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Limited impact of COVID-19 recovery packages on near-term CO_2 emissions pathways

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Abstract

Part of the economic recovery plans implemented by governments following COVID-19 is directed towards the energy transition. To understand the potential effects of these post-COVID green recovery packages on reductions of global greenhouse gas emissions until 2030, we investigated three different approaches. First, we analyzed simulation results of Integrated Assessment Models (IAMs) to infer the change in CO_2 intensity of GDP that could result from post-COVID low-carbon investment plans. Second, we investigated the scenarios the International Energy Agency (IEA) provided based on a bottom-up energy system model. Combining the two approaches, we found that green recovery packages implemented and planned globally can lead to an emissions reduction of merely 1%–6% from the 2030 baseline levels at most. Third, we looked into the results of the Adaptative Regional Input-Output model, which simulates the dynamic effects of economic crisis and fiscal stimuli through supply chains following labor shortage. The third approach shows that the increase of activity driven by fiscal stimuli leads to a rebound of CO_2 emissions even if they do not target carbon-intensive sectors. We conclude that green recovery packages targeting low-carbon technologies have a limited impact on near-term CO_2 emissions and that demand-side incentives, as well as other policy efforts to disincentivize the use of fossil fuels, are also crucial for scaling up climate mitigation.

1. Introduction

To foster economic recovery in the aftermath of the COVID-19 crisis, stimulus plans exceeding 18 trillion USD in March 2022 were adopted by 89 countries, with 95% of the funding concerning advanced economies and China (O'Callaghan *et al* 2021). These countries have also committed to strongly reducing their greenhouse gas emissions, in line with the Paris Agreement targets that require a rapid phase-out of fossil fuels and enhanced investments in low-carbon sources (Tanaka and O'Neill 2018). Many scholars have thus advocated for a 'green recovery' that would take advantage of this unprecedented amount of public spending to restart the economy on a more sustainable basis (Andrijevic *et al* 2020; Hepburn *et al* 2020, Li and Li 2021), after an unprecedented drop in global emissions (Forster *et al* 2020, Quéré 2021, Liu *et al* 2020, 2022). The design of recovery measures is critical to reducing CO_2 emissions (Gawel and Lehmann 2020, Hepburn *et al* 2020). At the beginning of the crisis, Hepburn *et al* (2020) provided a qualitative assessment of possible recovery measures based on three indicators: the impact on growth, the climate impact, and the speed of implementation. However, they did not provide quantitative insights on them. Andrijevic *et al* (2020) (thereafter, A20) advocated for a fraction of the fiscal stimulus to be dedicated to the energy transition, as they estimated that additional low-carbon investments amounting to 300 billion USD/year during the 2020–2024 period were needed to put the world on a pathway to limit the global warming to 1.5 °C. Tanaka *et al* (2022) analyzed this assessment. It argued that the required total energy investments could be larger in the near term, that energy investments must be sustained over the long term, and that other measures (in particular, high carbon pricing) were also needed to accompany energy investments. Using two IAMs, Rochedo *et al* (2021) showed that recovery investments would reduce emissions only by 3%–7% of the amount required by 2030 to achieve the 1.5 °C target. These two studies will be discussed further in section 4.

The objective of our study is to further assess the impact of stimulus packages on near-term emissions pathways by analyzing and comparing three different approaches. The first one builds upon A20, focusing on the impacts of low-carbon investments on CO_2 emissions. Correlations between low-carbon investments and the carbon intensity of GDP (the quantity of CO_2 emitted per GDP unit) from IAM results (McCollum *et al* 2018) are combined with an analysis of post-COVID recovery investments in low-carbon technologies (O'Callaghan *et al* 2021) to infer resulting emissions reductions. The second approach is the World Energy Outlook (WEO) reports of IEA published in October 2020 (IEA 2020) and 2021 (IEA 2021), which describe how different policies enforced in the post-COVID era can shape future energy scenarios. The third approach is that of Shan *et al* (2021) (thereafter, S21), who focuses on emissions rebounds following fiscal stimuli with a model simulating the propagation of disruptions along supply chains.

2. Methods

2.1. Diagnostics from IAM scenarios

The first approach exploits the relationships between the increase of investments in low-carbon technologies and the associated decrease of the carbon intensity of GDP simulated by six IAMs driven by carbon prices: AIM/CGE, IMAGE, MESSAGEix-GLOBIOM, POLES, REMIND-MAgPIE, and WITCH-GLOBIOM, as provided in McCollum *et al* (2018) (thereafter, M18). Four scenarios are considered for each model: a scenario reflecting current policies, a scenario where Nationally Determined Contributions (NDC) are implemented, and two scenarios with global carbon budgets of 1,000 and 400 $GtCO_2$ until 2100, corresponding to 2 °C and 1.5 °C targets, respectively. The model results are available at the regional level, with the following five aggregated regions: OECD90 + EU (OECD as it was in 1990 and EU countries), REF ('Reforming economies' indicating the former Soviet Union), LAM (Latin America), MAF (the Middle East and Africa), and Asia (remaining Asian countries, including China).

M18 quantified the investments in the energy system required to achieve these climate goals through carbon pricing while developing energy supply across the 21st century and minimizing the total discounted cost of mitigation (intertemporal optimization) or the step-by-step costs supported by the economy (recursive dynamics). These costs include investments, fuel costs, operation and maintenance costs, and welfare loss due to lower consumption. Satisfying the carbon budget constraint requires high carbon prices, incentivizing investments in energy efficiency and low-carbon energy sources, disincentivizing carbon-intensive energy production, and reducing energy demand. This generally leads to a decrease in the CO_2 intensity of GDP. Low-carbon investments are thus negatively correlated with the CO_2 intensity of GDP in 2030 across the scenarios, both at the global and regional levels (figure 1).

We follow three successive steps to calculate the CO_2 emissions reduction in 2030 for given low-carbon investments. First, for each model and region, we linearly regress the carbon intensity of GDP in 2030 (in $kgCO_2$ per USD2020) against the cumulative low-carbon investment over 2021–2030 across all scenarios. Second, for each model, we apply these relationships on a region-by-region basis to calculate the reduction of the carbon intensity of GDP for given low-carbon investments. Third, we deduce the CO_2 emissions reduction by using the GDP growth forecast of the International Monetary Fund (IMF). Considering the CO_2 intensity per GDP unit enables us to account separately for the effects of i) low-carbon investments on carbon intensity and ii) COVID-19 and fiscal stimuli on economic activity, which are already included in the IMF analysis. Low-carbon investments over 2021–2030 should also decrease CO_2 emissions after 2030, but we focus on emissions reductions until 2030. The emissions reductions before 2030 were linearly interpolated. The method discussed here is helpful for our purpose. Still, one should bear in mind that it carries certain limitations arising from using IAM simulations driven by carbon prices, among others (see section 4).

More technically, the regression slope $c_{r,\,m}$ represents the change in CO_2 intensity of GDP in 2030 (in $kgCO_2/USD$) in region r estimated from model m, accompanied by cumulative low-carbon investments of 1 billion USD between 2021 and 2030. Thus, increasing low-carbon investments by δI_r over this period yields a change in the regional carbon intensity of GDP, $\delta e_{r,m}$.

$$\delta e_{r,m}(2030) = c_{r,m} \cdot \delta I_r$$

As a result, the regional emissions changes by $\delta E_{r,m}(2030) = \delta e_{r,m}(2030) \cdot GDP_r(2030)$. Regional GDP values in 2030 are based on IMF growth projections of October 2021 for 2021–2026 (IMF 2021), extrapolated until 2030. The sum of $\delta E_{r,m}$ across regions gives the change in global emissions.

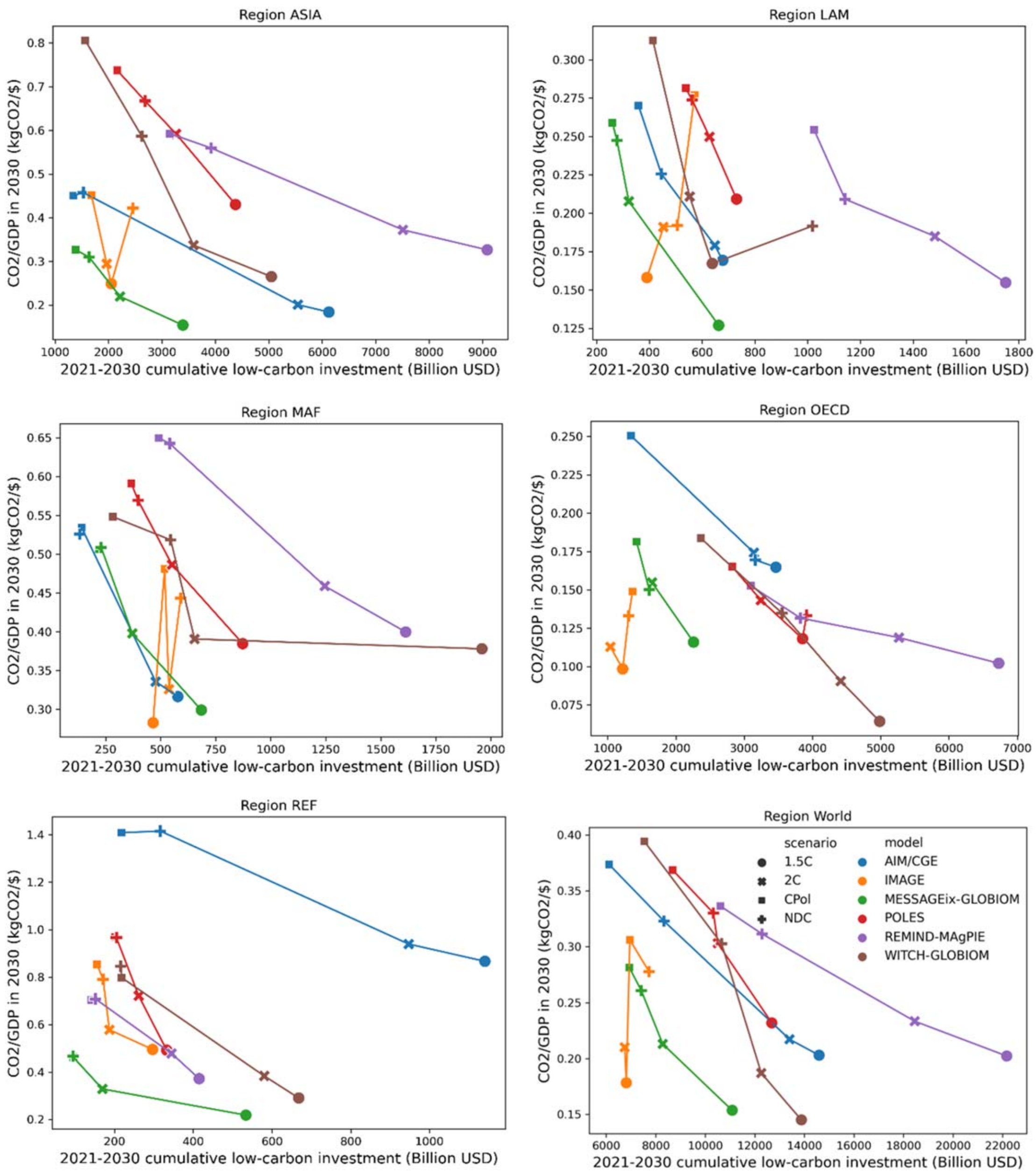

Figure 1. Relationship between the CO_2 intensity of GDP in 2030 and the 10-year (2021–2030) cumulative low-carbon investment in billion USD obtained from IAMs in M18. The monetary unit is USD2020. Each line is composed of four markers, one for each scenario. Each panel represents a different region: Asia, LAM: Latin America, MAF: the Middle East and Africa, OECD: OECD as it was in 1990 and EU countries, REF: former Soviet Union, and the whole world.

To estimate the increase in low-carbon investments until 2030, we use the classification of the Oxford Recovery Project (United Nations Environment Programme 2021). In M18, low-carbon investments cover 'investments into renewable electricity and hydrogen production, bioenergy extraction and conversion, uranium mining and nuclear power, fossil energy equipped with CCS, and the portion of electricity T&D and storage investments that can be attributed to low-carbon electricity generation'. For consistency with IAMs, we consider investments only in the categories of 'clean transport infrastructure, clean energy sector, building upgrades and energy efficiency as low-carbon investments within the recovery packages.' The other categories of green public investments are not considered as low-carbon investments. Namely, 'clean research and development investment and natural infrastructure and green spaces investments,' which are not modelled in IAMs analyzed by M18. Recovery packages inventoried by the Oxford Recovery Project are only partly dedicated to low-carbon technologies: low-carbon investments amount to 511 billion USD, 20% of total recovery investments (table 1).

The CO_2 emissions pathway is obtained by subtracting the emissions reduction from a baseline pathway that does not account for recovery packages. The IEA 'Stated Policies Scenario' from WEO (2020) (thereafter STEPS2020) is used as a baseline because it includes only a small fraction of recovery packages: low-carbon

Table 1. Total recovery investments by category. Data were obtained from the Oxford Recovery Project report, which reflected data available in the Oxford Recovery Observatory up to February 2022. In the Oxford Recovery Observatory, the total COVID-related fiscal spending amount to 14.6 trillion UDS and fall into three categories: recovery spending, rescue spending, and unclear spending. Investments in 'recovery spending' (total amount: 2.6 trillion UDS) are shown in table 1. More details can be found in SM 1.

Type		Billion USD	Share
Low-carbon investments:		*511.2*	*19.7%*
	Buildings upgrades and energy efficiency infrastructure investment	52.8	2.0%
	Clean energy infrastructure investment	153.2	5.9%
	Clean transport infrastructure investment	303.2	11.7%
	Clean new housing investment	2.0	0.1%
Other investments:		*2080.5*	*80.3%*
	Clean research and development investment	59.7	2.3%
	General research and development investment	366.1	14.1%
	Local (project-based) infrastructure investment	206.9	8.0%
	Natural infrastructure and green spaces investment	169.7	6.5%
	Other large-scale infrastructure investments	438.4	16.9%
	Traditional energy infrastructure investments	40.5	1.6%
	Traditional transport infrastructure investments	604.0	23.3%
	Disaster preparedness and capacity building	177.0	6.8%
	Military investments	18.2	0.7%
Total		*2591.7*	

investments packages announced before mid-2020 amounted to 63 billion USD (O'Callaghan *et al* 2021) when STEPS2020 was developed.

2.2. WEO scenarios of IEA

The second approach is based on the WEO reports from 2020 and 2021 (IEA 2020, 2021). We consider the following three scenarios proposed by the IEA: STEPS2020, its update in 2021 (STEPS2021), and the Sustainable Development Scenario (SDS2020). STEPS are scenarios '*which reflect current policy settings based on a sector-by-sector assessment of the specific policies that are in place, as well as those that have been announced by governments around the world*.' STEPS2020 and STEPS2021 incorporate NDCs and recovery measures adopted before mid-2020 and mid-2021, respectively. SDS2020 has the same assumptions as those in STEPS2020 regarding economic growth, except that stringent climate and sustainable development policies are implemented in SDS2020: '*a surge in clean energy policies and investment puts the energy system on track to achieve sustainable energy objectives in full, including the Paris Agreement, energy access and air quality goals*.'

These storylines describe the evolution of the energy system until 2050, from the extraction of fossil fuels to final energy use, energy markets, and investments required to satisfy the energy demand. The storylines are implemented in the World Energy Model (WEM), a technology-rich and data-intensive model. WEM computes how the energy system evolves to meet exogenous energy demand without feedback on the economy. STEPS2020 and SDS2020 have the same GDP growth.

SDS2020 incorporates a plan (sustainable recovery plan) designed to foster economic recovery while mitigating climate change. This plan is a set of various climate policies, from regulatory frameworks to market design and fiscal incentives, modeled with high granularity. For instance, the lifetimes of nuclear plants are extended, more stringent standards are applied to domestic appliance energy efficiency, coal-fired powerplants are retired early or retrofitted to capture and store carbon, and motorway speed is reduced. Decarbonization is not primarily driven by public investment: governments create appropriate policy frameworks, including carbon pricing. However, 70% of these investments are realized by private companies and are thus assumed to come from private finance.

2.3. Adaptative regional input-output model

The third approach developed by S21 analyses the impact of the pandemic and fiscal stimuli on global emissions. The description of the economic impact of the pandemic focuses on the propagation of shocks through supply chains, including the interdependencies across different sectors and regions. They applied to this case study an Adaptative Regional Input-Output model (ARIO) (Hallegatte 2008), which is designed to study the economic consequences of disasters.

It describes the economy as a set of households and producers belonging to different sectors and regions. Households create the final demand, and the supply from producers creates an intermediate demand. The production by a sector Δ of a good α requires three production factors: exogenous capital, exogenous labor, and other intermediate goods. Initially, production meets demand. Then comes the pandemic and associated restrictions: a temporary labor shortage in sector Δ leads the production of good α to decrease. Substitution between factors is impossible as actors cannot make the necessary adjustments on time. The demand of Δ for intermediate goods shrinks (backward propagation), as well as the downstream production that requires α (forward propagation). Firms can overproduce to rebuild their inventories to overcome the disruption, as labor and capital are not fully employed at pre-crisis production levels. Intermediate demand increases and then returns to the pre-crisis level. Significantly, fiscal stimuli increase final demand: a 1 billion USD fiscal stimulus targeting sector Δ is modeled as an increase of 1 billion USD of final demand for α. CO_2 emissions are computed as the sum of the activity of each sector multiplied by its exogenous emissions factor. The global carbon intensity of GDP is therefore susceptible to vary as the weight of different sectors and regions in the global economy changes and emissions factors evolve exogenously.

S21 analyzed several emissions pathways, termed fiscal stimuli (FS) scenarios, which differ by the severity of the pandemic and the fiscal measures taken until 2024 to mitigate economic damages. They differ in three regards: (i) the size of stimuli ('current FS' as of mid-2020 and 'FS+' where fiscal stimuli amount to 10% of 2019 GDP in major economies, both distributed until 2024), (ii) the distribution across sectors (either targeting high-technology sectors or heavy industry, or keeping the current distribution), and (iii) the evolution of the emissions factor of each sector, to account for climate policies beyond fiscal stimuli. Furthermore, three cases are considered for emissions factors: in one case, they remain at the current level (Carbon Intensive Scenario (CIS)). The other cases were derived from the WEO of 2019: emissions factors evolve consistently with the SDS scenario (SDS emissions factors) or the Stated Policy scenario (SPS emissions factors).

The main difference between ARIO and the other model approaches is that ARIO explicitly models dynamic changes in activity levels. This enables a realistic account of the economic decline and rebound following the pandemic. In contrast, partial or general equilibrium models like the IAMs in M18 might overestimate short-term flexibility and substitution possibility (Hallegatte 2008). But, contrarily to these IAMs, there is no 'investment' in ARIO that could increase the means of low-carbon production because capital is exogenous. Mitigation measures in ARIO appear only through sectoral carbon intensities, which are independent of fiscal stimuli.

3. Results

3.1. Linear regressions between low-carbon investments and carbon intensity

While the goodness of fit is very high in most IAMs, IMAGE displays poor correlations (table 3 and 4). The regional regression slopes are highly model-dependent but negative throughout, except those of a few regions in IMAGE. Energy demand in IMAGE is very sensitive to the carbon price driving the simulations of the 1.5 °C and 2 °C scenarios so that energy demand shrinks in response to high carbon prices, and energy investments, including low-carbon investments, are reduced in consequence, unlike those in most other IAMs (Tanaka *et al* 2022). Thus, high carbon prices decrease CO_2 emissions and low-carbon investments. In contrast, GDP, exogenous in IMAGE, is unchanged, and low-carbon investments are positively related to the carbon intensity of GDP in those IMAGE regions. Poor correlations can also be seen in the results of WITCH-GLOBIOM in MAF and LAM for two different reasons. In LAM, the NDC scenario is responsible for the poor correlation. It has high early low-carbon investments to achieve the renewable capacity derived from NDCs. Still, fossil fuel consumption is higher than in the 1.5 °C scenario since carbon prices are lower. In MAF, the 1.5 °C scenario is the outlier. Low-carbon investments, much higher than in the 2 °C scenario, are not associated with a lower carbon intensity of GDP for at least two reasons: GDP declines as oil & gas exports shrink, and additional investments are dedicated to the bioenergy production sector, which does not contribute to emissions reduction as the bioenergy consumption does not increase. Thus, the relationship between low-carbon investments and the carbon intensity of GDP holds only in a subset of IAM simulations we examine. For the sake of the analysis, we disregard these two models and apply the correlations estimated from other four models in the rest of this study.

3.2. Emissions pathways

The emissions reduction obtained from the first approach using our estimate of green recovery packages (table 1 and table 2) is 0.5-2.2 $GtCO_2$/year in 2030, representing merely a 1%-6% emissions reduction from the baseline level (figure 2 and table 5). This reduction is small: for comparison, the 2030 emissions level in SDS2020 is 8.98 $GtCO_2$/year lower than in STEPS2020. This 2030 emissions reduction in SDS2020 (i.e., 25% reduction relative to 2019 levels) is within the range of emissions pathways toward the 1.5 °C target with a high overshoot (IPCC 2022).

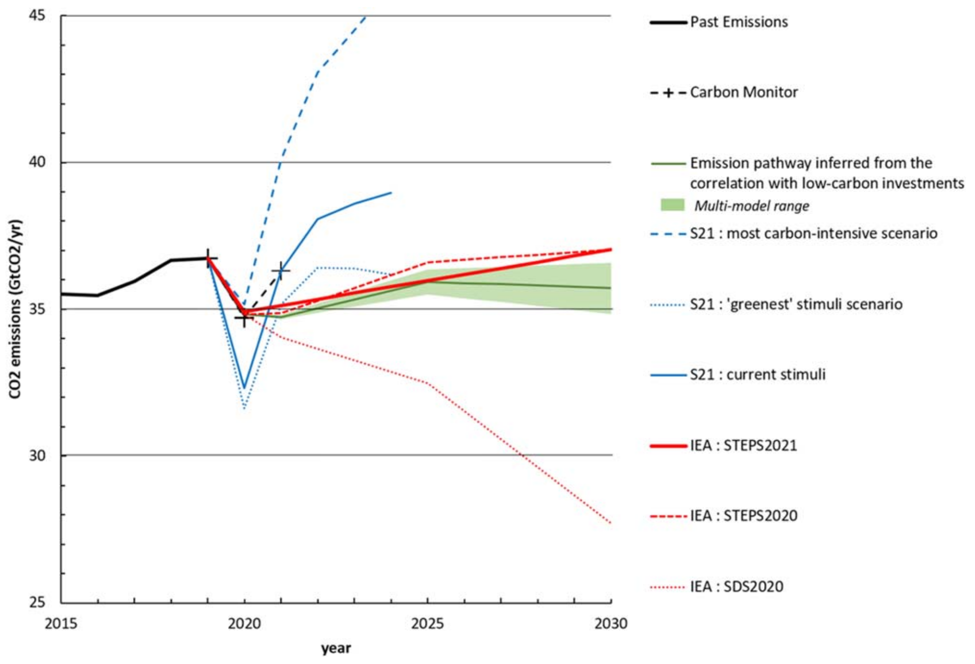

Figure 2. Global total anthropogenic CO_2 emissions pathways (in $GtCO_2$/year) until 2030. The black curve represents historical emissions until 2020 from the Global Carbon Project (GCP)(Friedlingstein *et al* 2022). The black cross represents the estimate by the Carbon Monitor (Liu *et al* 2020). The red curves are based on IEA WEO scenarios. The green curve represents the multi-model mean of emissions pathways obtained by subtracting the emissions reduction based on the correlation with low-carbon investments from the STEPS2020 baseline. The green area represents the multi-model range of such emissions pathways. Blue curves are obtained from S21: The most carbon-intensive scenario has CIS emissions factors, FS + targeting heavy industries. The current stimuli scenario has current FS and SPS emissions factors. The 'greenest' stimuli scenario has current FS targeting high-technology sectors and SDS emissions factors. All emissions pathways are adjusted to match the GCP estimates for 2019 (see SM 3 for scenario corrections).

Table 2. Low-carbon recovery investments by region. Data were obtained from the Oxford Recovery Project report. See the caption of table 1.

Region	δI_r(Billion USD)
ASIA	46.1
LAM	3.6
MAF	0.7
OECD	460.8
REF	0
Total	*511.2*

3.3. Low-carbon investments and emissions reductions

3.3.1. Investment and emissions reductions in IAMs

The slopes of the linear regression (figure 1, table 3) can be used to infer the amount of low-carbon investment in each region between 2021 and 2030 required to reduce emissions by 1 tCO_2/year in 2030 [USD/(tCO_2/year)], which is given as $\frac{-1000}{c_{r,m} \times GDP_r(2030)}$, with $GDP_r(2030)$ in billion USD. At the global scale, low-carbon investments per tCO_2 of emissions reduction in 2030 are obtained by dividing the global post-COVID low-carbon investments (table 2) by the amount of resulting emissions reduction in 2030 (table 5). This quantity was estimated to range from 230 to 1,120 USD/(tCO_2/year) across the IAMs, with a multi-model mean of 540 USD/(tCO_2/year).

The comparison between STEPS2020 and SDS2020 returns similar results: low-carbon investments during the 2021-2030 period in SDS2020 are higher by 570 billion USD/year than in STEPS2020. This corresponds to an additional cumulative investment of 5,690 billion USD. The emissions differ by 8.98 $GtCO_2$ in 2030, resulting in a low-carbon investment per tCO_2 reduction of 633 USD/(tCO_2/year).

By using the same IAM results as in our study (i.e., data from M18), A20 estimated that additional low-carbon investments of 300 billion USD/year until 2024 (hence, 1,500 billion USD until 2024) were required to

Table 3. Estimates of $c_{r,\,m}$ (in (kgCO$_2$/USD)/(billion USD) of each model and region. $c_{r,m}$ represents the change in CO_2 intensity of GDP in 2030 (in kgCO$_2$/USD) associated with an increase of 1 billion USD in low-carbon investments over 2021–2030.

$c_{r,\,m}$	Model					
Region	AIM/CGE	IMAGE	MESSAGEix-GLOBIOM	POLES	REMIND-MAgPIE	WITCH-GLOBIOM
ASIA	-5.9×10^{-5}	-1.2×10^{-5}	-8.8×10^{-5}	-1.4×10^{-4}	-4.7×10^{-5}	-1.6×10^{-4}
LAM	-2.9×10^{-4}	6.1×10^{-4}	-3.1×10^{-4}	-3.8×10^{-4}	-1.2×10^{-4}	-1.5×10^{-4}
MAF	-5.1×10^{-4}	1.1×10^{-3}	-4.5×10^{-4}	-4.0×10^{-4}	-2.3×10^{-4}	-8.6×10^{-5}
OECD90 + EU	-4.2×10^{-5}	1.1×10^{-4}	-7.1×10^{-5}	-3.5×10^{-5}	-1.3×10^{-5}	$-4.6\times10-5$
REF	-6.4×10^{-4}	-2.2×10^{-3}	-5.2×10^{-4}	-3.7×10^{-3}	-1.2×10^{-3}	-1.2×10^{-3}

Table 4. $R^2_{r,\,m}$, the determination coefficient of the regression of the carbon intensity of GDP in 2030 against the cumulative low-carbon investment over 2021–2030.

$R^2_{r,\,m}$	Model					
	AIM/CGE	IMAGE	MESSAGEix-GLOBIOM	POLES	REMIND-MAgPIE	WITCH-GLOBIOM
ASIA	0.995	0.001	0.946	0.999	0.992	0.914
LAM	0.971	0.851	0.944	0.999	0.907	0.387
MAF	0.985	0.339	0.953	0.979	0.992	0.551
OECD	0.994	0.463	0.920	0.851	0.948	0.998
REF	0.985	0.705	0.849	0.995	0.995	0.996

Table 5. Emissions reduction in 2030 (in GtCO$_2$/year) calculated from its correlation with low-carbon investments found in the Oxford Recovery Project database.

Model	Emissions reduction in 2030 (GtCO$_2$/year)	As a percentage of baseline emissions level in 2030
AIM/CGE	1.30	3.7%
MESSAGEix-GLOBIOM	2.22	6.2%
POLES	1.26	3.5%
REMIND-MAgPIE	0.46	1.3%

put the energy system on track to achieve the 1.5 °C target. Our corresponding estimate is 410–1,220 billion USD/year (see SM4). The A20 estimate is slightly below our range, which can be explained by the following methodological differences between the two studies. First, when deriving the relationship between low-carbon investments and emissions reductions from IAMs, A20 considered only 1.5 °C and current policies scenarios till 2024 at the global level. In contrast, our study considered four scenarios (including NDC and 2 °C scenarios) till 2030 at the regional level. Second, while A20 used the results from all available IAMs, our study excluded a subset of IAMs. Third, we incorporated the effect of GDP growth in estimating emissions reductions, which was not considered in A20. Fourth, the scope of low-carbon investments considered in A20 is wider than in our study (and therefore that in M18).

We further note that, whereas A20 and our study reached similar estimates of required low-carbon investments, the two studies provide different yet complementary perspectives. A20 emphasized how little the required low-carbon investment is, compared to the massive COVID-related fiscal spending, calling primarily for more green recovery investments. In contrast, our study focuses on the estimate of current green recovery packages and argues that current green recovery packages are inadequate for achieving the 1.5 °C target of the Paris Agreement and highlights the need for other measures to support climate mitigation efforts, as discussed in the rest of this paper.

3.3.2. Fiscal stimuli and emissions in ARIO

Our examination of the S21 results reveals that the main driver of emissions levels after the emissions drop and rebound is the assumed emissions intensity of each sector. In 2024, the emissions levels in scenarios with SDS and CIS sectoral carbon intensities (shown in S21) are about 8% lower and 20% higher, respectively, than in the reference scenario (based on SPS carbon intensities, 'current fiscal stimulus size', and 'current fiscal stimulus structure'). In contrast, the emissions levels change by less than 0.3% across different structures and sizes of fiscal stimulus for a given set of carbon intensities. Hence, varying the size and structure of fiscal stimuli has a minor impact compared to the choice of sectoral carbon intensities.

In the third approach, neither the size nor the structure of fiscal stimuli plays a decisive role: prioritizing high-tech industries over heavy industries is insufficient to reduce emissions. This approach provides valuable insights into the short-term emissions decline and rebounds following the pandemic through supply chains across different sectors and regions (until around 2021 in figure 2). However, such an approach is, in our opinion, of lesser use in assessing the role of fiscal stimuli on emissions pathways involving the longer-term decarbonization of the energy system (until around 2024 in figure 2) because emissions levels are essentially the direct outcome of the choice of sectoral carbon intensities, which are not driven by the fiscal stimuli in ARIO.

4. Discussion and conclusions

Our analysis of IAM results and the IEA scenarios adds further insight to the claim that low-carbon investments included in the recovery packages will not induce a sufficient change in the energy system to achieve the Paris agreement targets (Rochedo *et al* 2021, United Nations Environment Programme 2021, Tanaka *et al* 2022). The ARIO model provides more realistic insights than IAMs into the economic decline and rebound following the pandemic and the fiscal stimuli through the supply chain; however, we found that the ARIO model was not designed for simulating the effect of recovery packages on CO_2 emissions through fundamental changes in the energy system. It should also be noted that using the investment-emissions relationships has three caveats. First, it focuses on low-carbon investments, only a tiny fraction of fiscal stimuli, without considering fossil fuel investments that also influence emissions. Second, fiscal stimuli in the real world can only coarsely relate to low-carbon investments in IAMs. Third, low-carbon investments are partially associated with CO_2 emissions reductions in the results of IAMs driven by carbon prices. These imply that using the investment-emissions relationships may lead to overestimating CO_2 emissions reductions per unit investment. Each of the three caveats is discussed below.

First, the investment-emissions relationships only reflect a tiny part of the total fiscal stimuli (i.e., 511 billion USD of low-carbon investments for the fiscal stimulus of more than 18 trillion USD). Although the recovery of economic activity through fiscal stimulus measures is factored into the estimates of GDP levels in 2030, this approach assumes that only low-carbon investments affect the emissions intensity of GDP. Measures supporting carbon-intensive industries within fiscal stimuli are neglected, as well as recovery investments dedicated to carbon-intensive sectors (40 billion USD for traditional energy infrastructure and 600 billion USD for traditional transportation infrastructures), but could increase the carbon intensity of GDP. Hence, focusing on low-carbon investments may lead to overestimating subsequent emissions reductions.

Second, low-carbon investments in recovery packages cannot relate unambiguously to low-carbon investments in IAMs for two reasons: (i) investments are not categorized in the same way between the Oxford Recovery Project database and IAMs, and (ii) the allocation of investments across sectors and regions is different. Low-carbon investments modeled by IAMs are mainly supply-side investments (70% of low-carbon investments (IEA 2020)). In contrast, the supply side represents only 30% of current low-carbon recovery packages through clean energy infrastructure investments (table 1). The current regional allocation of the low-carbon investment packages differs from the allocation of cost-effective mitigation pathways in IAMs. 90% of the low-carbon investments from recovery packages are deployed in OECD90 + EU countries. 9% are deployed in Asia, less than 2% in Latin America, the Middle East, and Africa, and 0% in the former Soviet Union (table 2). These regional allocation mismatches will limit the investments' global efficiency, as also pointed out in the latest version of the WEO (IEA 2021) and the associated Sustainable Recovery Tracker updated in February 2022 (IEA 2022). Using the suboptimal investment allocation in the optimal IAM results implies that the number of emissions reductions for given low-carbon investments may be overestimated.

Third, in the IAM results we analyzed, low-carbon investments do not fully explain CO_2 emissions reductions because these IAMs are driven by carbon pricing that can induce changes in CO_2 emissions through other pathways. In IAMs, an increase in carbon prices incentivizes investments in energy efficiency and low-carbon energy sources, disincentivizes carbon-intensive energy production, and reduces energy demand to satisfy the carbon budget constraint (Tanaka *et al* 2022). The impact of low-carbon investments alone is limited: Rochedo *et al* (2021) used IAMs that directly simulated low-carbon investments (i.e., without being driven by carbon pricing) and has shown that, even if the recovery investments represent a significant part (17%–35%) of the investments in low-carbon technologies until 2030, they reduce emissions by only a small fraction (3%–7%) of what is needed to achieve the 1.5 °C target. Low-carbon investment is only one of the levers mobilized in the models to achieve a given climate policy target. This also suggests that the use of the investment-emissions relationships may lead to an overestimation of emissions reductions.

Our numerical analysis based on the investment-emissions relationships suggested that near-term CO_2 emissions reductions realized through current green recovery packages would be insufficient for climate mitigation toward the 1.5 °C target. The final discussion here further suggests that our estimate of such emissions reductions may be overestimated due to methodological limitations. Counterbalancing the rebound of emissions generated by fiscal stimuli and ensuring emission reductions on a long-term basis requires broader measures to disincentivize the use of fossil fuels, incentivize demand-side requirements, and make the most of low-carbon investments deployed by governments.

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Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: https://doi.org/10.5281/zenodo.6562873.

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Conflict of interest

The authors declare no conflict of interest.

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References

Andrijevic M, Schleussner C-F, Gidden M J, McCollum D L and Rogelj J 2020 COVID-19 recovery funds dwarf clean energy investment needs *Science* **370** 298–300
Forster P M *et al* 2020 Current and future global climate impacts resulting from COVID-19 *Nat. Clim. Chang.* **10** 913–9
Friedlingstein P *et al* 2022 *Global Carbon Budget 2021. Earth System Science Data* **14** 1917–2005
Gawel E and Lehmann P 2020 Killing two birds with one stone? Green dead ends and ways out of the COVID-19 crisis *Environmental and Resource Economics* **76** 504–507
Hallegatte S 2008 An adaptive regional input-output model and its application to the assessment of the economic cost of Katrina *Risk Anal.* **28** 779–99
Hepburn C, O'Callaghan B, Stern N, Stiglitz J and Zenghelis D 2020 Will COVID-19 fiscal recovery packages accelerate or retard progress on climate change? *Oxford Review of Economic Policy* **36** S359–81
IEA 2020 *World Energy Outlook 2020* (Paris: OECD Publishing)
IEA 2021 *World Energy Outlook 2021* (Paris: OECD Publishing)
IEA 2022 *Sustainable Recovery Tracker* (Paris: IEA) (https://iea.org/reports/sustainable-recovery-tracker)
IMF 2021 *World Economic Outlook: Recovery during a Pandemic—Health Concerns, Supply Disruptions, Price Pressures. Washington, DC, October.* International Monetary Fund
IPCC *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* ed P R Shukla *et al* 2022 (Cambridge, UK: Cambridge University Press)
Li R and Li S 2021 Carbon emission post-coronavirus: continual decline or rebound? *Struct. Change Econ. Dyn.* **57** 57–67
Liu Z *et al* 2020 Near-real-time monitoring of global CO2 emissions reveals the effects of the COVID-19 pandemic *Nat. Commun.* **11** 5172
Liu Z, Deng Z, Davis S J, Giron C and Ciais P 2022 Monitoring global carbon emissions in 2021 *Nat Rev Earth Environ* **3** 217–9
McCollum D L *et al* 2018 Energy investment needs for fulfilling the Paris Agreement and achieving the sustainable development goals *Nat. Energy* **3** 589–99

O'Callaghan B *et al* 2021 *Global Recovery Observatory*. Oxford University Economic Recovery Project https://recovery.smithschool.ox.ac.uk/tracking/

Quéré C L 2021 Fossil CO2 emissions in the post-COVID-19 era *Nat. Clim. Change* **11** 6

Rochedo P R R, Fragkos P, Garaffa R, Couto L C, Baptista L B, Cunha B S L, Schaeffer R and Szklo A 2021 Is green recovery enough? Analysing the impacts of post-COVID-19 economic packages *Energies.* **14** 5567

Shan Y, Ou J, Wang D, Zeng Z, Zhang S, Guan D and Hubacek K 2021 Impacts of COVID-19 and fiscal stimuli on global emissions and the Paris Agreement *Nat. Clim. Change* **11** 200–6

Tanaka K, Azar C, Boucher O, Ciais P, Gaucher Y and Johansson D J A 2022 Paris Agreement requires substantial, broad, and sustained policy efforts beyond COVID-19 public stimulus packages *Clim. Change* **172** 1

Tanaka K and O'Neill B C 2018 The Paris Agreement zero-emissions goal is not always consistent with the 1.5 °C and 2 °C temperature targets *Nat. Clim. Change* **8** 319–24

United Nations Environment Programme 2021 Are we building back better? Evidence from 2020 and pathways to inclusive green recovery spending