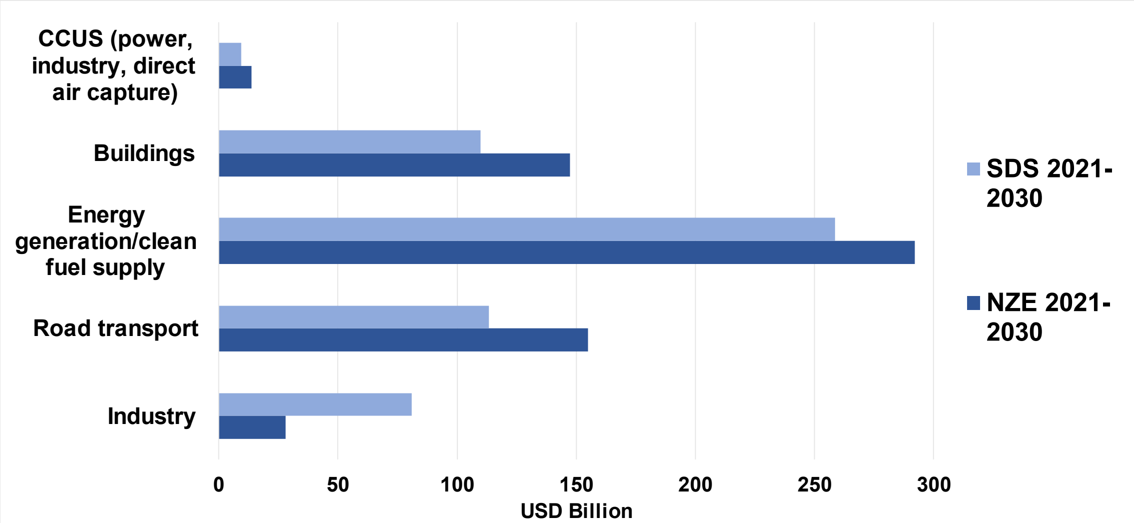
Scenario comparison: https://www.iea.org/reports/world-energy-outlook-2021/scenario-trajectories-and-temperature-outcomes

Looking specifically at advanced economies, IEA estimates that USD 1.5 trillion and USD 1.7 trillion would need to be invested globally in clean energy annually by 2030, in the Sustainable Development Scenario (SDS) and the Net Zero Emission 2050 Scenario (NZE), respectively. Existing policies are expected to induce USD 1 trillion of annual investments by 2030 (IEA Stated Policies scenario - STEPS), implying that USD 0.5 trillion and USD 0.7 trillion is needed in additional annual investments by 2030 to achieve the SDS and NZE scenarios, respectively.

When distinguishing between the first and second half of the 2021-2030 decade, additional annual investment needs in NZE in advanced economies are significantly higher for the 2026-2030 period than for the 2021-2025 period. This is mostly due to a rapid increase in the need to invest in renewables, electric vehicles and energy efficiency in buildings. Figure 12 depicts the average *annual* additional clean energy investment required for each sector in the time period 2021-2030 for advanced economies, to be in line with the SDS and NZE 2050 scenarios. It shows that most additional investments need to occur in clean power generation and fuel supply. Additional annual investment needs are substantial (but lower than in energy) in transport and buildings. Investment needs in these sectors are higher in the NZE than in the SDS scenario, mainly due to larger investments in electric vehicles and energy efficiency in buildings. Finally, for industry, the additional needed investments are significantly larger in SDS than NZE. This difference is partly due to a lower additional investment need in energy efficiency and bioenergy in industry in the NZE compared to SDS, as the NZE assumes a faster electrification than SDS.

Figure 12. Additional annual investments in clean energy needed in 2021-2030 in the Sustainable Development Scenario and the Net Zero Emissions 2050 Scenario for advanced economies, by sector

Average annual investment in billion USD. SDS = Sustainable Development Scenario; NZE = Net Zero Emission Scenarios.



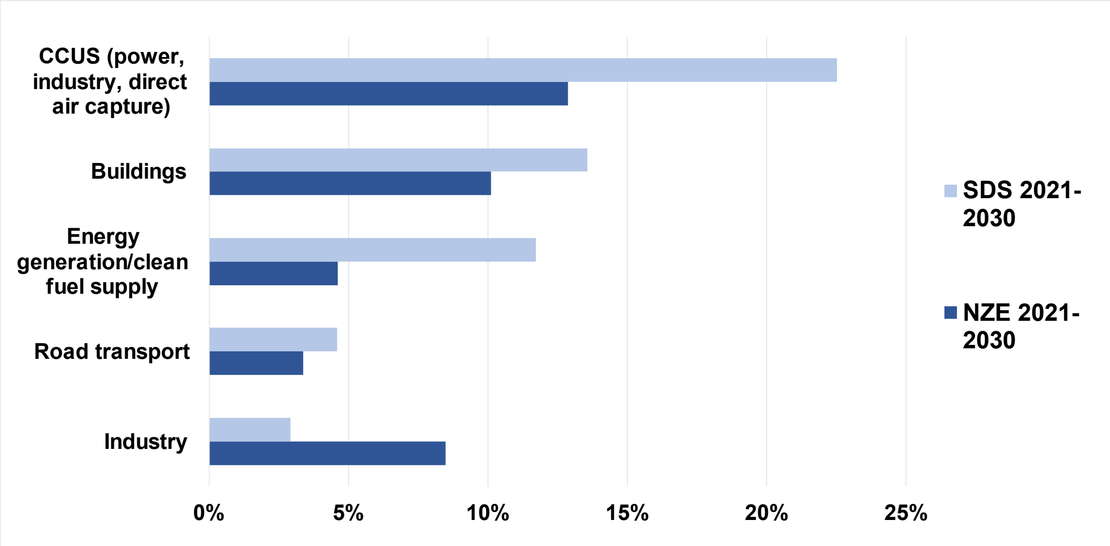
Note: The additional annual investment needs are calculated by subtracting the average annual investments in IEA's stated policy scenario (STEPS) (2021 numbers) from the average annual total investments for each sector in 2021-2025 in SDS and NZE, respectively. The same is done for the period 2026-2030 but using the STEPS for 2030. Note also that the figure only includes additional annual investment needs for advanced economies, as defined by the IEA.
Source: Detailed dataset behind World Energy Outlook 2022 and Box 1.A (IEA, 2022[5])

Comparing the investment needs for the 2021-2030 period in advanced economies with low-carbon public funding in OECD-countries as detailed in the LCTS database, Figure 13 suggests that for CCUS (across sectors), low-carbon post-COVID spending can stand for 13%-22.5% of annual average investment needs, depending on scenario. Furthermore, the low-carbon public funding can cover between 10-14% of the additional annual investments needed in buildings, 5-12% in power generation/clean fuels and 3%-4.5% of the additional average annual investment needed in the transportation sector, depending on the scenario. Finally, in industry, the public funding represents between 3% (in the SDS scenario) and 8.5% (in the NZE scenario) of investment needs.[14]

In short, Figure 13 suggests that in both scenarios, the post-COVID public funding in OECD-countries falls short of contributing to the necessary additional investment needs in industry (although for example deployment of renewable electricity may have an indirect effect on the industry sector) and road and maritime transport, compared to the other sectors. This might look surprising in view of the large amounts of public spending directed at the transportation in the LCTS database (Figure 6), but support to rail makes up a significant portion of public spending targeting this sector, whereas Figure 13 only concerns road and maritime transport (where investments in road transport, such as electric vehicles, makes up the largest part of annual average investments needs in both scenarios). Hence, the contribution of post-COVID public funding in OECD countries to investment needs specifically for road (and maritime) transport is small.

Figure 13. Annual average post-COVID low-carbon public spending 2021-2030 in OECD-countries to different sectors as a share of additional investment needs in the Sustainable Development and Net Zero Emission Scenarios for advanced economies

SDS = Sustainable Development Scenario; NZE = Net Zero Emission Scenarios



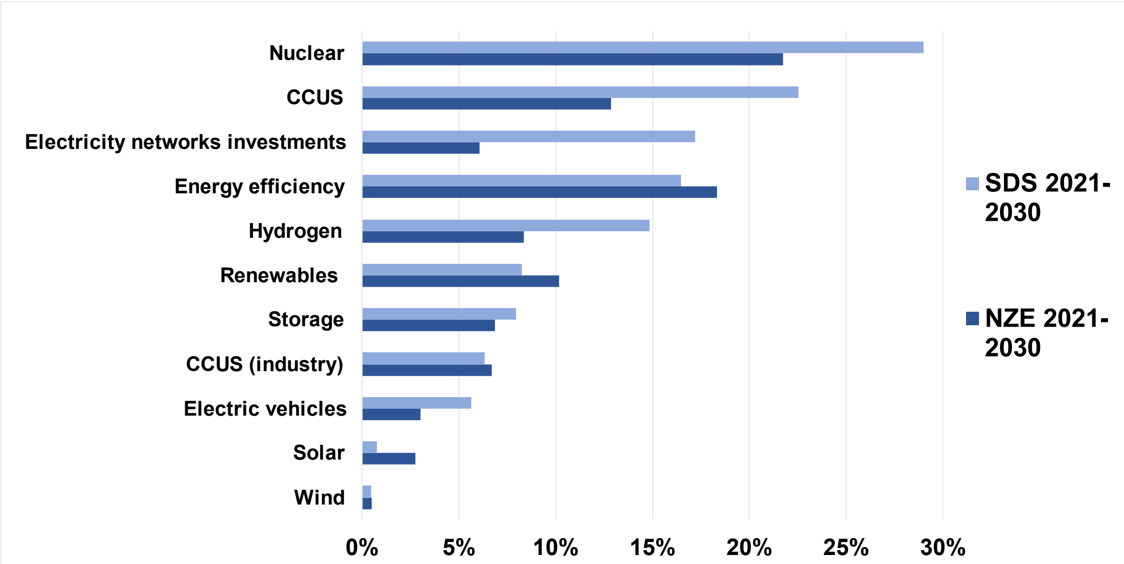
Note: Within each sector, we have not included the low-carbon post-COVID-19 public spending where it is not specified what technology is targeted within the sector.
Source: OECD Low-carbon Technology Support database (version May 2023), detailed dataset behind World Energy Outlook 2022 and Box 1.A (IEA, 2022[5])

Zooming in on specific technologies between 2021 and 2030, Figure 14 suggests that low-carbon public spending in OECD-countries makes a significant contribution to investment needs in advanced economies projected by the two scenarios for nuclear energy (25% of average annual investment needs on average across the two scenarios), CCUS across sectors (18%), energy efficiency (17%), and somewhat lower for electricity networks and hydrogen-based fuels (12%). However, low-carbon public spending contributes less to closing the average annual investment gap for renewable energy (9%), storage (7%), CCUS in industry (6%) and electric vehicles (4%), on average across the two scenarios. More specifically on renewable energy, the contribution from low-carbon public spending specifically targeting wind, solar and biofuels, as opposed to renewable energy in general, is marginal.

Generally, for the Net Zero scenario, Figure 14 shows similar trends as the Sustainable Development scenario, albeit a generally lower contribution from low-carbon public spending to closing the investment gap to be on track with net zero emissions in 2050. However, the contribution from post-COVID low-carbon spending to closing the investment gap in CCUS across sectors, electricity networks and hydrogen is significantly lower compared to the SDS. This is because the Net Zero scenario assumes a higher degree of electrification, more CCUS to reduce emissions and more hydrogen in fuel supply. On the other hand, the contribution from low-carbon public spending in closing the investment gap is slightly higher compared to the Sustainable Development scenario for energy efficiency, as the Net Zero scenario assumes lower investment needs in energy efficiency in industry.

Figure 14. Annual average post-COVID low-carbon public spending in selected technologies as a share of annual investment needs in IEA scenarios for advanced economies, 2021-2030

SDS = Sustainable Development Scenario; NZE = Net Zero Emission Scenarios



Note: Some of the technologies are summed across sectors, such as energy efficiency (from buildings and industry) and renewables (industry and power generation/fuel supply) and hydrogen (industry, fuel supply (clean fuels) and transport).
Source: OECD Low-carbon Technology Support database (version May 2023); detailed dataset behind World Energy Outlook 2022 and Box 1.A (IEA, 2022[5])

In short, while post-COVID fiscal policies in OECD-countries make a significant contribution – in particular for CCUS, nuclear, energy efficiency and hydrogen (depending on scenario) – they fall short of filling the potential annual average investment gap towards 2030 to be on track with net-zero targets.

4 Modelling the impact of post-COVID green fiscal policies

This section presents the results of a modelling exercise conducted in collaboration with E3Modelling (Energy, Economy and Environment Modelling) to analyse the potential greenhouse gas (GHG) emissions reductions towards 2050 induced by the fiscal measures described in Section 0. The analysis is based on model simulations with the GEM-E3 model where a Green Fiscal Push Scenario is compared with a Reference scenario without post-COVID low-carbon fiscal measures.

The modelling results shown below provide insights regarding the contribution of post-COVID investments to reaching climate goals, the amount of GHG emissions reductions across regions, the impact of different technologies on these reductions, projected changes in GDP, employment and sectoral outputs, and effects on international trade, including imports and exports of fossil fuels across regions.

Modelling and scenario design

The analysis in this section is based on simulations of the GEM-E3 model[15] (see Box 4 for an overview of the model). GEM-E3 is a large-scale dynamic multi-regional, multi-sectoral computable general equilibrium (CGE) model that since the 1990s has been used extensively by governments and public institutions to assess the socio-economic implications of energy and climate policies. Dynamic CGE models such as GEM-E3 are well adapted for the analysis of policies implying structural changes (that is, changes in the sectoral composition of economies) like those resulting from decarbonization policies. These models are based on a neoclassical framework, dealing only with real values and with almost-perfect markets for goods and capital. They focus on the long-term reallocation of resources across the different sectors and allow simulation of impacts of climate mitigation policies on emissions, macroeconomic variables, sectoral economic activity, and international trade patterns.

GEM-E3 covers 51 sectors (including an explicit representation of the financial sector) and 46 countries and regions, semi-endogenous dynamics based on R&D-induced technical progress, learning-by-doing and learning-by-research (Figure A A.8)

Table A A.4 shows the technology-specific learning rates assumed in the model) and knowledge spillovers, the representation of multiple households (ten representative households in each region which differ in income level, consumption patterns and skills), representation of five occupational types and endogenous involuntary unemployment in the labour market by occupational type and endogenous formation of labour skills. The model is calibrated to a wide range of datasets comprising of Input-Output tables, financial accounting matrices, institutional transactions, energy balances, GHG inventories, bilateral trade matrices, investment matrices and household budget surveys. All countries in the model are linked through endogenous bilateral trade transactions identifying origin and destination. Historical emissions data are retrieved from multiple sources including Edgar, UNFCCC and IEA databases.

Box 4. Overview of the GEM-E3 Model

The GEM-E3 model is a multi-regional, multi-sectoral, recursive dynamic computable general equilibrium (CGE) which provides details on the macro-economy and its interaction with the environment and the energy system. It is intended to analyse the conditions under which economic growth, and its distributional pattern, can be sustained in the presence of environmental or energy constraints shortages and reinforced by means of adequate public policies.

The model is calibrated to a wide range of datasets comprising of Input-Output tables, financial accounting matrices, institutional transactions, energy balances, greenhouse gas (GHG) inventories, bilateral trade matrices, investment matrices and household budget surveys. It is adjusted to a base year data set that includes a full Social Accounting Matrices for each country/region represented. SAMs are an extension of the Leontief input-output tables that allow the recording of the way goods and services are produced and consumed and the creation and distribution of incomes among economic agents. It includes 46 regions and 51 sectors, including explicit representation of the financial sector. Firms are assumed to operate in perfect competition, producing goods and services to maximise profits. Households optimise their inter-temporal utility under an inter-temporal budget constraint. Prices are computed by the model according to supply and demand interactions in the markets and different market clearing mechanisms, in addition to perfect competition. To capture the "inequalities" within households, the model features for each country ten households that are distinguished by income class with different consumption patterns, different saving rates and different sources of income according to the allocation of labour skills by type of household.

The model is dynamic, recursive over time, driven by accumulation of capital and equipment. Production is modelled through KLEM (capital, labour, energy and other material/intermediate inputs) production functions. Technical coefficients in production and demand are flexible in the sense that producers can alternate the mix of production not only regarding the primary production factors but also the intermediate goods. The specification of production and consumption follows the generalised Leontief type of models, by allowing substitution of inputs given sector-specific elasticities. Technology progress is explicitly represented in the production function, either exogenously, by using technology specific learning rates based on the literature (Appendix Table A.A.4), or endogenously, through R&D expenditure by private and public sector, both leading to technology-specific cost reductions. International trade modelling assumes that imported goods and services are an imperfect substitute for domestic goods and services in line with the Armington assumption. All regions in the model are linked via endogenous bilateral sector-specific trade. The combination of technological progress with international trade implies that technology-specific cost-reductions can benefit other countries through imports and exports.

The model is calibrated to solve the equilibria for each time period following a time-forward path. The dynamics of the model allow for feedback effects, where changes in capital allocation affect production levels, productivity, and market conditions. These feedback effects can further influence investment decisions and the allocation of capital in subsequent years. Human capital in the form of labour is assumed to be rigid in that there is no mobility among skills, but workers of the same skill are mobile across sectors. Households and firms decide endogenously to optimise education and training.

The model links economic activities to environmental outcomes through accounting for GHG emissions in CO_2 equivalents. The GEM-E3 environment module covers all major GHGs (CO_2, CH_4, N_2O, HFCs, PFCs and SF_6) both for energy and process-related emission sources. In the model, global, regional and sectoral constraints are linked to the internalisation of environmental externalities, changes in consumption or production patterns, external costs/benefits, taxation, pollution abatement investments and pollution permits. The model features a detailed representation of the energy system, for all power, transport, buildings and industry sectors, having also a soft-link with a bottom-up power supply module.

To allow for endogenous assessment of mitigation options, the model represents explicitly clean energy technology markets, including PV and wind equipment, hydrogen, CCS equipment, batteries and power technologies. Households endogenously decide on the purchase of conventional, hybrid or electric vehicles according to the cost of purchase and use and the vehicle stock levels. The model evaluates the impact of policy changes on the environment by calculating the change in emissions. Emission factors and energy efficiency improvements are realised either exogenously or endogenously through factor substitution. It is assumed that there is a time lag between the investment and the realization of the efficiency gains. Energy efficiency is calibrated through sector-specific cost curves. For non-CO_2 emissions a marginal abatement cost curve is used to equalise the marginal cost of abatement to the price of emission allowances or tax. Since some of the potential technologies that may develop in the future are not used yet in the base year used for calibration, artificially small shares are introduced for these non-existing technologies to allow for the possibility of their penetration in the future.

The reference scenario is a projection of economic development and GHG emissions to 2050 under the assumption that climate mitigation is limited to the pre-COVID climate and energy policies, similarly as the IEA's Stated Policies (STEPS) scenario.[16] The macroeconomic projections for this scenario take into account the most recent economic outlooks from the OECD, IMF and EC's DG ECFIN. Assumptions in the baseline scenario are chosen to project realistic changes in sectoral production and demand patterns and are calibrated using exogenous variables such as population, sector-specific technical progress and expectation of future sectoral growth.

The projection of GHG emissions in OECD and EU countries in the Reference scenario can be found in the annex in Figure A A.9. In the Reference scenario, GHG emissions are projected to significantly fall in the EU (27% reduction by 2030 and 58% reduction by 2050), compared to the reference year 2020. The emissions reductions in North America and other OECD countries is more limited (7% reduction by 2030 and 4% reduction by 2050 in North America; 1% reduction by 2030 and 2% reduction by 2050 in other OECD countries). The reference scenario projects reductions in energy and emission intensity due to a combination of electrification of the energy system, progressive increase in importance of renewable energy in the electricity mix, and improvements in sectoral energy efficiency. But these trends are mostly offset by the effect of GDP growth on emissions, leading to small emissions reductions overall.

The Green Fiscal Push Scenario is designed by implementing the low-carbon fiscal spending measures included in the LCTS database. Public spending is funded via additional debt taken by governments and repaid after the period under analysis. Technology-specific measures are grouped into 11 categories presented in Table 2. For example, renewable energy investments, CCS investments in the power sector and investments in nuclear energy are included in the electricity generation category. Each of these categories of investments is then individually modelled. Table A A.5 describes how public investment in the different categories is implemented in the scenario. For example, public spending towards electric vehicles is assumed to finance subsidies for the purchase of EVs. The subsidy is assumed to be equal to the price difference between EVs and conventional vehicles, so that the number of additional EVs purchased is equal to the amount budgeted for the measure divided by this price difference. This leads to an increase in the share of EVs compared to conventional cars.

Public spending in low-carbon technologies crowds in private investment. This crowding-in of private investment is endogenous for some technology groups (such as electric vehicles, as described above) and exogenously imposed for some others.[17] In the latter case, one euro of public investment is assumed to crowd in one euro of private investment. This is consistent with the design of many instruments in the database, which are investment or production subsidies or tax credits that apply only if some amount of private investment is leveraged. This is also consistent with the study by Aldy (2013[37]), who reports that the American Recovery and Reinvestment Act adopted following the global financial crisis (which included more than USD 90 billion directed at clean energy investments) leveraged more than USD 100 billion in private capital, and with existing evidence that the proportion of public investment in climate finance is around 50% (Meckling, 2022[38]).[18]

The rest of this section presents the results from the modelling analysis. Since the LCTS database is comprehensive only for OECD countries, the results focus on this set of countries (broken down as before into European Union, North America and other OECD countries). Impacts on emissions reductions in non-OECD countries via low-carbon technology cost reductions and international knowledge spillovers are presented separately.

Table 2. Technology groups used in the Green Fiscal Push Scenario

Technology groups	Technologies in the LCTS database
Electricity generation	Hydroelectric, PV, Wind, other renewable energy sources CCS power technologies Nuclear
Biofuels	Biofuel, and Biofuel for transport
Hydrogen	Hydrogen for industry, Hydrogen for transport, and other Hydrogen
Transmission and distribution	Transmission infrastructure, Smart grids, Electric superconductors
Batteries	Energy storage using batteries
Electric vehicles	Electric vehicles and charging
Rail	Rail passenger and freight
Public transport	Public transport and cycling infrastructure
Energy efficiency in buildings	Efficient heating and other renovation
CCUS (excl. electricity generation)	CCUS in industry, direct air capture
Energy efficiency in industry	Energy efficiency in industry

Source: OECD and E3M (2023)

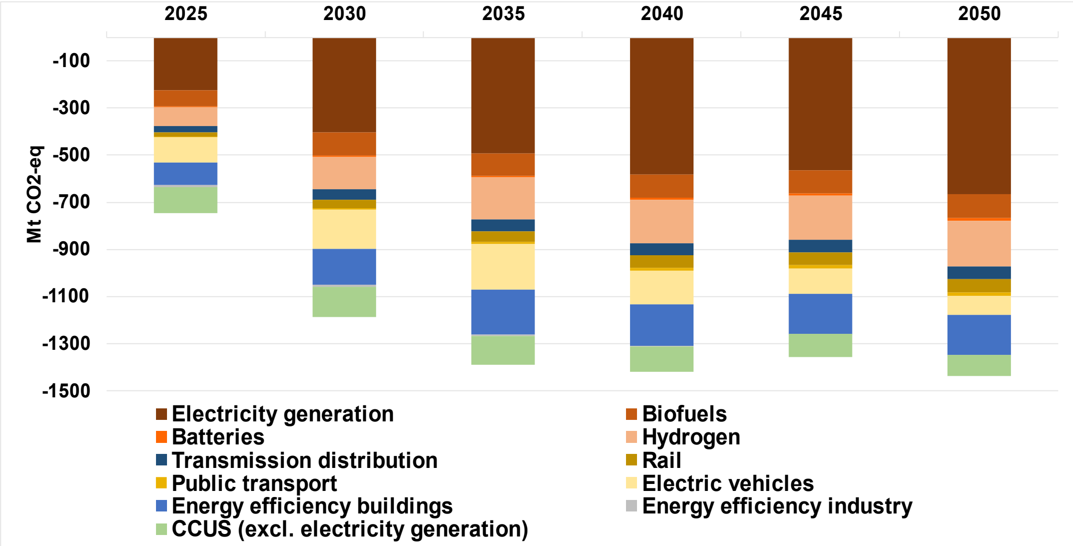
GHG emissions reductions

In the Green Fiscal Push Scenario, greenhouse gas emissions in OECD and EU countries are projected to fall by 1150 Mt CO_2-eq in 2030 and by 1400 Mt CO_2-eq in 2050, compared to the reference scenario. This corresponds to a 9% and 11% reduction in emissions in 2030 and 2050, respectively, for this group of countries. These results are consistent with the modelled impacts of hypothetical green recovery packages found in other studies (Dafnomilis et al., 2022[39]).[19]

The contribution of the various supported technologies to greenhouse gas emissions reductions is presented in Figure 15. 46% of the cumulative reduction in emissions by 2050 are achieved through investments in technologies related to electricity generation, in particular renewable energy. This is in line with the focus of fiscal measures adopted during the COVID-19 crisis on renewable energy adoption, as shown in Figure 6. Investments in hydrogen, energy efficiency in buildings, electric vehicles and CCUS in industry follow, with respectively 14%, 12%, 6%, and 6% of cumulative emissions reductions by 2050.

Figure 15. GHG emission reductions in the Green Fiscal Push Scenario, by technology group

Mt CO_2-eq absolute change in the Green Fiscal Push Scenario compared to the Reference Scenario (OECD countries)



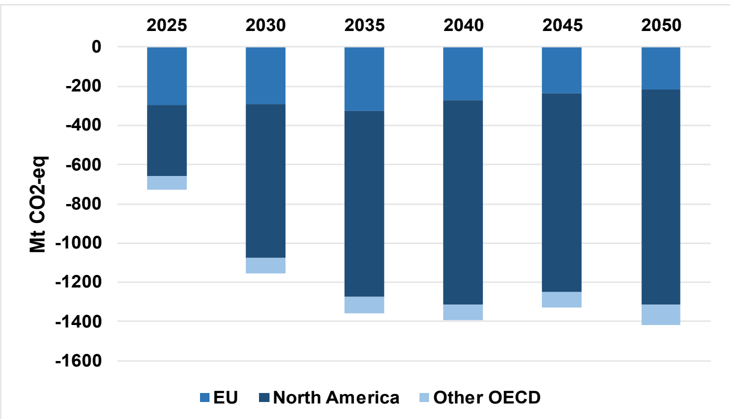
Source: OECD and E3M (2023)

GHG emissions reductions in the Green Fiscal Push Scenario also vary depending on the region (Figure 16). The cumulative emission reduction until 2050 in North America amounts to 1095 Mt CO_2-eq compared to the Reference Scenario (i.e. a 17% reduction), while the cumulative reduction in EU countries amounts to 217 Mt CO_2-eq (a 12% reduction compared to the Reference Scenario).

The emissions reduction in the US are comparable to the predicted model-based impact of the Inflation Reduction Act (IRA) found in studies by the Rhodium Group (Larsen et al., 2022[40]), Repeat (Jenkins, 2022[41]) and Energy Innovation (Mahajan et al., 2022[42]). These studies report an overall GHG emission reduction induced by the of IRA of between 600 and 1000 Mt of CO_2-eq in 2030. As a comparison, the Green Fiscal Push Scenario projects a decrease of 743 Mt CO_2-eq in 2030 for the U.S.

Figure 16. GHG emissions reductions by region

Mt CO_2-eq absolute change in the Green Fiscal Push Scenario compared to the Reference Scenario

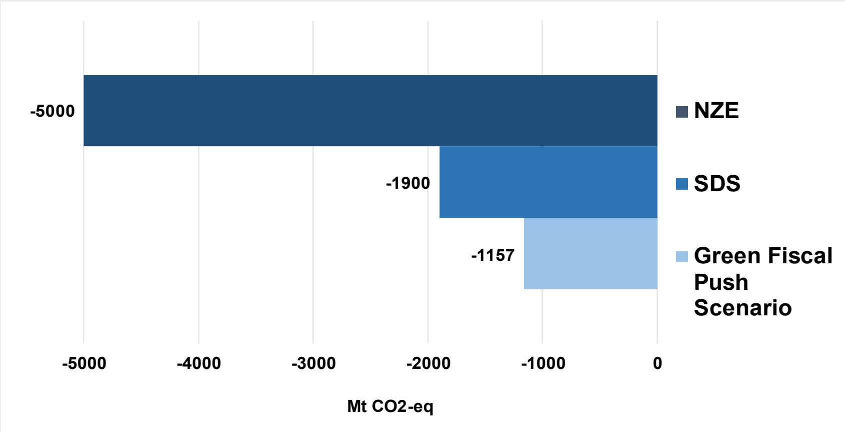


Source: OECD and E3M (2023)

Comparing the emissions reductions in the Green Fiscal Push Scenario with the necessary emissions reductions to meet net zero targets in the IEA Net Zero Emission Scenario suggest that post-COVID low-carbon public support measures could close up to 23% of the GHG emissions reductions needed in 2030 (Figure 17). Compared to the IEA's Stated Policy Scenario (STEPS), the Net-Zero Emissions scenario requires a reduction of 5 000 Mt CO_2-eq in 2030 in advanced economies. In comparison, the Green Fiscal Push Scenario based on the OECD LCTS database predicts a cumulative emissions reduction of approximately 1150 Mt CO_2-eq for OECD and EU member countries.

Figure 17. GHG emissions reductions in 2030 in the Green Fiscal Push Scenario and in the IEA's SDS and NZE scenarios (advanced economies only)

Reduction of Mt CO2-eq in 2030 compared to the Reference scenario



Note: The IEA NZE only include energy-related combustion emissions. The reduction in GHG emissions reported in NZE and in SDS in this graph is deducted by subtracting the GHG emissions in 2030 in the NZE and SDS, respectively, from the GHG emissions in 2030 in the Stated Policy Scenario (STEPS). We assume advanced economies made up 30% of global emissions in the SDS scenario.
Source: IEA (2021[1]), IEA (2021[35]), OECD and E3M (2023)

Since the Green Fiscal Push Scenario models some crowding-in of private investment, these results are in line with results presented in Chapter 3 showing that post-COVID low-carbon spending represent up to 12-14% of annual average investment needs to be on track with net-zero targets.

The GHG emissions reductions observed in Figure 15 are made possible by reductions in clean technology costs which occur during the first decade following public investments. As shown on Finally, results from the Green Fiscal Push Scenario suggest that post-COVID public spending in OECD and EU countries also induce emissions reductions in the rest of the world. Figure A A.12 shows that GHG emissions are reduced by 250 Mt in 2050 in emerging economies in the Green Fiscal Push Scenario. These reductions come from international knowledge spillovers, lower costs of cleantech equipment (such as wind turbines, solar panels, electric vehicles and hydrogen electrolysers) and other general equilibrium effects (e.g. changes in demand for fossil fuels).

Figure 18, the Green Fiscal Push Scenario triggers significant reductions in the unit production costs of critical green products such as batteries, hydrogen and equipment for wind and solar PV energy. These cost reductions are driven by R&D investments, knowledge spillovers as well as by learning by doing. They occur mostly in North America and the EU, where the bulk of public spending comes from in the LCTS database.

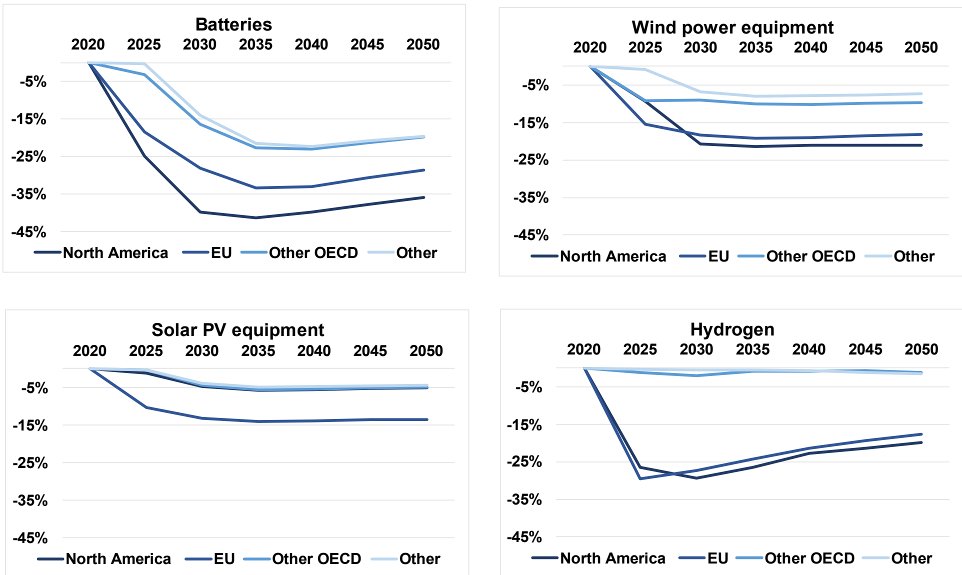
Relative to the Reference scenario, unit production costs for batteries decline by 40% and 35%, respectively, in North America and the EU by 2035. Hydrogen production costs decrease very rapidly by over 25% within five years, thanks to the large investments in R&D and demonstration in the 2020-2025 period. The cost reductions are also substantial in wind power equipment (-20% by 2030 in the two major implementing regions). Finally, solar PV equipment production costs fall less and mostly in the EU (by close to 15% in 2030).

Some cost reductions also occur in regions outside the EU and OECD with lower post-COVID public investment, due to international knowledge spillovers. These cost reductions can be observed with a 5-10 years lag, but are much smaller in magnitude as these countries do not benefit as much from learning by doing induced by larger production volumes. In hydrogen in particular, the cost reductions are negligible outside the EU and North America. However, the cost of batteries drops significantly in other regions, driven by an increase in production to serve a growing electric vehicles market worldwide.

Finally, results from the Green Fiscal Push Scenario suggest that post-COVID public spending in OECD and EU countries also induce emissions reductions in the rest of the world. Figure A A.12 shows that GHG emissions are reduced by 250 Mt in 2050 in emerging economies in the Green Fiscal Push Scenario. These reductions come from international knowledge spillovers, lower costs of cleantech equipment (such as wind turbines, solar panels, electric vehicles and hydrogen electrolysers) and other general equilibrium effects (e.g. changes in demand for fossil fuels).

Figure 18. Reductions in unit cost of production for batteries, hydrogen and wind and solar equipment

Percentage of change in the Green Fiscal Push Scenario compared to the Reference Scenario

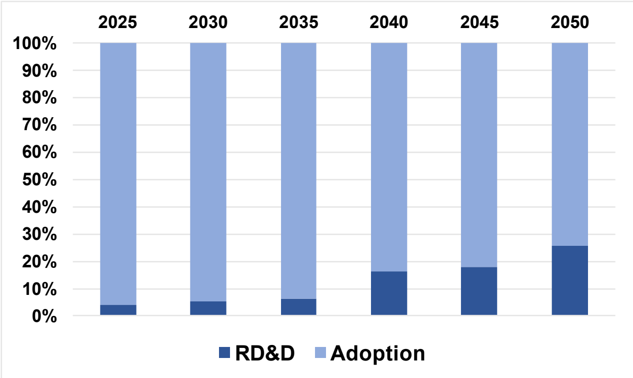


Note: "Other" includes Argentina, Brazil, China, India, Indonesia, Russia, Saudi Arabia and South Africa. The change per region is a weighted average across the countries, weighted by the production of batteries, hydrogen and wind and solar PV equipment in 2025 in each country.
Source: OECD and E3M (2023)

Figure 19 shows the proportion of emissions reductions until 2050 driven by measures to support research, development and demonstration (RD&D) taken in the period 2021-2030. The impact of RD&D support increases considerably over time. In 2030, only 5% of the emissions reductions in the Green Fiscal Push scenario are triggered by RD&D support measures which lead to improvements in the productivity of emerging technologies, such as hydrogen. In 2050 however, this proportion increases to 26%. This is because early-stage investments in RD&D translate into permanently higher productivity of clean technology and knowledge spillovers gradually diffuse across borders, leading to further cost reductions and adoption.

Figure 19. Emissions reductions triggered by RD&D vs adoption support

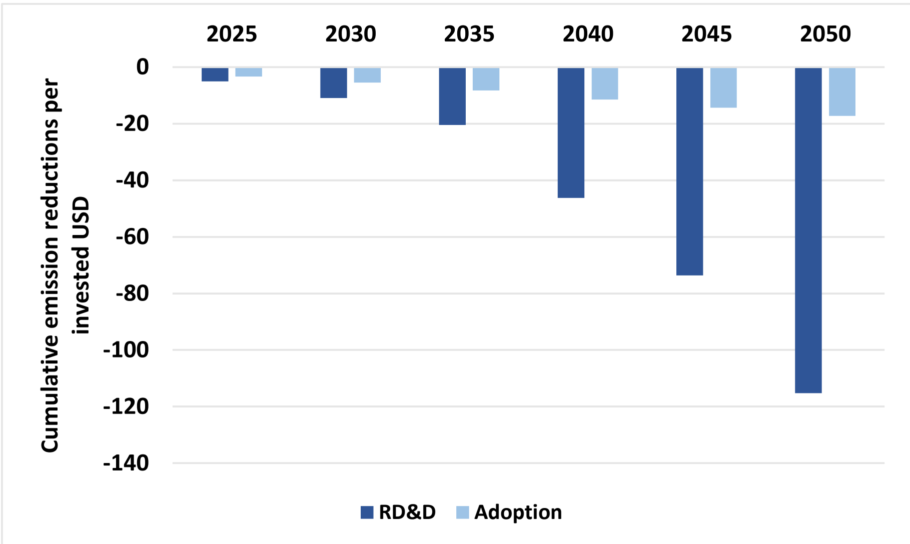
Percentage of total emission reductions in the Green Fiscal Push Scenario compared to the Reference Scenario related to research, development and demonstration and adoption, respectively



Source: OECD and E3M (2023)

A consequence of the growing cumulative effect of RD&D support measures on emissions reductions is that the cumulative emissions reductions per USD of public investment in RD&D grows significantly over time compared to the same USD spent on adoption support (Figure 20). In the Green Fiscal Push scenario, each dollar spent to support RD&D induces around 115 tons of cumulative emissions reductions by 2050. Meanwhile, the same dollar invested to support adoption triggers only around 17 tons of cumulative emissions reductions. This illustrates the large returns from investing in low-carbon R&D support in the long run, and reinforces the case for increasing support to innovation for the net-zero transition (Cervantes et al., 2023[9]).

Figure 20. Cumulative emissions reductions per dollar of RD&D vs adoption support



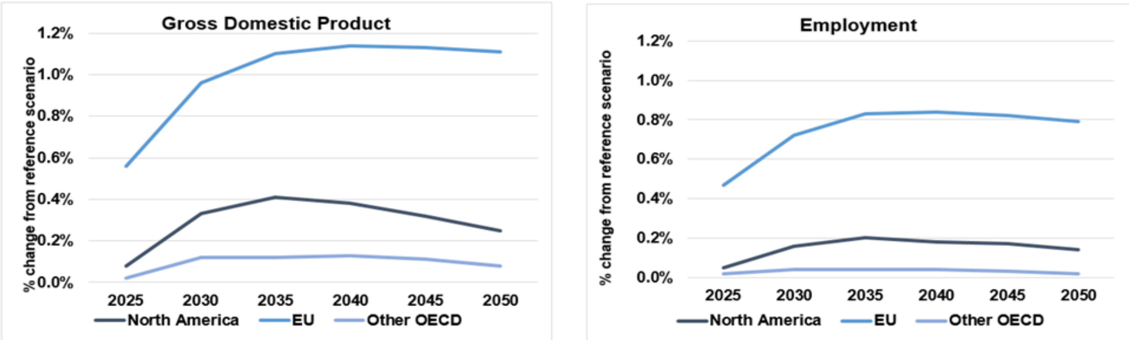
Note: The post-COVID public spending includes support to research, development and demonstration in the LCTS database.
Source: OECD and E3M (2023)

Macroeconomic and labour market impacts

The aggregate effect of the Green Fiscal Push Scenario on GDP and employment is small but positive across EU and OECD countries (Figure 21). This positive effect is mainly driven by productivity improvements induced by R&D investments and learning-by-doing. The EU benefits the most from the positive effects of low-carbon investments: GDP gains for the EU reach +1.1% in 2035. In North America, the GDP effect is positive at +0.4% in 2035, driven by the impact of the IRA in the US. GDP impacts are negligible in other OECD regions where public investments are much smaller. Effects on employment mirror GDP projections (Figure 21). Employment increase by 0.85% for the EU in 2035 and by 0.2% in North America. The effect on employment in other OECD countries is close to zero.

Figure 21. Impact of low-carbon public spending on GDP and employment towards 2050

Percentage of change in the Green Fiscal Push Scenario compared to the Reference Scenario

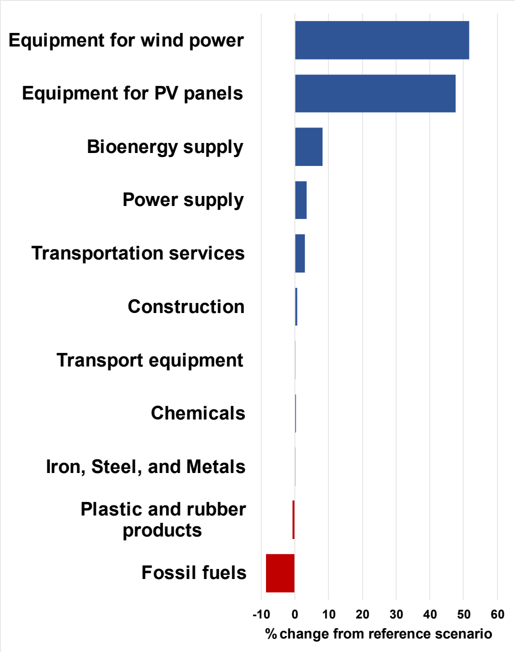


Source: OECD and E3M (2023)

The Green Fiscal Push Scenario has a significant positive impact on the domestic production of many "green" capital goods across OECD and other EU countries, compared to the reference scenario (Figure 22). Equipment for wind power is projected to increase by 51% by 2030 and equipment for PV panels increases by 48%. Green hydrogen production increases by USD 53 billion (not reported in the figure as the increase is infinite in percentage terms). Domestic production of bio-energy supply is increased by 8% compared to the reference. On the other hand, some emission-intensive sectors grow less quickly than in the reference scenario, but by a small margin: for example, the plastic and rubber products sector decreases by 0.8%. The only sector that significantly contracts is, unsurprisingly, the production and extraction of fossil fuels, which is reduced by 9%.

Figure 22. Change in gross output in 2030 by sector in Green Fiscal Push scenario

Percent change in the Green Fiscal Push Scenario compared to the Reference Scenario (selected sectors)



Note: "Fossil-fuel" includes natural gas extraction, coal extraction, crude oil extraction and refined oil. Basic pharmaceutical products, business services, other manufacturing, pulp and paper, and collective services are dropped as the percentage change is <0.1%. The hydrogen sector is not reported in the figure as the increase is infinite in percentage terms.
Source: OECD and E3M (2023)

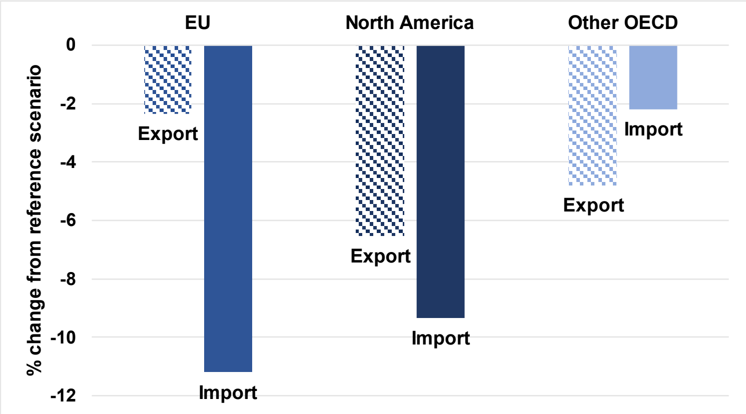
The Green Fiscal Push Scenario reduces investing countries' reliance on fossil fuels, which translate into lower fossil fuel imports (Figure 23). This is particularly the case in the EU, where the predicted imports of fossil fuels (oil, gas and coal) in 2030 fall by 11% in value. This decrease is much larger than the decrease in fossil fuel exports (-2%), contributing positively to the EU's trade balance. For North America, the scenario predicts a similar decrease in fossil fuel imports (-9%) but a larger reduction in fossil fuel exports (-7%), compared to the EU. In other OECD countries, exports fall by a similar magnitude (-5%) as for the U.S., but imports fall by a mere 2%. These differences reflect the EU's current larger dependence on fossil fuel imports and more pronounced substitution of fossil fuels compared to other OECD countries.

The reduction in oil imports makes up two thirds of the total import reduction of fossil fuels in the EU and in North America, and about a quarter of the total import reductions of fossil fuels in other OECD countries. In the three regions, gas import reductions largely make up the remaining reductions in fossil fuel imports.

To put these projections into perspective, the reduction in fossil fuel imports in the EU compared to the Reference scenario (shown in Figure 23) corresponds to USD 440 billion for the period 2021-2030. As a comparison, in 2022, the import of oil and gas from extra-EU regions to the EU amounted to USD 685.5 billion (of which 18% from the Russian Federation).[20] (Eurostat, 2023[43])

Figure 23. Changes in exports and imports of fossil fuel for the period 2021-2030 by region

Percent change in the Green Fiscal Push Scenario compared to the Reference Scenario

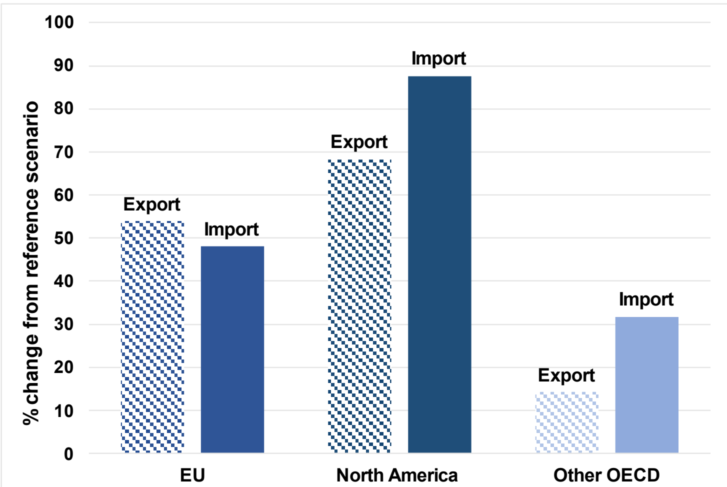


Note: Fossil fuels goods include coal, crude oil, gas, gas extraction and oil products.
Source: OECD and E3M (2023)

The Green Fiscal Push Scenario gives a significant boost to the output of climate technology equipment sectors, including equipment for solar PV, wind power, electric vehicles and batteries mirrors as shown on Figure 22. This translates into large increases in exports and imports of these goods (Figure 24). This growth in international trade is strongest in North America, where imports increase by 88%, while exports increase by 68%. For the EU, exports and imports increase by 53% and 48%, respectively. All clean equipment goods see an increase in export and import, except for wind power technology where imports are reduced by 16% in the EU thanks to investments in R&D which improve the competitiveness of the wind equipment sector in this region. There is a particularly strong increase in the export of batteries in both the EU and North America.

Figure 24. Changes in exports and imports of climate technology equipment for the period 2021-2030 by region

Percent change in the Green Fiscal Push Scenario compared to the Reference Scenario



Note: Climate technology equipment includes equipment for solar PVs, wind power, and EV transport including batteries.
Source: OECD and E3M (2023)

5 Conclusion: low-carbon technology support as part of more ambitious climate policy packages

This paper has analysed how fiscal stimulus spending packages adopted as a response to or in the aftermath of the COVID-19 pandemic have supported the development and deployment of low-carbon technologies, based on a new database covering 1166 measures announced in 2020-2021 by 51 countries representing 89% of global GDP and 79% of global annual CO_2-eq emissions.

The data shows that a substantial amount of public funding – USD 1.29 trillion – has been targeted at low-carbon technologies. Of this funding, 40% has been directed at the energy sector and around one third to transportation. With a mere 4% of total funding, industry – which is responsible for 23% of global CO_2 emissions – appears as the forgotten sector of the post-COVID green public spending.

An important difference of post-COVID green fiscal policies compared to post-GFC stimulus is a relative focus on emerging and early-stage technologies. Of the total funding analysed in this paper, 6.5% (USD 84 billion) concern the R&D and demonstration phases of innovation (including USD 31 bn for demonstration alone). An additional USD 100 bn (7.8% of low-carbon public spending) is channelled at technologies at the pre-adoption stage based on their Technology Readiness Level. This is a significant contribution to closing the USD 90 billion funding gap for which, according to IEA Net-Zero Emission Scenario, needs to be raised as soon as possible to complete a portfolio of demonstration projects by 2030 and keep the world on track for net-zero emissions by mid-century. Among low-emission technologies that are still in the early stages of innovation, hydrogen has been the main priority, followed by carbon capture utilisation and storage (CCUS) and smart grids. Relatively small budgets have been dedicated to nuclear innovation, zero-emission buildings and advanced batteries.

The analysis compares the amounts of low-carbon public spending to annual additional investment needs to reach net-zero emissions targets by 2050, as reported by the IEA. In general, post-COVID low-carbon public spending make a welcome contribution to these needs but fall short of filling the massive investment gap. For the period 2020-2030, in advanced economies, post-COVID low-carbon technology public funding in OECD countries represents up to 12-14% of the additional annual investment needs in the energy and buildings sectors, up to 9% in industry and around 5% in road transport.

There is, however, vast heterogeneity across technologies. The contribution of public spending appears determinant in areas such as nuclear energy (almost 30% of average investment needs), CCUS in the energy sector (23% of average investment needs), and electricity networks, energy efficiency and hydrogen-based fuels (15-17% of average investment needs). However, low-carbon public spending contributes less to closing the average annual investment gap for renewable energy, energy storage, CCUS in industry and electric vehicles (5-10% of average annual investment needs).

The results from a modelling exercise show that the measures included in the database could make an important contribution to global GHG emission reductions. In total, GHG emissions are projected to fall by 1150 Mt CO_2-eq in 2030 and by 1400 Mt CO_2-eq in 2050 in countries in the OECD and the EU, compared to a reference scenario. This represents a 12% emissions reduction in 2030 in the EU and North America compared to a scenario without low-carbon technology support measures. Half of this reduction in emissions comes from investments in the power sector, in particular renewable energy. By 2050, 26% of cumulative emissions reductions come from public support to R&D activities conducted between 2020 and 2030. As a consequence, a dollar spent on R&D support induces six times more cumulative emissions reductions by 2050 than the same dollar invested to support adoption. This illustrates the large returns from investing in low-carbon R&D support in the long run and reinforces the case for ambitious innovation policies for the net-zero transition.

The modelling analysis also shows that these measures have positive effects on GDP and employment and trigger significant growth of green sectors such as equipment for wind and solar energy. They also enable large reductions in fossil fuel imports, especially in Europe, thereby improving energy independence.

While public funding has a critical role to play for the net-zero transition, especially for early-stage technologies via support to R&D and demonstration, it remains that technology support policies are insufficient on their own. For example, for technologies whose demand is contingent upon the existence of some form of carbon pricing, such as carbon capture and storage (CCS), investment support alone is not enough to make the business case for investing in low-carbon assets. This is illustrated by the failure of CCS projects supported by green recovery measures adopted during the Global Financial Crisis (Agrawala, Dussaux and Monti, 2020[13]). Available estimates suggest that private actors would provide around 70% of the investment needed to build the global low-carbon infrastructure over the coming decades (Vivid Economics, UNFCCC Race to Zero campaign and the Glasgow Financial Alliance for Net Zero, 2021[6]).

Governments thus have a key role to play to also incentivise private funding. Existing studies suggest that financial capacities exist at the required scale – especially in developed economies – but that the challenge is to match investment demand and supply. This implies implementing a range of policies, both on the supply and on the demand side. This includes introducing clear trajectories of gradually increasing carbon prices, phasing out fossil fuel subsidies and implementing an array of other complementary policies. Such policies could include public infrastructure provision, standards and regulations, demand-side policies such as carbon contracts for differences or public procurement, and structural policies for example skills and labour market policies, entrepreneurship policies and competition policies.

In short, while government support measures adopted in the wake of the COVID-19 crisis have oriented investment towards sectors and technologies key for the low-carbon transition and could bring about significant emissions reductions, they cannot by themselves close the investment gap until 2030 to reach net zero emissions by mid-century. They must now be accompanied by more ambitious complementary climate policies that would induce private investment and trigger the deeper structural changes made necessary by net zero targets and the current fossil fuel energy price crisis.

Endnotes

[1] These investments exclude fossil fuels energy generation without CCUS, and oil, gas and coal in fuel supply. Other estimates of the additional investment needed to achieve net zero by 2050 arrive at similar numbers: McKinsey & Company (2022[55]) estimate the incremental investment need relative to the baseline 'current policies' scenario at USD 0.8 trillion per year, while Vivid Economics et al. (2021[6]) estimate the gap at USD 1.7 trillion per year from 2021–2025 and USD 3.6 trillion per year from 2026–2050. IRENA (2021[63]) reports a total investment need of USD 5.7 trillion on average each year towards 2030, while BloombergNEF (2021[62]) reports at total of USD 5.8 trillion yearly 2021-2050. However, these investments are gross investments and not additional investment with respect to a current policy scenario.

[2] The COVID-19 pandemic also led to a significant drop in global CO_2 emissions from energy combustion and industrial processes (34.2 $GtCO_2$ in 2020 comparing to 36.1 $GtCO_2$ in 2019), but this decrease was short-lived. As in previous economic crises, emissions quickly rebounded in 2021 to reach their highest ever annual level. A 6% increase from 2020 pushed emissions to 36.3 Gt CO_2 (IEA, 2022[56]).

[3] Between 2019 and 2020, energy-related investment as measured by the IEA decreased by 20% (from USD 1 900 bn to USD 1500 bn) because of the COVID-19 pandemic. This is due to lower energy demand because of lockdowns, restrictions, and uncertainties about recovery.

[4] "Green" here refers generally to measures which are environmentally positive, and can therefore also include measures which have a positive impact on other environmental dimensions than climate change mitigation, such as water, forests, etc.

[5] Based on the world's 20 largest countries. GRO includes recovery funding in more countries than the OECD Green Recovery and Nahm, Miller and Urpelainen (2022).

[6] The U.S. Inflation Reduction Act (IRA), which was initially announced in 2021 as the Build Back Better Act, was then amended and finally passed into law as the IRA in August 2022. The Recovery and Resilience Plans (RRP) under the European Commission's Recovery and Resilience Framework (RRF), were published in their final form after December 2021 for some EU member states, but were originally announced earlier.

[7] The GRO database covers 50 countries while the OECD database tracks 43 countries plus the EU as a whole.

[8] Measures with a negative environmental impact and measures with a potential indirect impact on the environment are not included. Measures with a negative environmental impact include for example "Traditional energy infrastructure", "Traditional transport infrastructure" or "Worker retraining and job creation". Measures with a potential indirect impact on the environment include for example "Communications infrastructure investment", "Education investment", "General research and development investment", "Other large scale infrastructure investment".

[9] Measures are categorised as "Research and Development (R&D)" if they explicitly mention "R&D" and categorised as "Demonstration" if they explicitly mention "pilot (project)", "prototypes", "limited number of projects", 'trials", "demonstration", "test/testing", or "laboratory for the development of ...".

[10] On the date of publication of this report, 7 OECD member countries (out of 38) had not fully validated the data.

[11] These estimates are subject to change. The original budgetary document (JCX-18-22) was complemented in late April 2023 by an updated estimate (JCX-7-23) which suggests that repealing most tax credits would raise USD 570 billion, twice as large as the original estimate.

[12] It should be noted that the public spending used to calculate the percentages in Figure A A.5 and the description of how emerging technologies were prioritised across countries in this report countries are based on policy measures where the various emerging technologies are specifically mentioned. Countries can in reality have higher budget targeting emerging technologies.

[13] Including all emerging technologies shown in Figure 9.

[14] Note that the contribution of low-carbon technology public funding to industry in the LCTS database is close to zero in the 2026-2030 period in the SDS scenario, slightly higher in the Net Zero scenario.

[15] A detailed technical presentation of the model is available at: https://e3modelling.com/modelling-tools/gem-e3/

[16] 122 climate targets in place as of March 2022 as reported in the Climate Policy Database (NewClimate Institute, PBL Netherlands Environmental Assessment Agency and Wageningen University and Research, 2023[77]). For the EU, the Reference scenario assumes a greenhouse gas emission reduction of 40% in 2030 compared to 1990-levels and is aligned with the REF2030 used by the European Commission. For the US, the reference scenario includes neither IIJA nor IRA.

[17] Except for EVs, public transport, hydropower, rail, and water and waste management.

[18] In practice, crowding-in of private investments varies over time and across technologies and sectors. It will depend on the degree to which the government policies and incentives reduce the financial risk for private investors, on the maturity of the technology and on overall market conditions (such as the availability of financing or the cost of capital). For example, the Climate Policy Initiative and IRENA (2023[75]) report that for renewable energy technologies, the share of public investment in 2020 ranged from 17% for solar PV to 97% for hydropower plants.

[19] Dafnomilis et al. (2022[39]) suggests that a green post-COVID public spending programme equivalent to 1% of global GDP in fiscal support directed to climate change mitigation measures for three years could reduce global CO2 emissions by 4700 to 7000 Mt CO2-eq by 2030 compared to pre-COVID projections, depending on the model used (i.e. a 10%-16% reduction).

[20] Until the end of 2021, Russia was the main supplier of petroleum oils and natural gas to the EU. After Russia's invasion of Ukraine, the European Union reacted with several packages of sanctions, which directly and indirectly affected the trade of oils and natural gas. Trade in value in 2022 therefore takes into consideration a significant increase in oil and gas prices.

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Annex A.

Table A A.1. Overview of databases and trackers

	Scope	Measures covered	Updates	Environmental dimensions	Sources
OECD Green Recovery Database	43 countries in total plus the EU (as a whole)	Policies related to economic recovery from the COVID-19 crisis. This includes emergency measures where they have clear environmental implications (e.g. unconditional bail-outs of environmentally damaging firms)		Climate Change mitigation, Climate change adaptation, Air pollution, Biodiversity, Water, Waste & recycling	(OECD, 2022[12])
Global Recovery Observatory	The 50 largest economies	Data is focusing on 'recovery' spending as opposed to 'rescue' spending	The Observatory database is updated weekly and the full database is updated regularly	Greenness' based on potential impact on long- and short-term Green House Gas emissions, air pollution, natural capital, quality of life, inequality and rural livelihood	(O'Callaghan et al., 2021[10])
Energy Policy Tracker	38 major economies and eight Multilateral Development Banks (MBDs)		From February 2020 to December 2021	Clean energy in power generation, energy resource extraction, mobility and building sectors	(Energy Policy Tracker, 2021[24])
IEA Sustainable Recovery	Worldwide	Sustainable recovery spending	The Tracker is updated periodically	Sustainable recovery policies that are defined as policies driving spending on clean energy	(IEA, 2022[21])
Nahm, J., S. Miller and J. Urpelainen (2022)	20 largest economies	Inventory of fiscal stimulus spending during the COVID-19 pandemic		Areas that will also cut emissions, including electrifying vehicles, making buildings more energy efficient and installing	(Nahm, Miller and Urpelainen, 2022[26])

				renewables	
Climate Action	16 Member States of the EU and ten other key economies	Rescue and recovery spending	In the present analysis as of May 2021	Low-carbon measures	(Hans et al., 2022[44])

Source: authors' own elaboration

Table A A.2. Amounts reported in different COVID recovery trackers

	Total number (bn USD)			
Climate Action	**Total stimulus**	**Only recovery**	**Green measures**	**Green measures related to climate change mitigation**
OECD Green Recovery Database		2,041	1,090	949
Global Recovery Observatory	20,612	3,895	1,070	
Energy Policy Tracker		1,256		477
IEA Sustainable Recovery	18,200			714
Nahm, J., S. Miller and J. Urpelainen (2022)	14,000			860
Climate Action	11,100		641	

Note: The differences between the databases above lead to different results when comparing total numbers.
Source: authors' own elaboration

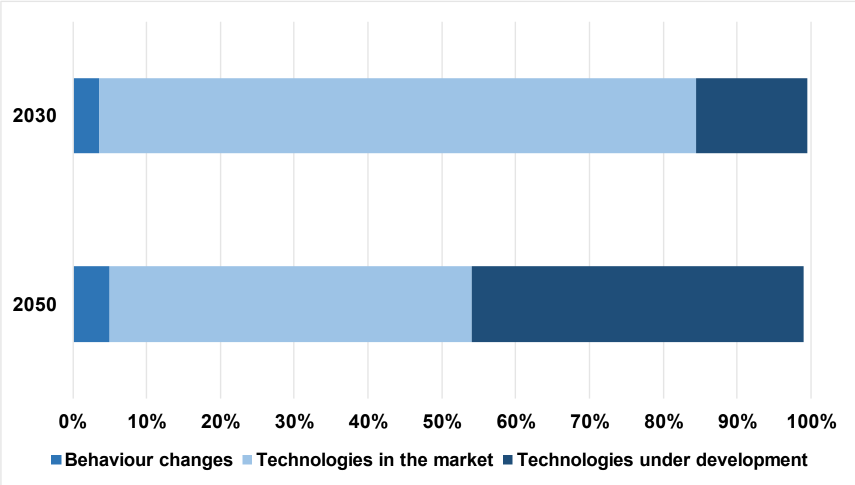
Table A A.3. List of countries in the Low-carbon Technology Support database

Argentina	Czech Republic	Israel	Portugal
Australia	Denmark	Italy	Romania
Austria	Estonia	Japan	Russia
Belgium	European Union	Korea	Saudi Arabia
Bulgaria	Finland	Latvia	Slovak Republic
Brazil	France	Lithuania	Slovenia
Canada	Germany	Luxembourg	South Africa
Chile	Greece	Malta	Spain
China	Hungary	Mexico	Sweden
Colombia	Iceland	Netherlands	Switzerland
Costa Rica	India	New Zealand	Türkiye
Croatia	Indonesia	Norway	United Kingdom
Cyprus	Ireland	Poland	United States

Source: authors' own elaboration

Figure A A.1. Share of CO2 emissions savings from mature and early-stage technologies in the IEA Net Zero scenario

Cumulative CO2 emissions savings in the Net Zero pathway, relative to 2020



Source: IEA (2021[1])

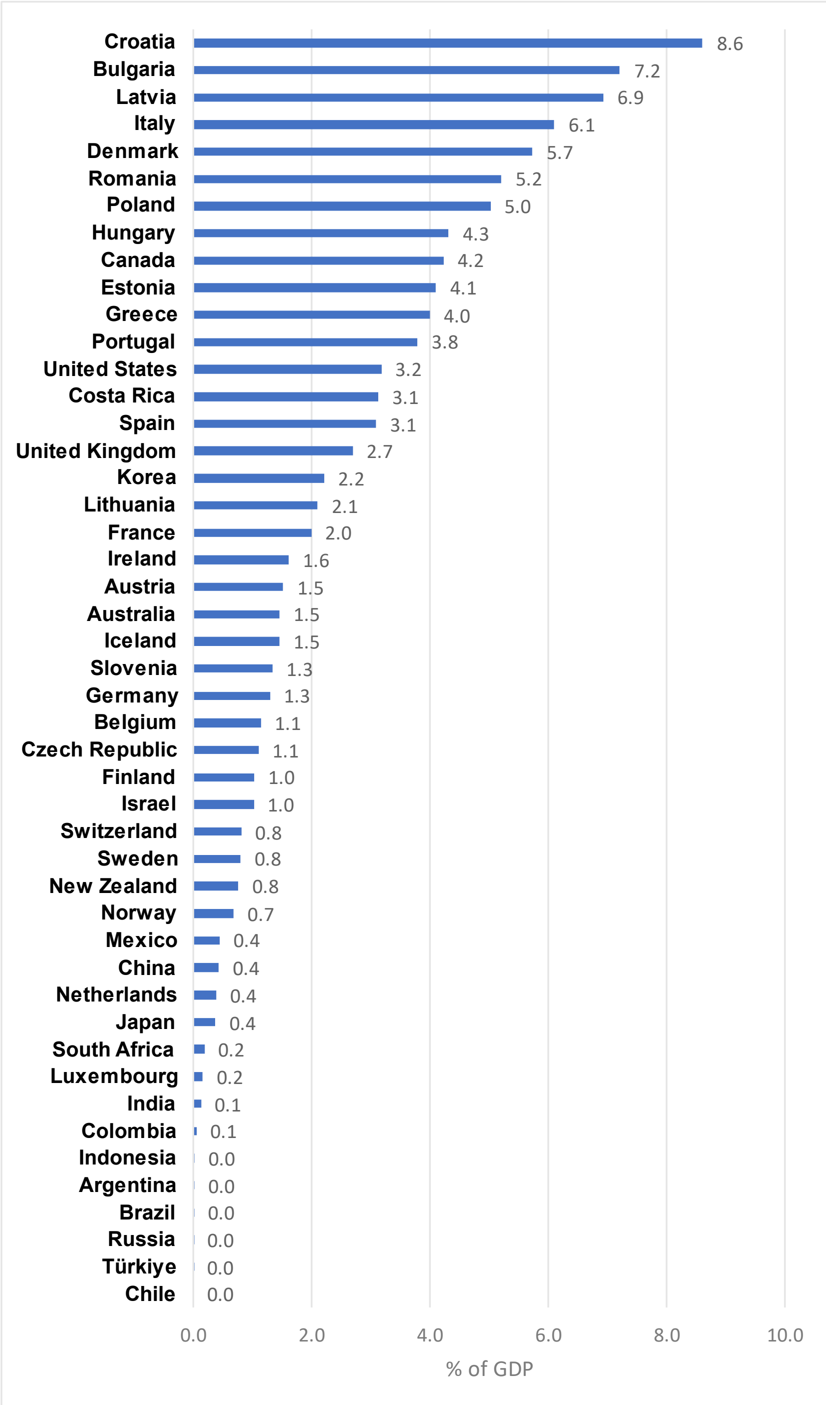
Figure A A.2. Post-COVID low-carbon technology public spending in covered countries (absolute values)

Low-carbon technology public spending in billion USD

Source: OECD Low-Carbon Technology Support database (version May 2023).

Figure A A.3. Post-COVID low-carbon technology public spending in covered countries (share of GDP)

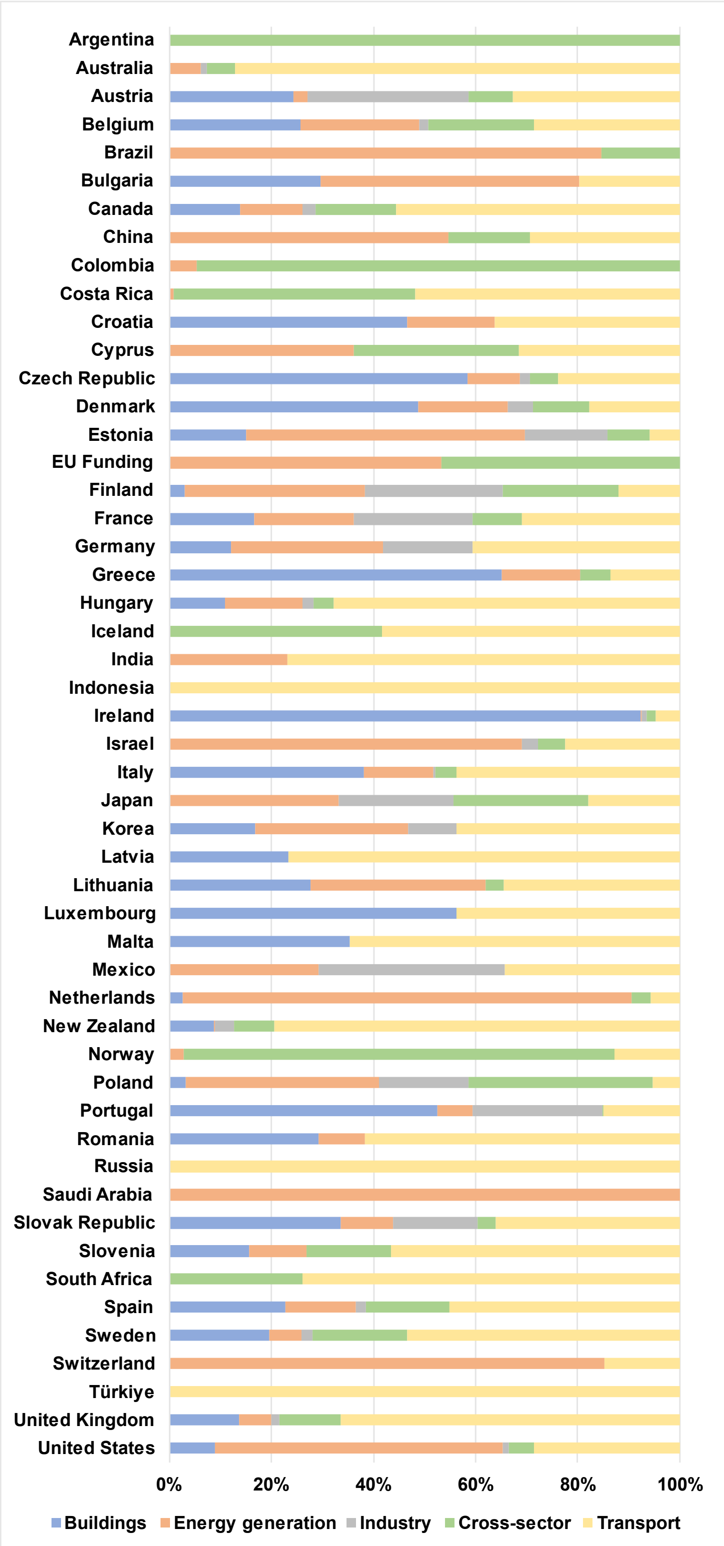
Low-carbon technology public spending as a share of GDP



Source: OECD Low-Carbon Technology Support database (version May 2023), (OECD, 2023[32]), (World Bank, 2023[45]).

Figure A A.4. Distribution of post-COVID low-carbon public spending to various economic sectors across countries

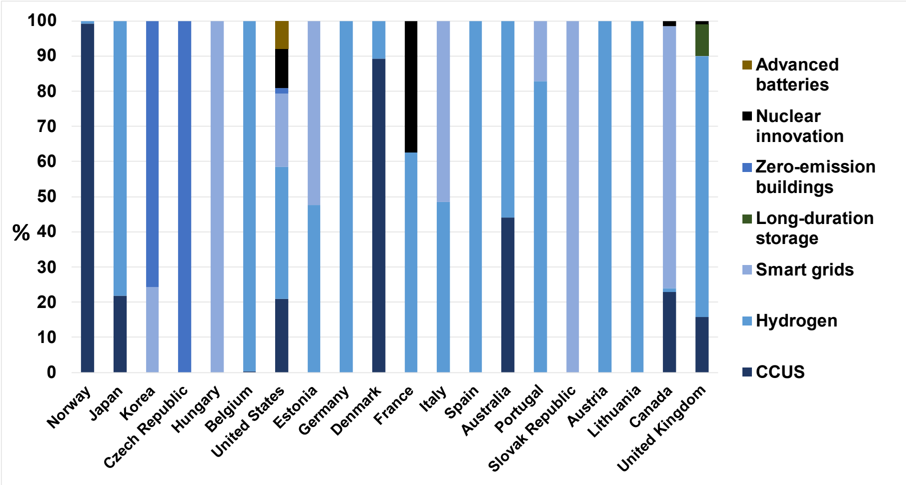
Percentage of the total post-COVID low-carbon public spending



Source: OECD Low-carbon Technology Support database (version May 2023).

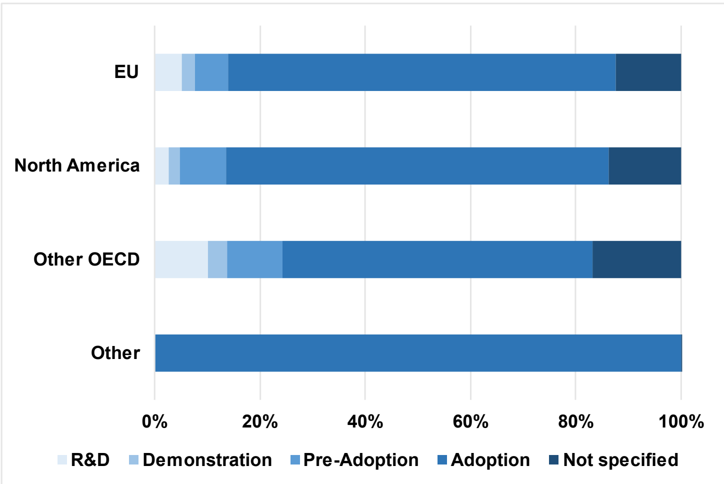
Figure A A.5. Post-COVID low-carbon public spending in emerging technologies across countries

Support for selected emerging technologies, as percentage of total funding targeting low-carbon emerging technologies



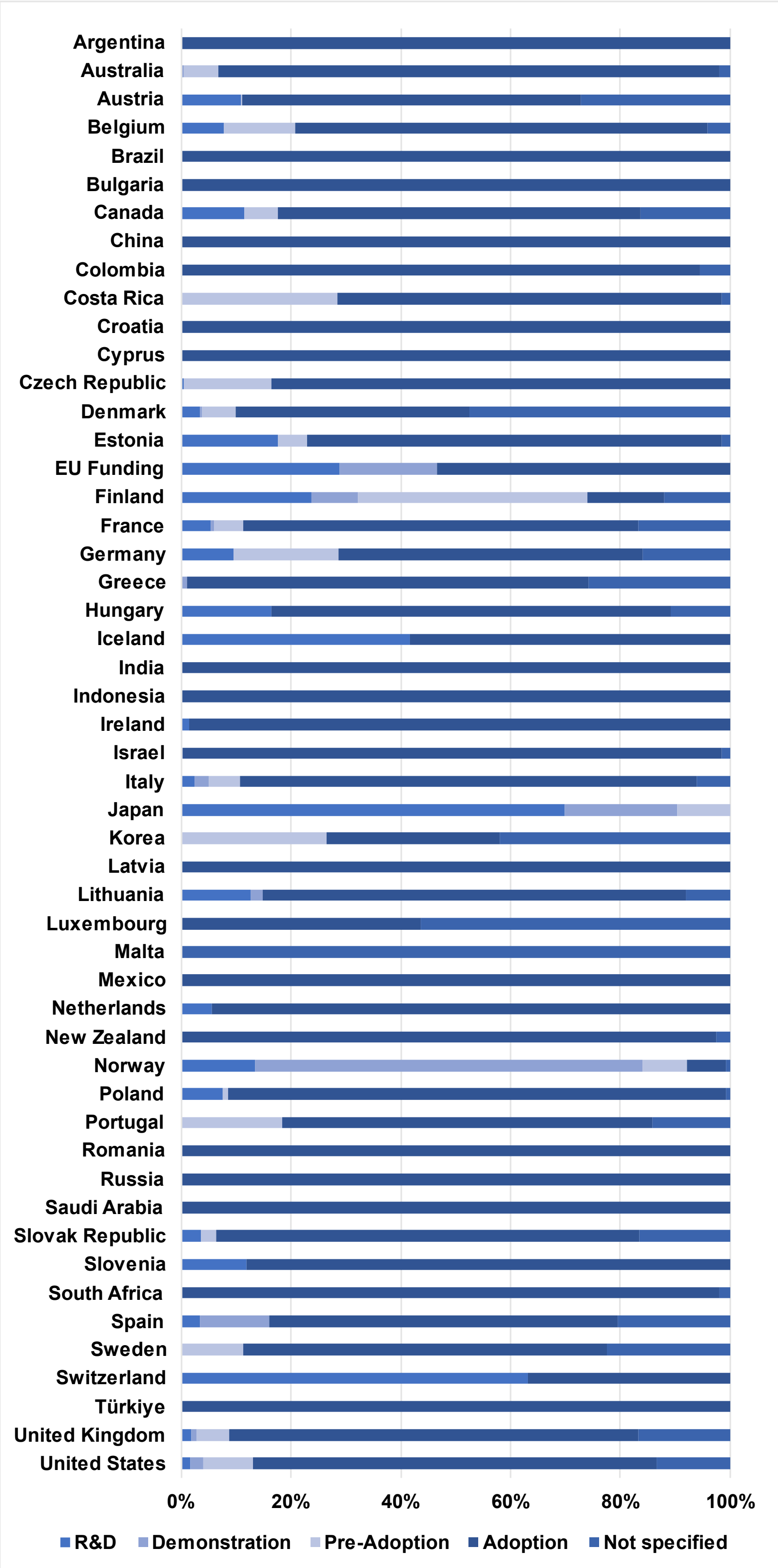
Note: Long-duration storage is specifically mentioned in public spending in the United Kingdom only (USD 100 million). For Norway, public spending targeting emerging technologies as a share of the country's total low-carbon technology public spending is significantly larger than for other countries. This is due to the Norwegian government's financial support to the CCUS project "Langskip", where the financial aid from the government is estimated at NOK 16.8 bn (approximately USD 2 bn), covering the initial investment cost and operating costs across 10 years (Government of Norway, 2020[46]). Post-COVID public investments not targeting any sectors or technologies (USD 8.5 bn) are excluded from this graph.
Source: OECD Low-carbon Technology Support database (version May 2023).

Figure A A.6. Spending by innovation stage as a percentage of total low-carbon technology support spending across regions



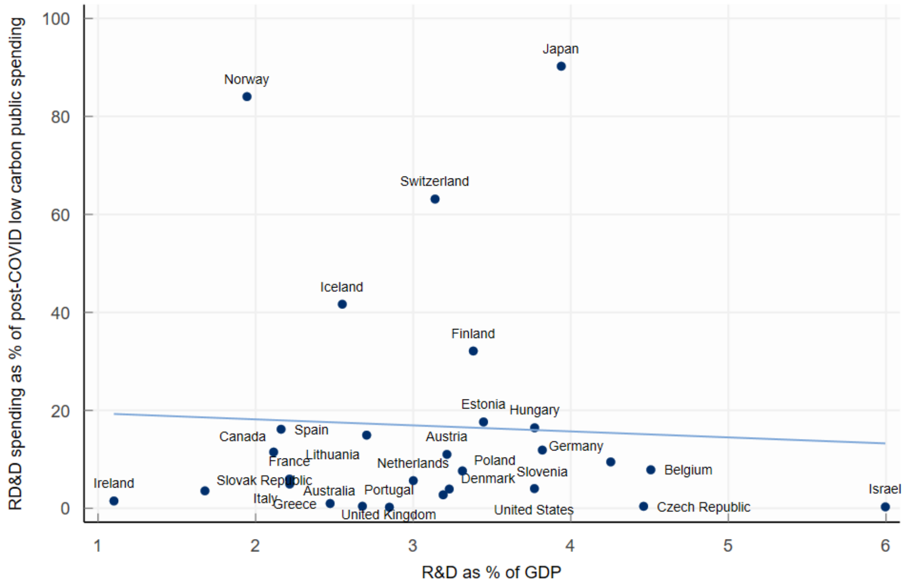
Source: OECD Low-carbon Technology Support database (version May 2023).

Figure A A.7. Spending by innovation stage as a percentage of total low-carbon technology support spending across countries



Source: OECD Low-carbon Technology Support database (version May 2023).

Figure A A.8. RD&D spending as share of post-COVID public spending and R&D as share of GDP



Note: The y-axis shows the percentage of post-COVID public spending related to RD&D, the x-axis shows the percentage of R&D spending as a share of Gross Domestic Product (GDP) in the last available year. The numbers of R&D spending and GDP refer mostly to 2020, except for Australia, Austria, China, France, Ireland, Luxembourg, New Zealand, Romania, South Africa, Sweden, and Switzerland referring to 2019, and South Africa to 2017. Brazil, Bulgaria, Colombia, Costa Rica, Croatia, Cyprus, India, Indonesia, Malta, Saudi Arabia are dropped as there are no values for R&D spending. Türkiye and Chile are dropped as there are no reported monetary values for these countries in the database.
Source: OECD Low-carbon Technology Support database (version May 2023), (OECD, 2023[32]), (OECD, 2022[47])

Table A A.4. Learning rates used in GEM-E3 model

Technology	Learning rate used	Source
Wind	10%	Rubin et al. (2015[48]), Aleluia Reis et al. (2023[49])
PV	12%	Rubin et al. (2015[48]), Aleluia Reis et al. (2023[49])
CCS equipment	11%	Rubin et al. (2015[48])
Hydrogen	18%	Schoots et al. (2008[50]), Schmidt et al. (2017[51]), Lane et al. (2021[52])
Batteries	18%	BloombergNEF (2022[53])
EV	18%	BloombergNEF (2021[54])

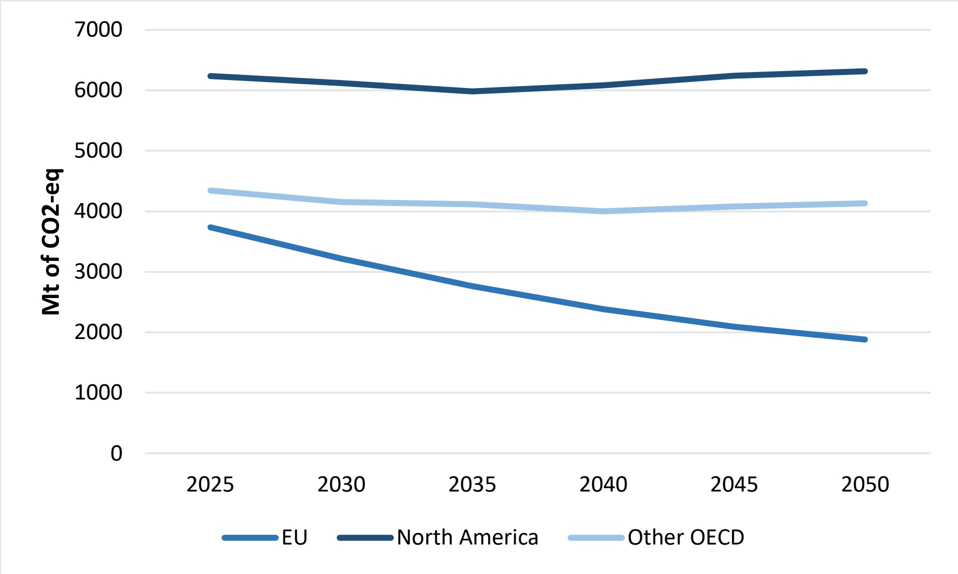
Source: OECD and E3M (2023)

Table A A.5. Technology groups and methodology of their implementation in the model

Technology group	Selected examples of specific technologies	Methodology of model implementation
Electricity generation	Solar panels, wind turbines, hydropower, CCUS (related to power generation sector)	R&D renewable energy: R&D investments ultimately increasing the sector's total factor productivity (used learning rate in Figure A A.4
		Adoption renewable energy: Increase in capacity of renewable power supply technologies, based on the overnight investment costs. Increase in demand for clean energy by investments (financed by surpluses of all agents).
Renovation	Efficient heating and appliances, retrofitting of buildings,	Subsidy to fund the renovation expenditures performed by households. Increase in demand for renovation goods and efficiency in energy use for heating and cooling purposes. The efficiency effect is cumulative and permanent.
Electric vehicles	Electric vehicles, charging infrastructure	Increase in the share of EVs compared to conventional cars. Increase in the stock of electric vehicles/charging stations by assuming a subsidy for the purchase of new EVs/charging stations. The funds are divided by the subsidy (equal to the price difference between an EV and a conventional car) to obtain an estimate of number of subsidised/served EVs. serve. Increasing in this way the relative percentage share of electric vehicles compared to conventional vehicles.
		Increase in demand for EVs and reduction in demand for conventional cars. Institutional transfer from the government to the households.
Biofuels	Bioethanol, biodiesel	Funding the entire cost of biofuel production and substituting the use of conventional fossil fuels in all transport modes.
		Increase in investments in the biofuels sector (financed by surpluses of all agents).
Rail transport	Rail infrastructure	Activity change = change in the rail tracks length, GDP and the price of oil
		Increase in demand for rail-freight and rail-passenger services (substituting road freight services and private transport respectively) compared to the activity levels in the Reference scenario + increase in demand for rail investments (financed by surpluses of all agents)
Public transport	Cycling infrastructure, sustainable urban mobility, public transport	Increase in demand for public transport substituting private road transport compared to the activity levels in the Reference scenario.
		Increase in investments in the road transport sectors (financed by surpluses of all agents)
Batteries	Long-duration storage, advanced batteries	R&D investments ultimately increasing the sector's total factor productivity (used learning rate in Table A A.4). No assumptions made for adoption.
Hydrogen	Hydrogen technologies	R&D hydrogen: R&D investments ultimately increasing the sector's total factor productivity (used learning rate in Table A A.4)
		Adoption hydrogen: funding the entire cost of hydrogen production. Change in the fuel mix (industry, freight, passenger transport) and increase in investments in the hydrogen sector (financed by surpluses of all agents)
CCUS (industry)	CCUS (industry) technologies	Funds split into the sector-specific investments (cement, steel & iron and chemicals production), costs calculated based on literature and funds translated into the total potential amount of CO_2 captured based on the reduction of emission intensity.
		Increase in demand for CCS equipment (investments financed by surpluses of all agents)
Transmission & distribution	Electricity transmission infrastructure, smart grids	Increase in the electrification of the system (for the industrial and service sectors). Investments in the power grid are associated with the level of electrification based on the E3M expertise and in-house data of PRIMES energy model (investments financed by surpluses of all agents).
Energy efficiency in industry	Heat recovery, light-weight optimised energy efficiency technologies	Increase in energy efficiency in each sector (namely "Ferrous metals", "Non-ferrous metals", "Chemical products", "Paper products", "Non-metallic minerals"), based on the E3M expertise and in-house data of PRIMES energy model for energy savings. Investments made in the respective industry (financed by surpluses of all agents).

Source: OECD and E3M (2023)

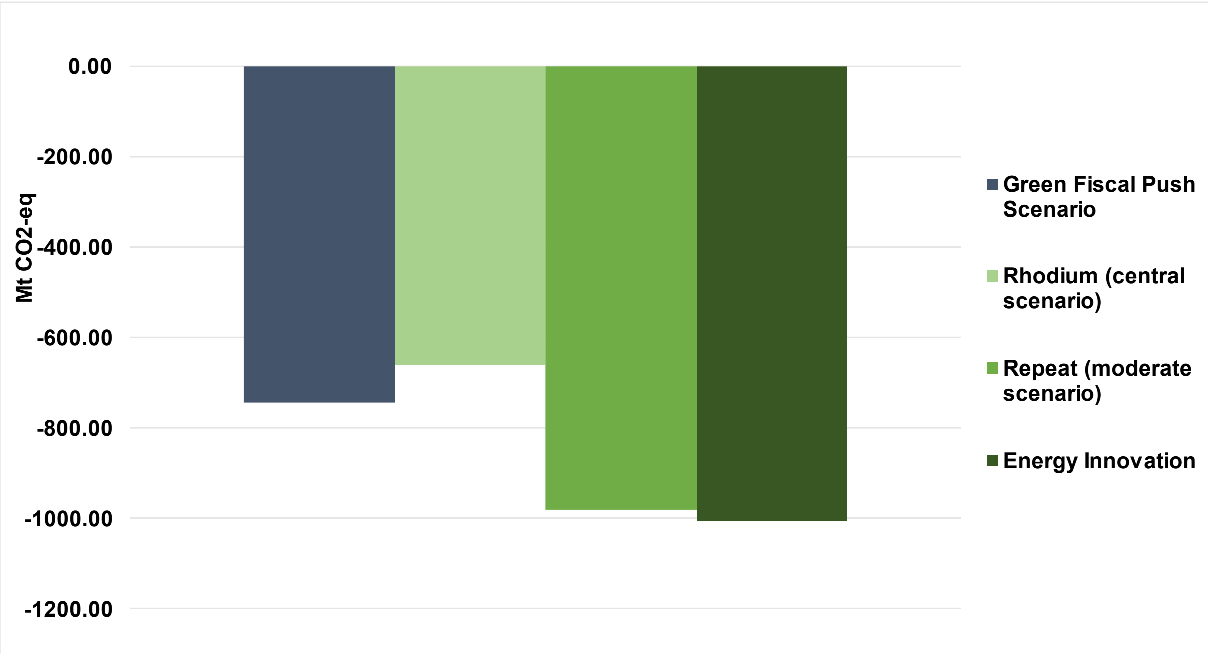
Figure A A.9. GHG emissions projections in the Reference Scenario by region



Source: OECD and E3M (2023)

Figure A A.10. Projected GHG emission reduction effect of post-COVID public low-carbon technology public spending in the U.S. across different analyses

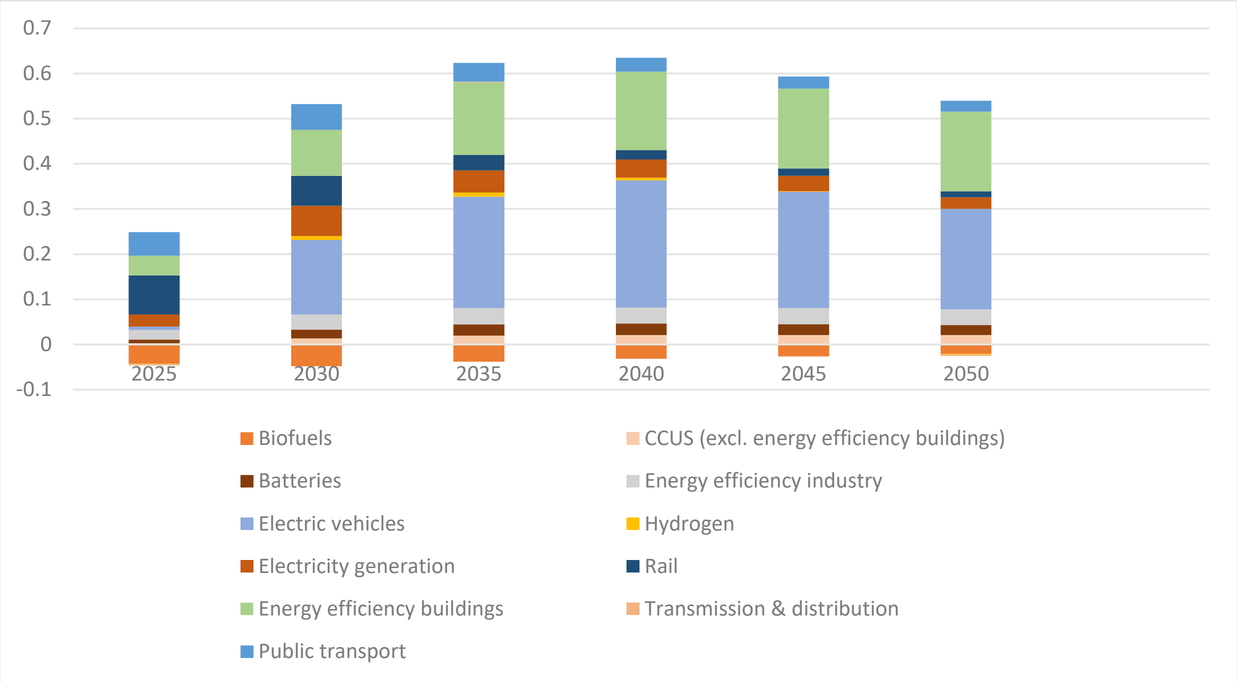
Difference in Mt CO_2-eq from reference scenario in 2030



Note: Note that the various projections are compared to their own reference scenario, which may differ across scenarios. More specifically, note that the Reference scenario, which is used to compare the projections in the Green Fiscal Push Scenario, includes neither IIJA nor IRA.
Source : (Larsen et al., 2022[40]), (Jenkins, 2022[41]), (Mahajan et al., 2022[42]), OECD and E3M (2023)

Figure A A.11. Impact of post-COVID low-carbon public spending on GDP by technology

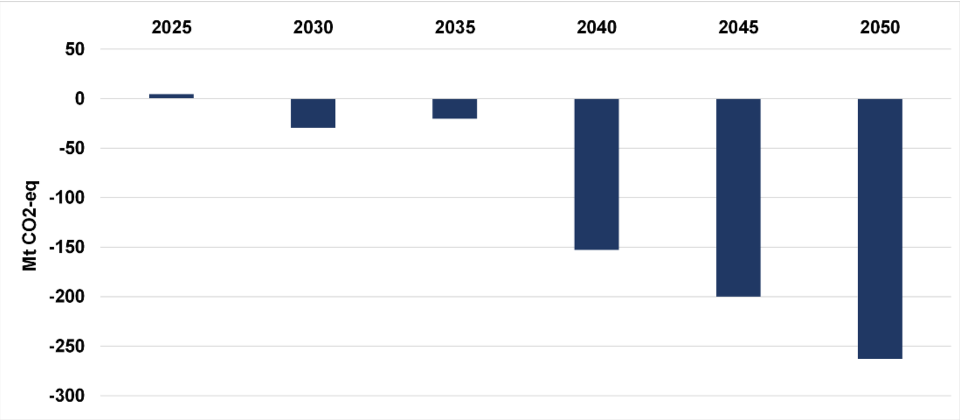
Percentage of change in the Green Fiscal Push Scenario compared to the Reference Scenario in 2030



Source: OECD and E3M (2023)

Figure A A.12. GHG emission reductions in emerging economies associated with international technology spillovers and other general equilibrium effects

Change in GHG emissions (Mt CO2-eq) compared to the Reference scenario, 2025-2050



Note: No post-COVID public spending is assumed to take place in emerging economies in this version of the Green Fiscal Push Scenario. Emerging economies include Brazil, China, India, Indonesia, Russia and South Africa.
Source: OECD and E3M (2023)