Exploring the impact of the COVID-19 pandemic on global emission projections

Assessment of green versus non-green recovery

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Table of Contents

List of Figures

List of Tables

Abbreviations

CO₂	carbon dioxide
CAT	Climate Action Tracker
ERP	economic recovery package
GCP	Global Carbon Project
GDP	gross domestic product
GHG	greenhouse gas
Gt	gigatonne (billion tonnes)
GW	gigawatt (billion watts)
IAM	integrated assessment model
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
IMF	International Monetary Fund
JRC	Joint Research Centre
NDC	Nationally Determined Contributions
NIES	National Institute for Environmental Studies
OECD	Organisation for Economic Co-operation and Development
PBL	PBL Netherlands Environmental Assessment Agency
PIK	Potsdam Institute for Climate Impact Research
UNEP	United Nations Environment Programme
VAT	value-added tax
WEO	World Energy Outlook
WSF	Germany's Economic Stabilisation Fund (*Wirtschaftsstabilisierungsfonds*)

Acknowledgements

Main findings

COVID-19 is primarily a global health crisis, but the pandemic also has a substantial impact on socio-economic activities and energy use, and therefore on CO_2 emissions. Due to the population lockdowns, restrictions in movement and reduced energy demand, global emission levels in 2020 will, by most accounts, show the largest annual decline in history. Moreover, the pandemic and the recovery measures taken in its wake will likely affect emissions for the years to come. The extent of this impact is uncertain to an unprecedented degree, due to the unpredictable future course of the pandemic and large uncertainties surrounding the national and international recovery trajectories.

This report assesses the implications of the COVID-19 pandemic and associated recovery measures on emissions out to 2030 and global emission pathways towards meeting the Paris climate goals. Due to the high uncertainty surrounding the course of the pandemic and its impact on CO_2 emissions, we only present 'what-if' scenarios, based on explorative 'ex-post' calculations (using sources available before June 2020) for several potential emission pathways and factors that could affect their course, including rebound effects. Furthermore, we review and summarise the most recent insights (up to June 2020) published in the literature on post-COVID emissions projections and green recovery trajectories, and provide a framework for analysing the 'greenness' of recovery packages, using Germany as a case study. Finally, we explore how integrated assessment models can be used to explore both the short-term and long-term effects of the pandemic and associated recovery measures.

Our main findings are as follows:

- Based on data and projections of the IEA and Global Carbon Project published in April and May 2020, **our median estimate for the global CO_2 emission reduction in 2020**, compared to 2019 levels, **is –8%** in case of prolonged lockdowns worldwide until the end of 2020, **and –4% to –5%** if lockdowns are shorter and Europe and North America recover faster in the second half of 2020.

- For the longer term, our ex-post calculations indicate that the impact of the general slowdown of the economy would lead to **an annual global emission reduction of –2.5 to –4.5 GtCO₂e (–4% to –7%) in 2030, compared to pre-COVID current policy projections, for IMF's *Baseline* and *Longer and New Outbreak* scenario, respectively**. These numbers are based on IMF's (April 2020) GDP projections for 2020-2024 and model decarbonisation rates from post-COVID current policies scenarios. However, **the impact of a rebound to fossil fuels**, with lower decarbonisation rates, **the emission reduction in 2030 is projected to be smaller (–3.0 instead of –4.5 GtCO₂e in the *Longer and New Outbreak* scenario) or may even turn into an increase (+0.5 instead of –2.5 GtCO₂e in the *Baseline* scenario).**

- **The effect of the COVID-19 pandemic on projected emissions under the Nationally Determined Contribution (NDC) scenarios is limited so far, because NDC targets have not changed at this point**. For countries whose reduction targets are defined per unit of GDP, including China and India, the pandemic will likely affect NDC emission projections through its effects on GDP growth, but **information at this level is not yet available.** The NDC projections of UNEP (2019, pre-COVID) (54-56 GtCO₂e in 2030) partly overlap with our post-COVID estimates for the current policies scenarios (55-60 GtCO₂e in 2030).

- At this point, **the COVID-19 pandemic is expected to have little effect on estimates of the 2030 GHG emission levels consistent with a least-cost pathway in line with the Paris Agreement goals**, **as the 2020 drop in emissions is not due to structural changes**. While the CO_2 emissions reduction in 2020 is probably unprecedented, **a consistent, similar rate of decrease would need to be maintained for decades in order to achieve the 1.5 °C warming limit**. Low-carbon development needs to play a key role in countries' recovery strategies to avoid that emissions bounce back or even overshoot previously projected levels by 2030, as shown in our projections.

- **Assessing the effect of the fiscal stimulus packages** announced by governments in response to the pandemic **requires an in-depth analysis of individual measures. To this end, we propose a classification defining 'green', 'grey'**[1] **and 'colourless' measures** (both sector-specific and economy-wide). Besides tracking incoming economic recovery packages, attention should focus on how to account for the environmental effects of additional rescue measures such as airline bailouts, how to include non-budgeted measures, and how to account for regulatory roll-backs.

- Using the classification method mentioned above, a pilot assessment of the €130 billion fiscal stimulus package announced by the German government on 3 June 2020 reveals that 'green' recovery measures account for approximately 31% of this stimulus. While the package does not contain unambiguously 'grey' measures, some measures currently coded as 'green' or 'colourless' may require further assessment once more information becomes available. Approximately 21% of the package is in line with the green measures defined by IEA's *Sustainable Recovery Plan.*

- Based on our ex-post method, **we estimate that full implementation of IEA's *Sustainable Recovery Plan,*** assuming similar decarbonisation rates and global GDP growth as IEA, **would result in global GHG emissions of 49 to 52 GtCO₂e in 2024, which is below 2019 levels**.

- To further assess the impact of the pandemic and associated recovery measures, Integrated Assessment Models (IAMs) are most suitable for long-term projections, and less suitable to account for short-term dynamics. The latter can be partly overcome by making use of projections from macroeconomic models such as E3ME and GEM-E3-FIT, provided that a series of inputs representing different long-term future scenarios are carefully constructed beforehand. This way, IAMs can provide valuable input on the feasibility of post-COVID transition pathways towards zero carbon emissions.

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[1] In line with the EU Technical Expert Group on Sustainable Finance (2020, p. 51) and MacKenzie (2020), we propose to henceforth use the word 'grey' rather than 'brown' for polluting measures, to accommodate different cultural contexts and avoid racial connotations. When citing papers that use the word 'brown' as an indicator of 'polluting', we refer to this as "brown" [grey].

1 Introduction

COVID-19 is primarily a global health crisis, but the pandemic also has a substantial impact on socio-economic activities and energy use, and therefore on CO_2 emissions. Due to the population lockdowns, restrictions in movement and reduced energy demand, emission levels in 2020 will, by most accounts, show the largest annual decline in history. Moreover, the pandemic will likely affect global CO_2 emissions for the years to come. The extent of this impact is uncertain to an unprecedented degree, due to the unpredictable future course of the pandemic and large uncertainties surrounding the national and international recovery trajectories.

This report explores the implications of the COVID-19 pandemic and economic recovery measures on CO_2 emissions out to 2030 and on the global emission pathways towards meeting the Paris climate goals. The impact of the pandemic on energy demand and associated emissions is highly uncertain for 2020, and even more so for the medium-term (out to 2030) and long-term projections (out to 2050). Therefore, this report only presents "what-if" scenarios, based on explorative calculations, to gauge the effect of different possible recovery trajectories on potential emission pathways. These calculations were conducted at the global level, due to the pandemic nature of COVID-19 and the limited availability of national data at this point.

Chapter 2 takes stock of the impact of the COVID-19 pandemic on current global emissions and expected trends. More specifically, this chapter first focuses on emission data and projections for 2020 (as published between April and June of this year) and then combines this information with IMF's economic forecasts to adjust the pre-COVID emission projections up to 2030. These 'ex-post' calculations are presented for the current policies scenarios and compared with the NDC scenarios and least-costs scenarios in line with the Paris Agreement goals. Finally, this chapter identifies the main uncertainties surrounding these projections, particularly in terms of possible rebound effects at the sector level.

Chapter 3 discusses green versus 'non-green' recovery, by (i) identifying green recovery criteria, and (ii) proposing a framework to track and evaluate economic stimulus packages, including a classification of recovery measures based on their potential mitigation (or intensification) of GHG emissions. The proposed framework is demonstrated using Germany as a case study, as this country has the most detailed recovery measures planned so far. Finally, this chapter discusses how to assess the impact of recovery measures on GHG emissions. As an example, the ex-post method introduced in Chapter 2 is used to project global emissions under full implementation of IEA's *Sustainable Recovery Plan* (IEA, 2020b).

Finally, **Chapter 4** explores how the impact of the COVID-19 pandemic on emission projections can be captured through modelling, i.e. moving beyond the trend analyses and ex-post calculations presented in the current report. Specifically, this chapter evaluates the suitability of Integrated Assessment Models (IAMs) to explore the short-term impacts of the pandemic – such as the effect of lock-downs and reduced transport – versus the long-term impacts of both the pandemic and the recovery measures taken, in terms of structural changes in the economy, energy production, consumption patterns, mobility and lifestyles.

2 Impact of the COVID-19 pandemic on global emissions in 2020 and out to 2030

This chapter addresses the following key questions:

- What is the impact of the COVID-19 pandemic on global CO_2 emissions in 2020?
- What is the impact of the COVID-19 pandemic on global CO_2 emissions out to 2030?
- What are the main uncertainties in these global trends, particularly in terms of rebound effects?
- What are the general implications for policy?

2.1 Global CO_2 emission estimates for 2020

As the COVID-19 pandemic unfolded in recent months, its implications for daily global CO_2 emissions soon became apparent, with significant consequences expected for this year's annual total. The global CO_2 emission estimates for 2020 reviewed in this section[2] show significant reductions compared to 2019, including a full range from –4% to –11%. The median estimate shows a reduction of –8% in case of prolonged lockdowns worldwide until the end of 2020, and a reduction of –4% to –5% if lockdowns are shorter and Europe and North America recover faster in the second half of 2020. The above estimates are based on several sources published in April and May 2020, including reports by the IEA and Global Carbon Project. The estimated emission reduction for 2020 is in the order of magnitude of the yearly decrease rate required over the following decades to limit global temperature rise to 1.5ºC.

In April 2020, the **International Energy Agency IEA** was the first to publish an authoritative report to estimate the energy impact of a widespread global recession caused by months-long restrictions on mobility and social and economic activity. Their *Global Energy Review* (IEA, 2020a) presents emissions data for the first quarter of 2020 and emission projections for 2020 as a whole. According to this report, global total energy-related CO_2 emissions in 2020 are expected to fall to 30.6 $GtCO_2$ (an annual decline of 8%, or almost 2.6 $GtCO_2$), the lowest level since 2010 (see Figure 1). Such a year-on-year reduction would be the largest ever, six times larger than the previous record reduction of 0.4 $GtCO_2$ in 2009 – caused by the global financial crisis – and twice as large as the combined total of all previous reductions since the end of World War II. A reduced lockdown period and faster recovery in the second half of 2020 in Europe and North America, and shorter lockdowns in other regions, would reduce the negative impact on Asian manufacturing countries (IEA, 2020a). This would limit the 2020 decline in global CO_2 emissions to about 5%, based on IEA's estimates for this year's oil, coal and natural gas consumption (IEA, 2020a).

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[2] This section presents data and projections for the whole 2020 period. For a more detailed breakdown of daily CO2 emissions by the Global Carbon Project see the data presented here: https://mattwjones.co.uk/covid-19/ . For a regularly updated estimates on daily CO_2 emissions see the Carbon Monitor analysis here: https://carbonmonitor.org .
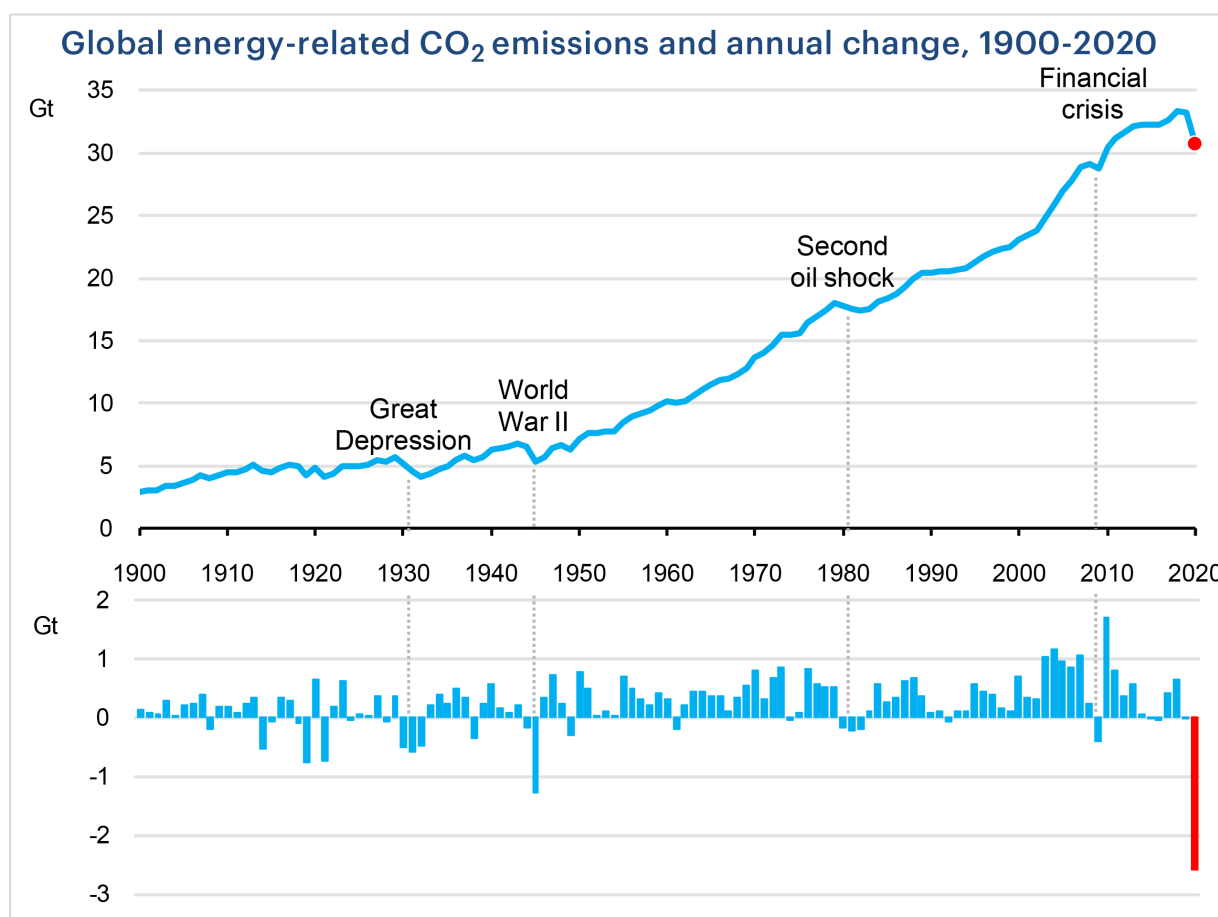
Figure 1: Global energy-related CO₂ emissions and annual changes, 1900-2020 (IEA, 2020a)

Also in April 2020, **Climate Action Tracker** (a collaboration between the New Climate Institute and Climate Analytics) published a report including emission estimates and policy recommendations in response to the pandemic (Climate Action Tracker, 2020). Their report estimates that the economic damage caused by the COVID-19 pandemic could result in a fall in global CO_2 emissions from fossil fuels and industry by at least 4–11% in 2020. In addition, they project that 2021 emissions may change by 1% above to 9% below 2019 levels (Climate Action Tracker, 2020).

In May 2020, **Le Quéré et al.** (2020) published their estimates from the **Global Carbon Project** in the leading journal *Nature Climate Change*, showing reductions in daily global fossil CO_2 emissions[3] of 17% (11% to 25% for ±1σ) by early April 2020 compared with mean 2019 levels. Reduced surface transport accounted for almost half of these reductions. At the peak of confinement, daily fossil CO_2 emissions in individual countries declined by 26% on average. Le Quéré et al.'s estimates of the pandemic's impact on 2020 annual emissions are in the same line as the numbers discussed above (Climate Action Tracker, 2020; IEA, 2020a), with a low estimate of –4% (–2% to –7%) if pre-pandemic conditions return by mid-June, and a high estimate of –7.5% (–3% to –13%) if some restrictions remain worldwide until the end of 2020.

[3] Fossil CO_2 emissions include sources from fossil fuel use (combustion, flaring), industrial processes (cement, steel, chemicals and urea) and fossil product use.

Finally, in the same month, **Enerdata** (a leading energy intelligence and consulting company) published their updated *Global Energy Trends* report (Enerdata, 2020), in which they estimate CO_2 emissions in 2020 to decline by –8.5 %, as a direct result of reduced socio-economic activity (mostly transport and industry) and larger share of renewables in the energy mix. However, according to their projections, the strong increase of renewables in the energy mix is temporary; a rebound effect of fossil emissions in 2021 is likely, depending on economic recovery.

Methodology of data sources

The four sources discussed above base their projections on various trends in energy use and GDP growth. Firstly, IEA's projections (IEA 2020a) are mainly based on the plummeting use of carbon-intensive fuels (coal, oil and natural gas) in the first half of 2020, which they extrapolated to an expected reduced demand for these fuels during the rest of this year. The IEA also assumed that global GDP would decline by about 6% in 2020, broadly in line with the *Longer and New Outbreak* Scenario of the International Monetary Fund (IMF, 2020c). Secondly, Climate Action Tracker's (2020) projections for the total energy and industry CO_2 emissions take into account the short-term (2020-2021) economic projections of the IMF (2020c) and other organisations, applying the full range of changes in carbon intensity of energy and industry as a function of GDP assumed in IEA's *World Energy Outlook* (IEA, 2019) for 2020 and 2021 (IMF, 2020c). Thirdly, Le Quéré et al. (2020) estimated the changes in fossil fuel CO_2 emissions for three levels of confinement and for six sectors of the economy, as the product of the fossil fuel CO_2 emissions by sector before confinement and the fractional decrease in those emissions due to the severity of the confinement and its impact on each sector. Their detailed analysis was performed for 69 countries, 50 US states and 30 Chinese provinces, which together represent 85% of the world population and 97% of global fossil fuel CO_2 emissions. Finally, Enerdata based their forecasts on energy consumption and emission projections at country and regional level, made by various international bodies including the European Commission, Organisation for Economic Co-operation and Development (OECD), IMF and the Asian Development Bank.

Based on the literature discussed here, **we estimate the median reduction in 2020 annual global emissions at 4% to 5% if the lockdown period is limited, and at about 8% if some restrictions remain worldwide until the end of 2020**. The collective understanding is that projections for 2020 (and 2021) heavily depend on a multitude of factors: the duration and extent of the lockdowns; the time it will take to resume normal activities; the degree to which life will resume its pre-confinement course; and the effects of the economic downturn on the carbon intensity of economic activity, as the effects of the lockdowns on economic activity, GDP growth and CO_2 emissions are inherently linked (Le Quéré *et al.*, 2020).

This estimated reduction for 2020 is in the order of magnitude of the yearly decrease rate required over the following decades to limit global temperature rise to 1.5°C. Given that renewable energy systems seem to be most resilient to COVID-19 lockdown measures, as demand for renewable electricity has been largely unaffected by the overall fall in energy use (IEA, 2020a), this crisis can provide opportunities to set structural changes in motion by implementing economic stimuli aligned with low carbon pathways, at least in the short term (Le Quéré *et al.*, 2020). In the long term, additional renewable capacity additions may be hampered due to lower investments in renewables (see Section 2.3).

However, the decline in emissions projected for 2020 is likely to be only temporary. Historical data show that a decrease in emissions caused by a crisis is often followed by an increase in emissions during and after economic recovery. For example, the global CO_2 emissions decline of 1.4% in 2009 as a result of the 2008–2009 Global Financial Crisis was immediately followed by a 5.1 % growth in emissions in 2010, the highest year-on-year increase on record (Le Quéré *et al.*, 2020). Additionally, the present economic crisis associated with COVID-19 is markedly different from previous economic crises in that it is more deeply anchored in constrained individual behaviour, rather than in systemic issues. Approximately 60% of the emission reductions estimated for 2020 can be attributed to the decline in surface transport and energy demand, which are directly related to population lockdowns (sharp decrease in public and private transport) and associated decrease in power demand from industry and public spaces (Enerdata, 2020). For the power sector specifically, the drop in CO_2 emissions is accentuated by the increased share of renewables in the energy mix due to the plummeted demand for fossil fuels. This trend in the energy mix is likely to be reversed once the lockdown measures are ended and the transport and industry sectors return to pre-pandemic activity levels (Enerdata, 2020).

2.2 Emission projections up to 2030

This section assesses the effect of the COVID-19 pandemic on emission projections out to 2030, by adjusting pre-COVID model projections using the 2020 emission estimates of the IEA and Global Carbon Project and IMF's GDP projections published in April 2020. We conducted these *ex-post* calculations for the current policies scenario, in which we compared two GDP scenarios related to the length of the lockdowns (*Baseline* versus *Longer and New Outbreak* (IMF, 2020c)) and two decarbonisation rates (model rates versus reduced rates due to a rebound to fossil fuels). We compare these outcomes to projections for the NDC scenarios and the least-costs mitigation scenarios to meet the Paris Agreement goals.

2.2.1 Current policies scenario

Based on IMF's (April 2020) GDP projections for 2020-2024 and model decarbonisation rates, our ex-post calculations indicate that the impact of the general slowdown of the economy would lead to an annual global emission reduction of –2.5 to –4.5 GtCO$_2$e (–4% to –7%) in 2030, compared to pre-COVID current policy projections. These numbers apply to IMF's *Baseline* and *Longer and New Outbreak* scenario, respectively. However, in case of a rebound to fossil fuels, with lower decarbonisation rates, the emission reduction in 2030 is projected to be smaller (–3.0 instead of –4.5 GtCO$_2$e in the *Longer and New Outbreak* scenario) or may even turn into an increase (+0.5 instead of –2.5 GtCO$_2$e in the *Baseline* scenario).

The *current policies scenario* projects GHG emissions assuming that all currently adopted and implemented policies (defined as legislative decisions, executive orders, or equivalent) are realised and that no additional measures are undertaken. To assess the impact of the pandemic on these projections, we first calculated the **median pre-COVID estimate,** using the most recent (pre-COVID) current policy projections from eight international modelling groups whose input is also used in UNEP's 2019 *Emissions Gap Report* (Rogelj *et al.*, 2019). Specifically, we used the numbers published in Roelfsema et al. (2020), who reported results from (i) International Institute for Applied Systems Analysis (MESSAGE–GLOBIOM model), (ii) Japan's National Institute for Environmental Studies (AIM model), (iii) PBL Netherlands Environmental Assessment Agency (IMAGE model), (iv) Potsdam Institute for Climate Impact Research (REMIND–MAgPIE model) and (v) RFF–CMCC European Institute on Economics and the Environment (WITCH model). In addition, we included (vi) Joint Research Centre (POLES model) (Keramidas *et al.*, 2020), (vii) the current policies projection of the IEA's 2019 WEO (IEA, 2019) and (viii) the Climate Action Tracker (2019). **Based on the projections of these eight modelling groups, our median estimate of global GHG emissions in 2030 for the pre-COVID-19 current policies is 60 GtCO$_2$e (range of 56–65 GtCO$_2$e).**

Next, we applied an ex-post method, inspired by Climate Action Tracker (2020), to adjust the pre-COVID current policies model projections for 2030 to a 'post-COVID' estimate, based on the assumptions outlined below. In short, we calculated the total global energy and industry-related CO_2 emissions for the period 2020–2024 using Kaya's equation (Kaya, 1990), in which we applied IMF's (2020c) short-term (2020–2024) GDP projections for two scenarios (IMF *Baseline* versus IMF *Longer and New Outbreak*) [4] and two decarbonisation rates (CO_2/GDP) (model rates and lower rates for Fossil Rebound, see point 2 below). For the period 2025-2030, we used our ex-post calculations for 2024 as a starting point to apply the pre-COVID estimate for the emissions growth projected by the models mentioned above. The resulting CO_2 emissions projections are based on the following assumptions:

1. **For 2020**, the global fossil CO_2 emissions[5] were calculated as the CO_2 emissions in 2019 (Le Quéré *et al.*, 2020) multiplied by the change in GDP in 2020 (IMF, 2020c), multiplied by the change in decarbonisation rate – i.e. the change in CO_2 emissions per unit of GDP (CO_2/GDP). To estimate the latter, we conceptually mapped IMF's (2020c) projected GDP growth rates for 2020 (–3% in the *Baseline* scenario and –5.8% in the *Longer and New Outbreak* scenario) to the CO_2 emissions decline of 4.2% and 7.5% projected for 2020 by Le Quéré et al. (2020). This assumption resulted in decarbonisation rates of 1.2% and 1.8%, respectively, for the two IMF scenarios.[6] Note that these rates are significantly lower than the past decade's average rate of 2.7% (Le Quéré *et al.*, 2020) and the median 2.4% projected by the model studies.

2. **For 2021-2024**, global fossil CO_2 emissions were estimated by taking into account IMF's (2020c) short-term (2021-2024) GDP projections for their *Baseline* and *Longer and New Outbreak* scenarios, and applying different decarbonisation rates, assuming two scenarios:
   a. The *Model decarbonisation* scenario, which assumes for 2021-2024 an annual CO_2/GDP decrease of 2.4%, i.e. the median estimate of the decarbonisation rate based on the eight model studies cited above;
   b. The *Rebound to fossil fuels* scenario, which assumes for 2021-2024 an annual CO_2/GDP decrease of 1.2% (IMF *Baseline*) or 1.8% (IMF *Longer and New Outbreak*). In other words, we assumed that the lower decarbonisation rates estimated for 2020 (see point 1 above) would also apply to the period 2021-2024, as a result of a fossil rebound and possible delay in policy implementation.

   For each IMF GDP scenario and decarbonisation scenario, the fossil CO_2 emissions in 2024 were estimated as: CO_2 emissions (2020) X Change in GDP (2020-2024) X Change in CO_2/GDP (2020-2024).

3. **For 2025-2030**, we assumed the CO_2 emissions trends projected by the model studies, using the estimated CO_2 emissions in 2024 (see point 2 above) as a starting point.

4. For **2020-2030**, the non-CO_2 GHG emissions and CO_2 land-use related emissions were assumed to follow the same trend as the original model projections, since there is no data available for the impact of the COVID-19 pandemic on these emissions.

Based on the methods and assumptions outlined above, our post-COVID emission projections for the current policies scenario out to 2030 are as follows. When accounting only for the pandemic's expected

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[4] The IMF Baseline scenario assumes that the pandemic fades in the second half of 2020 and containment efforts can be gradually unwound; the IMF Longer and New Outbreak scenario assumes that the outbreak takes longer to contain in 2020 and that a second outbreak occurs in 2021 (IMF, 2020c). See also Appendix A.1.

[5] Fossil CO_2 emissions include sources from fossil fuel use (combustion, flaring), industrial processes (cement, steel, chemicals and urea) and fossil product use.

[6] We recognise that the IMF's updated GDP projections published in June 2020 would change our estimated decarbonisation rates. The pandemic-induced changes in CO_2 emissions cannot be fully linked to changes in GDP growth, but their link is assumed in our ex-post method.

effects on GDP growth, we estimate that **global GHG emissions in 2030 for the current policies scenario will be reduced by about 2.5 to 4.5 GtCO₂e (–4% to –7%) compared to the pre-COVID current policies projection** (Figure 2). These numbers apply to IMF's *Baseline* and *Longer and New Outbreak* scenarios, respectively. More specifically, compared to the pre-COVID projection of 60 GtCO₂e (range 56–65 GtCO₂e), our post-COVID estimate for the current policies projection in 2030 is 57 GtCO₂e (range of 53–62 GtCO₂e) for the *Baseline* scenario, and 55 GtCO₂e (range of 51–60 GtCO₂e) for the *Longer and New Outbreak* scenario (see Table 1). The impact on the energy CO₂ emissions is illustrated in Figure 3. When accounting not only for the pandemic's expected effects on GDP growth but also assuming lower decarbonisation rates **in case of a rebound to fossil fuels**, **the emission reduction in 2030 is projected to be smaller (–3.0 instead of –4.5 GtCO₂e in the *Longer and New Outbreak* scenario) or may even turn into an increase (+0.5 instead of –2.5 GtCO₂e in the *Baseline* scenario).** In the latter scenario, global GHG emissions would return to 2019 levels by 2025, and in the former scenario by 2030 (Figure 2).

It is important to note that the post-COVID projections presented above for the current policies scenario do not account for the recovery measures currently taken to address the economic fallout from the pandemic. In addition, the results are only indicative (based on simple calculations compared to the model-based pre-COVID projections), and strongly driven by IMF's GDP estimates published in April 2020, which are likely to change in the coming months.
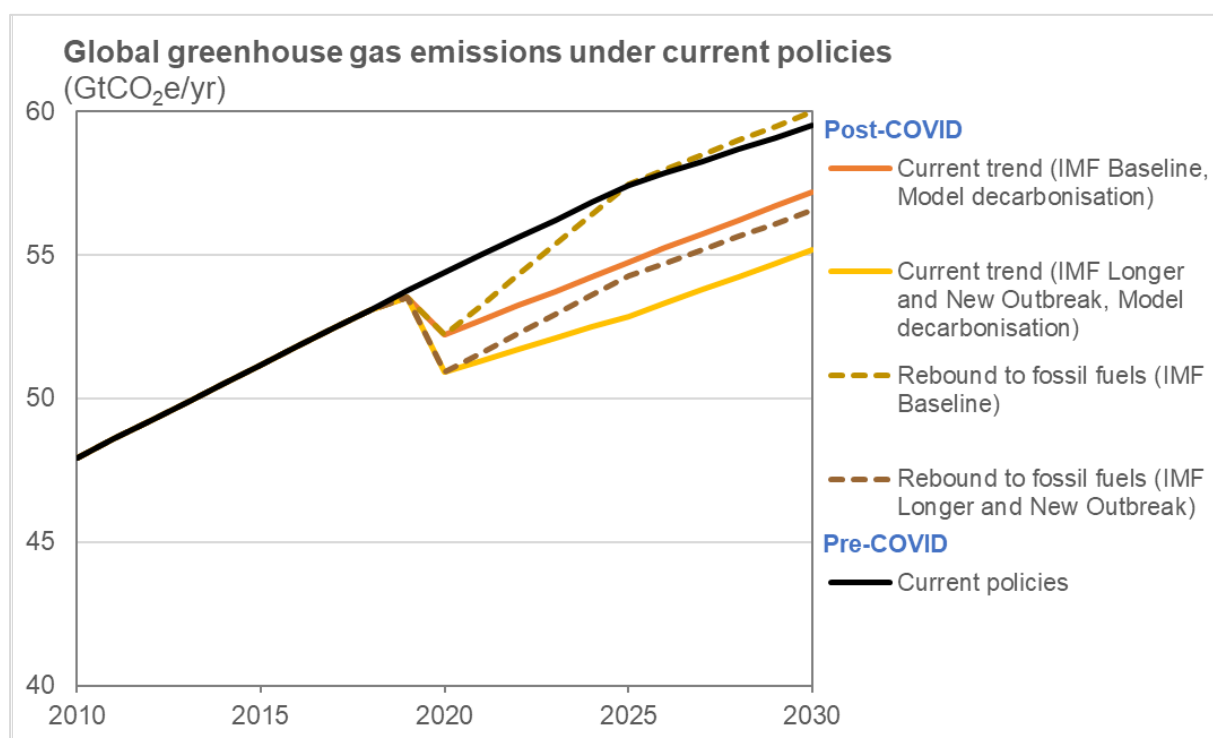
Figure 2: Global total greenhouse gas emissions (median estimates) in the current policies scenario for 2010-2030, for various scenarios related to the COVID-19 pandemic. Source: this study.
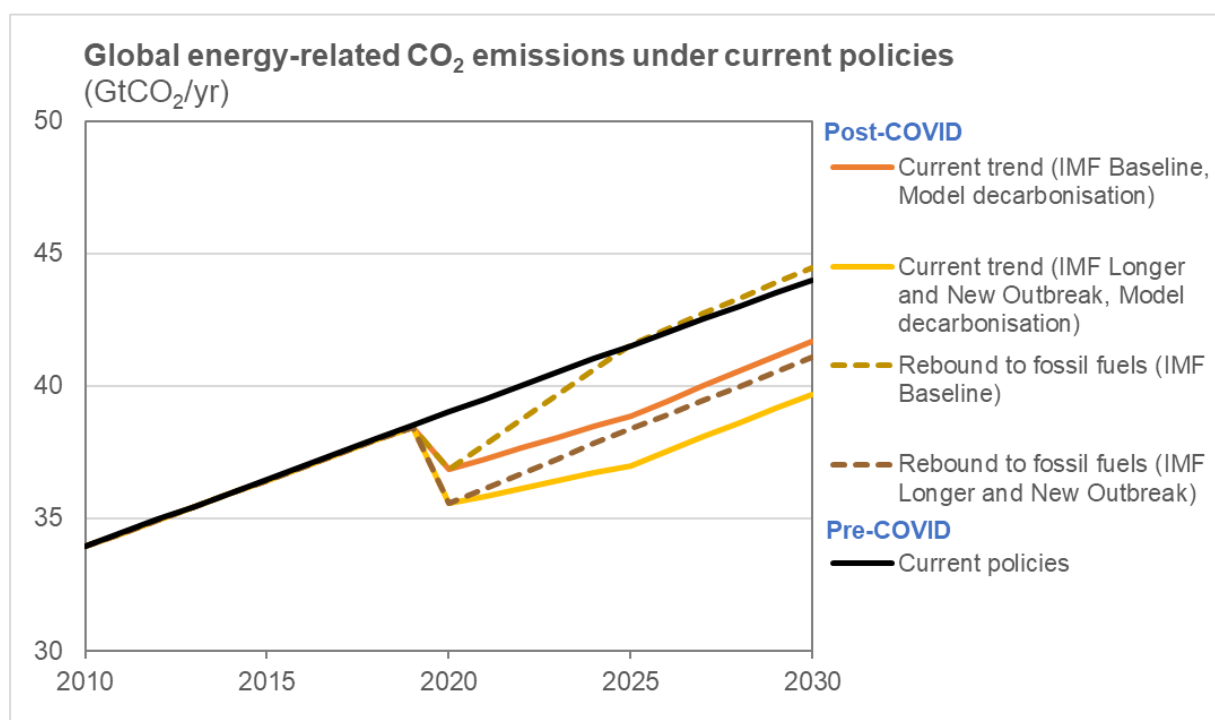
Figure 3: Global fossil CO_2 emissions (median estimates) in the current policies scenario for 2010-2030, for various scenarios related to the COVID-19 pandemic. Source: this study.

Table 1: Global total GHG emission estimates for the current policies scenarios in 2030 (median and 10th to 90th percentile range from the model studies). Post-COVID estimates are based on pre-COVID model projections

Current policies scenario	Global emissions in 2030* [GtCO₂e]
Pre-COVID-19	
Original model studies	60 (56–65)
Post-COVID-19 (ex-post calculations):	
Current trend (IMF Baseline, Model decarbonisation)	57 (53–62)
Current trend (IMF Longer and New Outbreak, Model decarbonisation)	55 (51–60)
Rebound to fossil fuels (IMF Baseline)	60 (55–61)
Rebound to fossil fuels (IMF Longer and New and Outbreak)	57 (52–58)

* rounded to the nearest Gt.

2.2.2 NDC scenarios and updates

The effect of the COVID-19 pandemic on projected emissions under the NDC scenarios is limited so far, because NDC targets have not changed at this point (most are set for 2030). For countries whose reduction targets are defined per unit of GDP, the pandemic will likely affect NDC emission projections through its effects on GDP growth, but information at this level is not yet available. Therefore, we assumed that the NDC emission projections of UNEP (2019) still apply. Their pre-COVID NDC projections (54-56 $GtCO_2e$ in 2030) partly overlap with our post-COVID estimates for the current policies scenarios (55-60 $GtCO_2e$).

The NDC scenarios estimate the level of global total greenhouse gas emissions resulting from the full implementation of the mitigation actions pledged by countries in their Nationally Determined Contributions (NDCs) (e.g., den Elzen *et al.*, 2016; Rogelj *et al.*, 2016; Roelfsema *et al.*, 2020). So far, the emission projections for the NDC scenarios are not affected by the COVID-19 pandemic, as the NDC reduction targets are mainly defined for the year 2030 (except for the US (2025) and some other, smaller, countries) and these targets have not changed at this point[7]. However, for countries whose reduction targets are defined per unit of GDP, including China and India, emission projections under the full implementation of the NDCs will depend on these countries' GDP growth projections, which are likely to be significantly affected by the COVID-19 pandemic. To date, there are no studies available that have explored this effect. Furthermore, the effect of NDC updates for the 2020 Glasgow UN Climate Conference is limited so far, because due to the pandemic this conference has been postponed to 2021 and only few (small) countries have updated their targets at this point (recent updated information will be presented at: www.pbl.nl/indc and www.climateactiontracker.org).

Therefore, this study assumes no change in the NDC emissions projections made before the pandemic, and adopts the numbers published by UNEP (2019) (see Table 2). According to their projections, full implementation of the unconditional and conditional NDCs would lead to global GHG emissions in 2030 of 56 and 54 $GtCO_2e$ respectively. This range partly overlaps with our post-COVID median estimates for the current policies scenarios (range from 55 to 60 $GtCO_2e$ in 2030, with the lower estimate representing the *Longer and New Outbreak* scenario without fossil rebound, and the upper estimate representing the *Baseline* scenario with fossil rebound; details see Table 1).

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[7] https://www4.unfccc.int/sites/NDCStaging/Pages/LatestSubmissions.aspx (accessed July 7, 2020).

Table 2: Global total GHG emissions in 2030 under different scenarios of UNEP (2019) (median and 10th to 90th percentile range). All projections taken from UNEP (2019), except for the post-COVID estimate (our calculations).

Scenario	Number of models in set	Global emissions in 2030* [GtCO2e]
Current policies (pre-COVID-19)	8	60 (56–65)
Current policies (post-COVID-19 estimates, based ex-post calculations, see Table 1)		55–60 (51–62)
Unconditional NDCs (pre-COVID-19)	11	56 (54–60)
Conditional NDCs (pre-COVID-19)	12	54 (51–56)
Below 2.0°C (66% chance)	29	41 (39–46)
Below 1.8°C (66% chance)	43	35 (31–41)
Below 1.5°C in 2100 and peak below 1.7°C (both with 66% chance)	13	25 (22–31)

* rounded to the nearest Gt.

2.2.3 Least-cost mitigation scenarios consistent with the Paris Agreement's temperature limits

At this point, the COVID-19 pandemic is expected to have little effect on estimates of the 2030 GHG emission levels consistent with a least-cost pathway in line with the Paris Agreement goals (limiting global average temperature rise to well below 2 °C and pursuing to limiting it to 1.5 °C). The pathways towards 2030 may change slightly, but it is too soon to draw conclusions as the currently observed drop in emissions is not due to structural changes.

The least-cost pathways in line with the Paris Agreement goals indicate the emission levels needed to limit global average temperature increase to well below 2 °C and pursuing to limit it to 1.5 °C. So far, there are no 1.5°C / 2°C scenario studies available that account for the impact of the COVID-19 pandemic. Based on the literature discussed in Chapter 2.1, the impact of the pandemic on 2020 CO_2 emissions is an estimated reduction of between 1.5 and 3 $GtCO_2$ below 2019 levels, while, on average, reductions of 1 $GtCO_2$ and 1.6 $GtCO_2$ would be needed *every year* until 2030 to limit global warming to 2 °C and 1.5 °C, respectively (Figure 4). Based on these numbers, the pandemic is expected to have little effect on the long-term estimate of emission levels required in 2030 to limit temperature rise to 1.5°C / 2°C. Thus, the emissions gap in 2030, defined as the difference between projected global GHG emissions in 2030 under the NDC scenarios and emissions under least-costs pathways limiting warming to below 2 °C and 1.5 °C, is expected to remain the same.

In terms of cumulative CO_2 emissions, the estimated impact of the COVID-19 pandemic over the period 2020–2030 is a decrease of about 25 to 45 $GtCO_2$ under the current policies scenario (about 6 to 10% lower) compared to the pre-COVID estimates (Table 3). Thus, the pandemic is expected to slightly reduce the implementation gap, i.e. the difference between estimated total global emissions in 2030 under the NDC scenarios versus emissions under current policies.

Table 3: Cumulative CO_2 emissions over 2020-2030, current policies scenario (median and 10th to 90th percentile range). Pre-COVID estimate from UNEP (2019) and post-COVID estimates based on our calculations.

Current policies scenario	Cumulative CO₂ emissions over 2020-2030* [GtCO₂]
Pre-COVID-19	
Original model studies	495 (460–580)
Post-COVID-19 (ex-post calculations):	
Current trend (IMF Baseline, Model decarbonisation)	465 (425–550)
Current trend (IMF Longer and New Outbreak, Model decarbonisation)	450 (410–530)

* rounded to the nearest Gt.

Note: numbers include CO_2 emissions from energy, industry and land use, but exclude non-CO_2 greenhouse gases
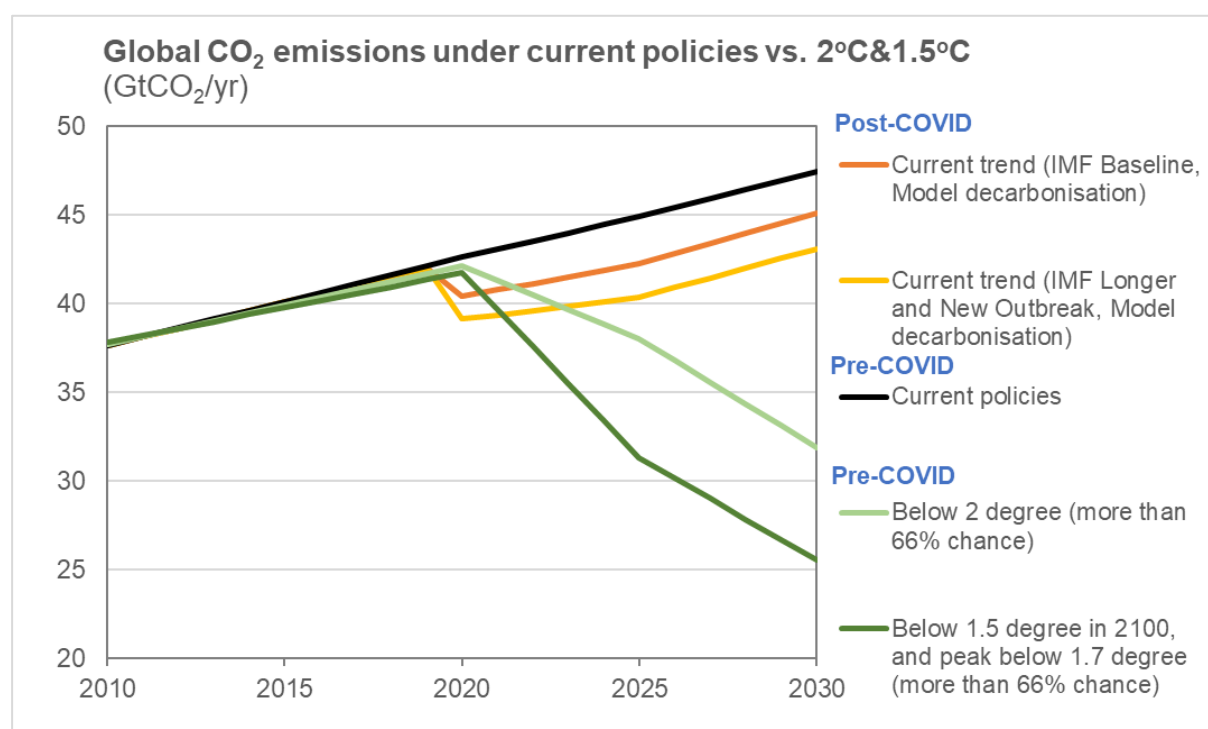

Figure 4: Global CO_2 emissions projections for the current policies scenarios (median estimates) for the period 2010-2030 for various scenarios related to the COVID-19 pandemic (source: this study), compared against the 1.5 °C and 2 °C scenarios from UNEP (2019).

2.3 Assessment of uncertainties and sectoral rebound effects

The COVID-19 pandemic has only increased the uncertainties with regard to emission projections, especially for the short-term (2020-2024). The full impact of the pandemic on emissions is yet unknown, and will depend on many factors, including the time needed to develop a vaccine, lifestyle and mobility changes, and the size and design of macroeconomic policy responses. These factors will determine whether rebound effects at the sector level will be positive or negative in terms of their climate impact.

As mentioned in Chapter 2.2, our projections up to 2030 are ex-post, showing a slight decrease (4–7%) in overall emissions for that time horizon, based on the projected economic effects of the COVID-19 pandemic over 2020-2024. However, the full impact of the pandemic is yet unknown, as there are numerous other factors (other than GDP growth) that will determine the ultimate effect on emissions. One of the key issues is the duration of the pandemic and the time needed to develop a vaccine. Recovery paths around the world will be shaped by the duration of national and local lockdown and relaxation measures, public health developments such as a possible second wave of the pandemic, and even changes in lifestyle (e.g. more people working from home versus a shift from public to private transport modes). Moreover, these pathways will be influenced to a great extent by the size and design of macroeconomic policy responses (IEA, 2020b).

Investments in renewable energy are also uncertain. Although they have generally shown to be more resilient to the current economic downturn than fossil energy, investments in renewable power projects are still expected to fall by 10% in 2020 compared to 2019 (IEA, 2020c). While this decrease is smaller than the decline observed for fossil fuel investments, which witnessed the largest annual fall in history (around 20%, a decline of about $400 billion, see IEA, 2020c), the flat trend in investments in clean energy and efficiency since 2015 is far from enough to put the world on a more sustainable pathway and bring a lasting reduction in emissions (IEA, 2020c).

Projections with respect to recovery at the sectoral level should be treated with caution as well, especially for the short-term. The current crisis has resulted in a very different type of economic shock than has been experienced in the past. The purposeful restriction of economic activity—and restrictions on the movement of people—will likely affect emissions across sectors of the economy in very different ways than in past financial crises. For example, while the 2008 financial crisis had significant financial repercussions and led to a wave of home foreclosures, it did not restrict transport or commercial energy use in the way that is occurring today (Hausfather, 2020). In the current crisis, emissions have been reduced in almost every sector except the residential sector; as mentioned in Chapter 2.1, the transport and power sectors alone are responsible for about 60% of the reduction in 2020 emissions as they are affected most by the recession and containment measures (Enerdata, 2020). Rebound effects in these and other sectors can have both negative and positive effects on emissions (see Table 4), depending on economic recovery policies and changes in working conditions, societal norms and lifestyles. Thus, the COVID-19 pandemic has only increased the uncertainties with regard to emission projections, especially for the short-term (2020-2024).

Table 4: Possible rebound effects by sector, with either positive or negative effects on CO_2 emissions. Source: Enerdata (2020) and this study.

Sector		Rebound effect	
		Positive	**Negative**
Surface Transport		Reduced commuting as more people work from home Increased "soft mobility" (non-motorised transport such as bicycling)	Increased private car use and decreased public transport use, due to fear of contagion Lower incentive to purchase electrical vehicles, due to low oil prices and lower incomes
Industry		State support conditional on sustainability measures Self-sufficiency / local production as new central paradigm	Increased production – catch up with demand Climate targets set aside due to low fossil prices
Power		Lower investments in fossil fuels vs. renewables this year (IEA, 2020c) State support conditional on sustainability measures	Reduced growth of renewable power capacity this year (2020) due to lower renewable investments (IEA, 2020c) Coal bounce back (especially in Asia) due to low coal prices
International bunkers	*Aviation*	Decrease in flying, people using only necessary flights Airlines complying to stricter emissions standards	Increase in flying, as a reaction to months of confinement Unconditional state support Weakened international effort to implement pre-COVID climate protection measures
	Shipping	Decreased global trade	
Public services		Reduced demand for heating, electricity, public sector services, and offices as people work more from home	
Residential			Increased energy use, especially during winter periods, as people work more from home Less financial support for retrofits (e.g. insulation) Lower incentive for retrofitting due to low oil and gas prices

2.4 Conclusion: General implications for policy

The message is clear: while the CO_2 emissions reduction in 2020 is probably unprecedented, a consistent, similar rate of decrease would need to be maintained for decades in order to achieve the 1.5 °C warming limit. The decline in emissions in 2020 due to the COVID-19 pandemic may only be temporary, if no structural changes are made. Greener investments are needed now to avoid a lock-in to carbon intensive energy sources and potential future stranding of high-carbon assets. Moreover, low-carbon development strategies and policies needs to play a key role in the economic stimulus packages that are currently being rolled out in response to the COVID-19 pandemic. Otherwise, emissions could bounce back and even overshoot previously projected levels by 2030, despite lower economic growth (Climate Action Tracker, 2020).

3 Assessment of green vs. 'non-green' recovery

3.1 What is considered as 'green recovery'?

Around the world, countries are launching economic recovery packages to cushion the effects of the COVID-19 pandemic. This offers an excellent opportunity to promote sustainable development. Recent literature, published since the start of the pandemic, shares a fairly homogenous definition of 'green recovery' and 'green' versus 'grey'[8] stimulus measures. However, some minor differences remain about the 'greenness' of specific measures and how to deal with 'colourless' measures that maintain the status quo. We propose to slightly expand Vivid Economics' (2020) classification, adding economy-wide measures and a 'colourless' category.

'Green stimulus' generally includes all policy interventions "to stimulate short-run economic activity while at the same time preserving, protecting and enhancing environmental and natural resource quality both near-term and longer-term" (Strand and Toman, 2010). Recent literature published since the start of the pandemic (overview see Table 5) further develops this concept to transparently define green stimulus at the sector level and for different types of policy intervention. To the best of our knowledge, the *Green Stimulus Index* by Vivid Economics (2020) currently proposes the most comprehensive list of green and "brown" [grey] policy archetypes for the agriculture, energy, industry, transport and waste sectors(Vivid Economics, 2020)(Vivid Economics, 2020). Climate Action Tracker (2020) uses a similar approach and transparently defines green recovery versus a 'rebound to fossil fuels', but this source is not fully comprehensive in categorising all existing types of policy interventions.

Some minor differences exist in the literature with regard to specific sub-sectors. For example, in their *Sustainable Recovery Plan*, the IEA (2020b) classifies policy interventions that facilitate a coal-to-gas switch as 'green transition measures', and also includes R&D and deployment of technologies that can reduce pollution and emissions from coal and gas electricity generation in this category. In contrast, both Vivid Economics (2020) and Climate Action Tracker (2020) do not consider any investments in the prolonged use of coal, oil, and gas as 'green'.

An additional issue is that many of the recently announced recovery measures cannot directly be classified as green or grey. Hepburn et al. (2020), who analysed 300 rescue measures taken by G20 countries as of April 2020, introduce the term 'colourless' to classify measures and interventions that maintain the status quo (finding it applied to ~92% of the measures analysed). Such a 'colourless' category might be particularly relevant for economy-wide measures (such as VAT reduction) and measures whose environmental impact has yet to be analysed. Vivid Economics (2020) separates non-environmentally relevant stimulus measures by sector (~67% of global fiscal stimulus as of June 2020) before classifying the remaining measures as either green or "brown" [grey]. An alternative, and stricter, approach could be to define all measures that are not clearly green or which have no "green strings attached" (Vivid Economics, 2020) as grey measures.

Informed by this literature review, we propose the following classification for recovery measures, building on the classification by Vivid Economics (2020):

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[8] In line with the EU Technical Expert Group on Sustainable Finance (2020, p. 51) and MacKenzie (2020), we propose to henceforth use the word 'grey' rather than 'brown' for polluting measures, to accommodate different cultural contexts and avoid racial connotations. When citing papers that use the word 'brown' as an indicator of 'polluting', we refer to this as "brown" [grey].

Green measures: all green policy archetypes for the agriculture, energy, industry, transport, and waste sectors defined by Vivid Economics (2020), plus our addition of economy-wide (cross-sector) measures that can be considered green (see Table 6 in Annex A.2);

Grey measures: all "brown" [grey] policy archetypes for the agriculture, energy, industry, transport, and waste sectors defined by Vivid Economics (2020), plus our addition of economy-wide (cross-sector) measures that can be considered grey (see Table 7 in Annex A.2)

Colourless measures: all measures that do not clearly fall into the green and grey categories summarised above, especially economy-wide measures (such as economy-wide VAT reduction) and measures that are considered neither green nor grey (e.g. investments in digitalisation or artificial intelligence)

Table 5: Defining 'green recovery' in response to COVID-19: overview of recent literature (April-June 2020)

Source	Criteria for green recovery	Other notes
Vivid Economics' Green Stimulus Tracker (2020)	• Binary classification into green and "brown" [grey] stimulus funding • Use of archetypes to classify recovery measures into green and "brown" [grey] (pp.12-15) • Each of these measures is further rated by level of severity and coverage (1-3 scale, pp. 15-16) • Flow of green versus "brown" [grey] stimulus is assessed using countries' baseline environmental policy performance	• Index assessment conducted for 18 countries • Regular updates to account for newly announced recovery measures • Assessment also includes non-climate issues (e.g. ban on wildlife trading)
CarbonBrief Tracker (2020)	• List of green recovery measures for selected countries (EU, Germany, South Korea, Denmark, China and India); no listing of grey or colourless measures	
IEA WEO Special Report on Sustainable Recovery (2020b)	• Detailed list of green recovery measures in the electricity, transport, buildings, industry, fuels, and innovation sectors (Chapter 2)	• Development of a *Sustainable Recovery Plan*
Hepburn et al. (2020) Will COVID-19 fiscal recovery packages accelerate or retard progress on climate change?	• Classification of rescue and recovery measures into green measures (potentially reducing long-run GHG emissions), "brown" [grey] measures (likely increasing net GHG emissions beyond the base case), and colourless measures (maintaining the status quo) • No further explanation or examples on methodology provided	• Subjective assessment of 300 implemented <u>rescue</u> policies implemented in G20 countries as of April 2020: 4% 'green', 4% 'brown', 92% 'colourless'
Stern et al. (2020) Better Recovery, Better World: Resetting climate action in the aftermath of the COVID-19 pandemic	• Green recovery is the central theme of this briefing (with some examples such as sustainable infrastructure provided), with direct link to forthcoming OECD's Green Budgeting Framework and general reference to World Bank's Green Stimulus Framework (Hallegatte and Hammer, 2020) • Defines the need to develop tools and metrics for investors to identify green versus "brown" [grey] investments and those 'transitioning through the 50 shades to green'	

Source	Criteria for green recovery	Other notes
Eyl-Mazzega et al. (2020) "Green" or "Brown" Recovery Strategies?	• Differentiation between three types of recovery plans (recovery measures and climate actions): 1 Recovery plans on track to promote more sustainable economic models and a green transition ('green light') 2 Elements of the recovery plans can foster a greener transition, but formal commitments are still missing / some elements are insufficient ('yellow light') 3 Recovery plans will eventually lead to an increase in GHG emissions ('red light')	• Qualitative assessment of recovery plans in selected G7 countries and countries in Asia, Africa, and Latin America (pp. 3-6)
IMF (2020a) Greening the Recovery	• Binary classification into green and "brown" [grey] activities, including a list of examples for green recovery measures • No further definition of green versus "brown" [grey] recovery measures	
Government of the Netherlands (2020) Outline for an EU Green Recovery	• Differentiation between expenditures that harm climate and environmental objectives − link to exclusion list of JTF in Art.5 (European Commission, 2020) − versus green recovery measures • List of several potential green recovery measures provided (p. 2)	
World Bank (2020) Proposed Sustainability Checklist for Assessing Economic Recovery Interventions	• Checklist includes six questions on *Decarbonisation and Sustainable Growth, and Long-term Risks* (p.3) to assess recovery measures	
CAT Petersberg Dialogue Briefing (2020)	• Binary classification of recovery measures (including examples) in six sectors, distinguishing between 'do good' (recommended measures) and 'do no harm' (measures to avoid) • Further conceptualisation of a generic 'green stimulus framework', building upon: 1 Activating economic stimulus and job creation within next 18 months 2 Enabling inclusive growth prospects and enhanced resilience beyond 18 months 3 Promoting decarbonisation and sustainable growth prospects	• No quantification nor tracking of any specific COVID-19 recovery measures
Energy Transition Commission (2020) Seven Priorities to help the global economy recover	• Identification of focus areas in the energy sector for green recovery measures (five), opportunity to accelerate phase-out of fossil fuel industry, and call to not roll-back carbon pricing and other regulation	

3.2 A framework for assessing economic stimulus packages

Assessing economic stimulus packages – both in terms of their impact on economic development and their impact on emissions – requires transparent tracking of already announced and incoming recovery plans. For this purpose, we propose to break down economic recovery packages into single components, each of which can then be classified as either green, grey, or colourless according to the definitions and coding methodology introduced in Chapter 3.1 and Annex A. This approach allows to obtain detailed information on the type, scope, and sectoral coverage of economic recovery packages, providing direct input for subsequent analyses on their impact on GDP growth and GHG emissions.

As a case study, we applied this approach to analyse one of the economic recovery packages recently announced by Germany. The German recovery package was chosen for this pilot analysis because of the detailed information available on the package's components and its general relevance for economic recovery for the European Union.

The case of Germany: tracking the fiscal stimulus package announced 3 June 2020

In response to the outbreak of the COVID-19 pandemic in the European Union, between April and June 2020 Germany announced the following four major fiscal rescue and recovery programmes (IMF, 2020b):

1 **Supplementary budget** of €156 billion (4.9% of GDP)
   - o Healthcare provisions
   - o Expanded access to subsidies for short-term work ("Kurzarbeit")
   - o Grant programme for small business owners and self-employed persons
   - o Temporarily expanded duration of unemployment insurance and parental leave benefits
2 **Public guarantees programme** through Germany's Economic Stabilization Fund (WSF) and the public development bank KfW, increasing the total volume by at least €757 billion (24% of GDP)
3 **Local government support programmes** of €141 billion in direct support and €63bn in state-level loan guarantees (5,6% in GDP)
4 **Fiscal stimulus package** of €130 billion (4,1% of GDP)

Our present assessment focuses on the fourth programme, i.e. the fiscal stimulus package (*Konjunktur- und Krisenbewältigungspaket*) of €130 billion, which was announced on 3 June 2020 (Government of Germany, 2020b). The three other fiscal rescue programmes were not considered in this analysis.

Figure 5 presents a preliminary analysis of how this fiscal stimulus package can be broken down into green, grey, and colourless measures using the methodology presented in Chapter 3.1 and Annex A.2. Annex A.3 Germany's fiscal stimulus package announced on 3rd of June 20203 lists all measures included in the package and their respective coding.

Share of economic recovery measures by 'colour type' per sector
(% of total recovery package of EUR 130 billion)

Total across all sectors

69%   31%

Economy-wide	Energy	Transport	International bunkers	Buildings	Forestry	Agriculture
68.2% / 0.0%	0% / 15.7%	0.1% / 12.1%	0% / 1.5%	0% / 1.6%	0% / 0.5%	0.2% / 0%

▨ Colourless   ▨ Green

Figure 5: Economic recovery measures in Germany's fiscal stimulus package of 3 June 2020, classified by 'colour type' and sector. Source: This study.

Our findings can be summarised as follows:

- The fiscal stimulus package contains a **high share of economy-wide measures, most of which can be considered colourless** (~68% of EUR 130 billion).
- Although the fiscal stimulus package **does not contain measures that are unambiguously grey**, some of the economy-wide measures currently classified as colourless require further analysis to better evaluate their environmental impact (e.g. the economy-wide VAT reduction for six months without preferential treatment of green products).
- The fiscal stimulus package **includes green recovery measures of approximately EUR 41 billion (31% of EUR 130 billion)**, mainly aimed at the energy and transport sectors. In addition, the package includes several measures that are considered green, but which have not been specifically budgeted (e.g. removal of the cap on national solar capacity). Furthermore, some measures currently coded as green may require re-evaluation once more detailed information becomes available, particularly in the aviation and shipping sectors.
- **Approximately 21% of the fiscal stimulus package is in line with measures identified in IEA's *Sustainable Recovery Plan*** as defined in Table 3.1 of its *World Energy Outlook Special Report* (IEA, 2020b) (see Figure 6 below).

Share of economic recovery measures by 'colour type' per IEA sector coding
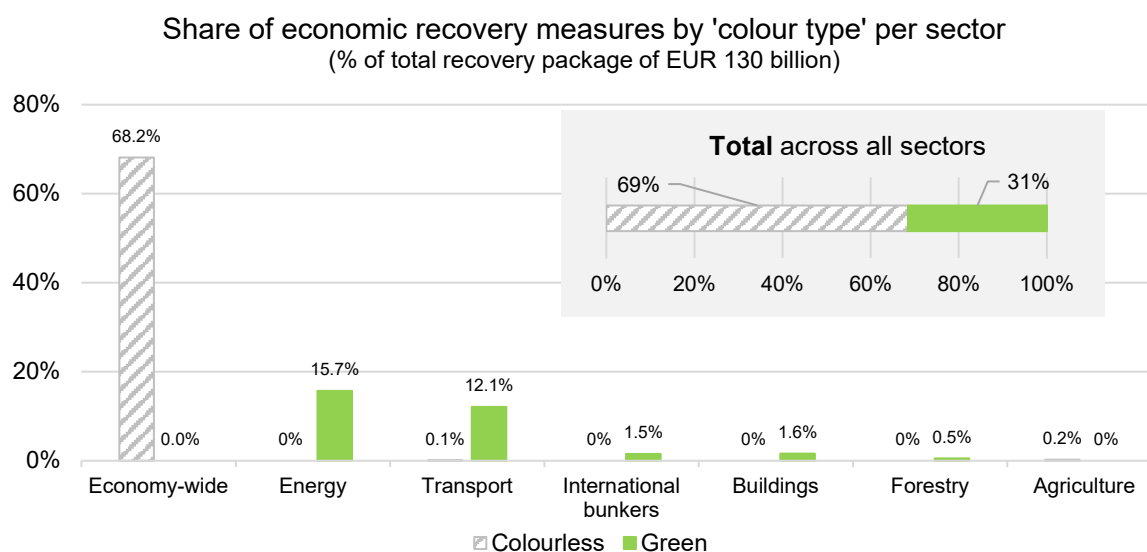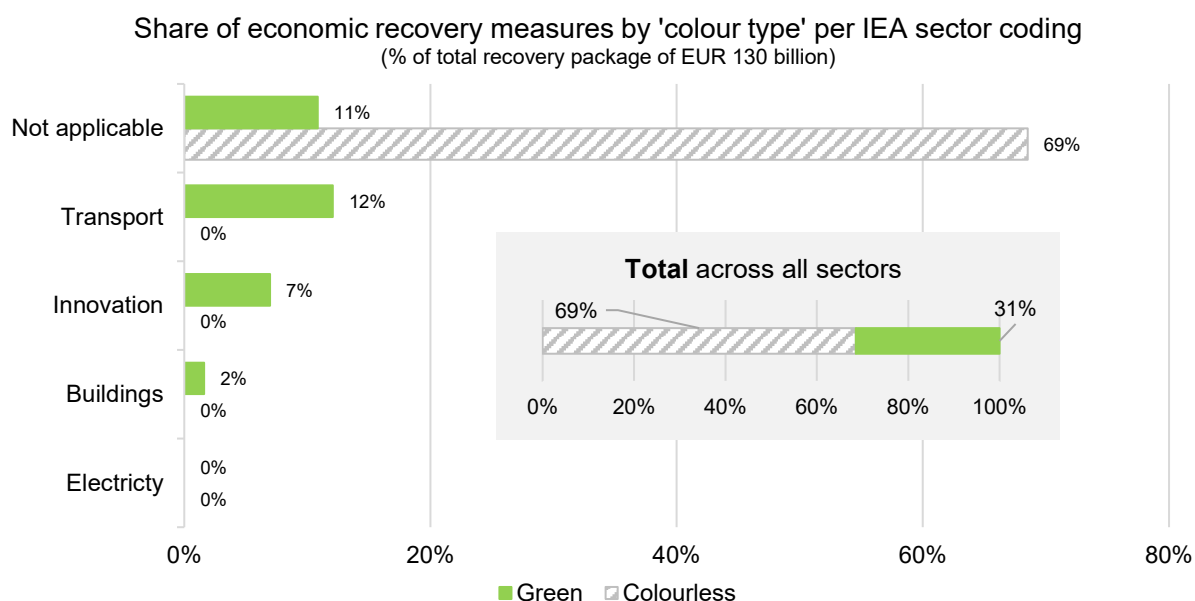### (% of total recovery package of EUR 130 billion)

Figure 6: Economic recovery measures in Germany's fiscal stimulus package of 3 June 2020, classified by 'colour type' and sector as defined in the Sustainable Recovery Plan of IEA (2020b). The "not applicable" category applies to measures not covered by IEA (2020)

Our preliminary analysis of Germany's fiscal stimulus package raises several points for consideration to track and analyse economic recovery efforts in the future.

1   **Inclusion and coding of additional rescue measures, such as airline bailouts, will further substantiate the analysis** and provide a more complete overview of the entire range of fiscal recovery and rescue measures. For example, in May 2020 the Germany government agreed on a rescue package for Lufthansa of around EUR 9 billion, without any environmental conditions attached (Government of Germany, 2020a; Sweney, 2020). This measure, not covered in the analysis above, would be classified as a grey measure according to our methodology (Chapter 3.1). This is in line with Vivid Economics (2020), who already track airline rescue measures in their Green Stimulus Index and categorise them as "brown" (i.e. grey).

2   **Further analysis is needed to assess the environmental impact of economy-wide measures initially classified as colourless**; for example, the impact of Germany's economy-wide VAT reduction without preferential treatment of green products.

3   **Recovery measures currently not budgeted should be analysed individually** to quantify their economic stimulus effect; for example, the removal of the cap on national solar capacity and the increased target for offshore wind production (from 15GW to 20GW by 2030), for which no public budgets have been communicated.

4   **To be comprehensive, the analysis should also account for regulatory roll-backs**, not only those already implemented but also the ones that are currently discussed in different countries; for example, the lobby efforts by industry representatives to postpone stricter CO_2 standards for cars in the EU, and the proposed lower CO_2 price for German industry.

3.3 Estimating the impact of recovery measures on GHG emission pathways

Transparent tracking of recovery measures, as piloted for one of Germany's recent rescue packages (Chapter 3.2), enables subsequent analysis of these measures' impact on GDP growth and GHG emission pathways. However, assessing the impact of country-specific rescue packages, which have a relatively short time horizon, requires considerable assumptions and data that are unavailable at this point. Using IEA's *Sustainable Recovery Plan* and our ex-post approach outlined in Chapter 2.2, we estimate that full implementation of IEA's green recovery measures would result in global GHG emissions of 49 to 52 GtCO$_2$e in 2024.

In an explorative analysis at the global level, Climate Action Tracker (2020) uses the scenarios underpinning the McCollum et al. (2018) study to estimate plausible 2030 emission levels from both optimistic and pessimistic COVID-19 recovery scenarios. They calculated and plotted the emissions intensity of GDP in 2030 against the annual green investment share of GDP sustained over the period 2020-2030, and found a linear negative correlation between these two parameters (see Figure 7).

Impact on emissions intensity of GDP from increased green investment
Sustained investment from 2020–2030 increases emissions efficiency of economies
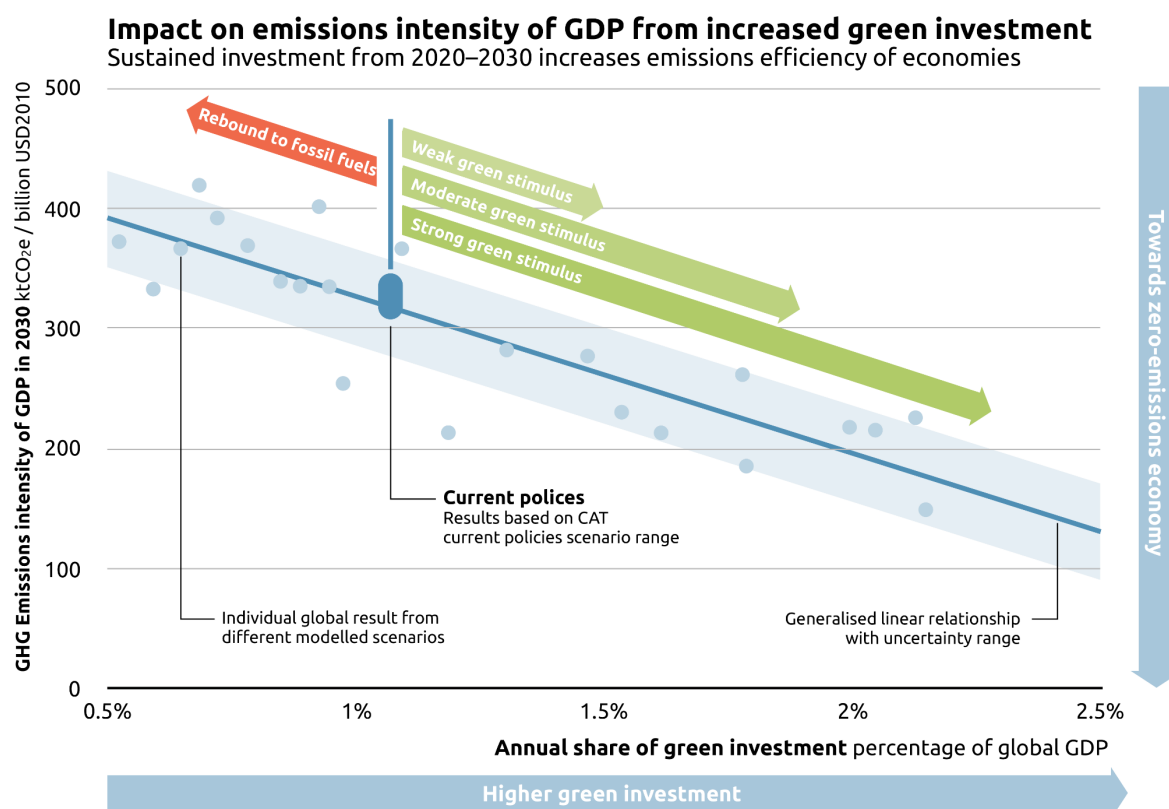
Figure 7: Relationship between green investment in period 2020-2030 and GHG emissions intensity of GDP in 2030. Source: Climate Action Tracker (2020), whose analysis is based on data from McCollum et al. (2018).

For assessing the emissions impact of country-specific recovery measures, Climate Action Tracker's (2020) approach has several limitations, which reflect the general challenges for assessing country-specific economic recovery packages in terms of their GHG emission impacts:

- The McCollum et al. (2018) scenarios used by Climate Action Tracker (2020) build on least-cost emissions pathways assessing the direct low-carbon investments needed in order to stay below a 2°C and 1.5°C global temperature rise. However, the economic recovery packages proposed by national governments comprise different types of policy instruments and subsidies for different sectors, which may not be directly comparable with direct (low-carbon) investments

taking place throughout the economy. For this reason, any country-specific analysis of the emissions impact of economy recovery packages would need to assess the effectiveness and magnitude of these policies to trigger direct low-carbon investments.

- Based on McCollum et al. (2018), Climate Action Tracker's (2020) explorative assessment assumes an *annual share of green investment (percentage of global GDP)* as sustained investment over the period 2020 to 2030. Applying this approach to assess national economic recovery packages would require assumptions on how these lead to sustained investment across the coming decade – which is way beyond the duration of most recovery plans (being around 18 months).

For assessing the emissions impact of recovery packages at the global level, an alternative to Climate Action Tracker's (2020) analysis could be to follow a similar approach as outlined in Chapter 2.1 of the present paper for the exploratory analysis of post-COVID-19 current policies scenarios. Using this approach, we estimated global emissions in 2024 assuming the decarbonisation rates that could be achieved under full implementation of IEA's (2020b) *Sustainable Recovery Plan* (see Figure 8)*.* To this end, we estimated the change in CO_2/GDP (decarbonisation rate) using the global GDP and CO_2 emission projections provided in IEA (2020b), arriving at 4-6% for the period 2021-2023.

In addition, we adopted IEA's (2020b) assumption of a 0.8 $GtCO_2e$ emission reduction due to investments tackling methane leakages from oil and gas operations by 2023. Applying these rates and GDP growth from IMF's *Baseline* scenario to the pre-COVID current policies model projection, **we estimate global GHG emissions under full implementation of IEA's *Sustainable Recovery Plan* at 49 to 52 $GtCO_2e$ in 2024 (Figure 8).** This finding is in line with IEA's (2020b) energy-sector GHG emissions trajectories and IEA's (2020b) own estimate of about 4.5 $GtCO_2e$ annual emission reduction by 2025 (see Figure 3.10 in IEA's *Sustainable Recovery Plan*), for which they assumed that the real global GDP would increase to 3.5% in 2023 relative to a baseline scenario in which there is no increase in renewable energy investments.
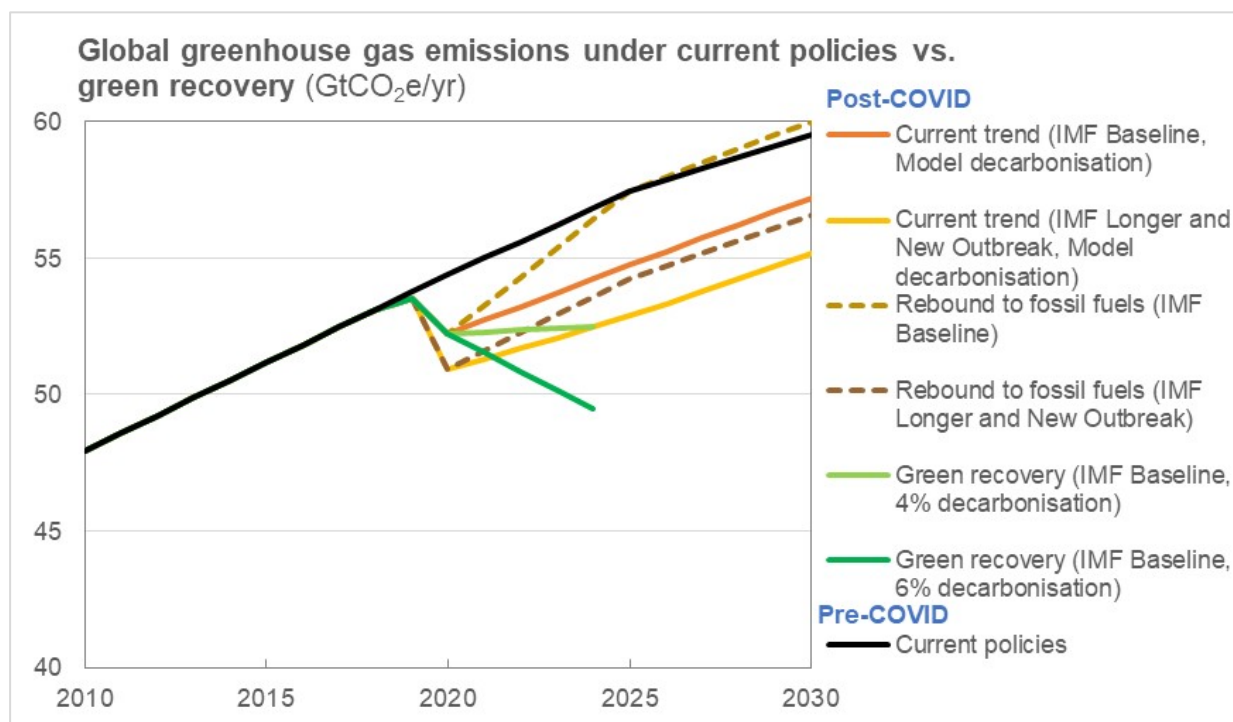

Figure 8: Global GHG emissions projections (median estimates) for the current policies scenarios and two recovery scenarios (4% and 6% decarbonisation based on full implementation of IEA's (2020b) *Sustainable Recovery Plan*) for the period 2010-2024/2030, including various scenarios related to the COVID-19 pandemic. Source: this study.

4 Capturing the impact of the pandemic and recovery measures through modelling

To assess the very-short-term (2020) to short-term (2021-2024) effects of the pandemic on GHG emissions, trend analyses and ex-post methods such as presented in Chapter 2.2 are more suitable and more practical than modelling with Integrated Assessment Models (IAMs). This is due to the complexity of these models which are designed for mid- and long-term projections and require detailed data. To account for the shock effect of the pandemic and capture the effects of economic rescue measures on long-term (2030-2050) emissions, IAMs could make use of projections from macroeconomic models such as E3ME and GEM-E3-FIT, provided that a series of inputs representing different long-term future scenarios are carefully constructed beforehand. This way, IAMs can provide valuable input on the feasibility of post-COVID transition pathways towards zero carbon emissions.

4.1 Modelling short-term effects: the challenges

As discussed in Chapter 2.1, the COVID-19 containment policies of national governments led to large reductions in global energy demand and CO_2 emissions in the first half of 2020. The impact of the pandemic on global energy demand and CO_2 emissions is highly uncertain for the remainder of 2020, and this is even more true for mid-term and long-term projections. In particular, the impact of economic recovery measures and behavioural changes in response to the pandemic – not to mention the future course of the pandemic as long as a vaccine is not available – is beset with large uncertainty.

To assess the very-short-term (2020) to short-term (2021-2024) impact of the pandemic on GHG emissions, the first approach is to use trend analyses based on emission trackers, sector-level activity data and short-term GDP projections (see e.g. Climate Action Tracker, 2020; IEA, 2020a; Le Quéré *et al.,* 2020). In addition, the ex-post method presented in this paper (Chapter 2.2) provides a transparent approach to estimate post-COVID emissions based on pre-COVID projections from integrated assessment models such as IMAGE and REMIND-MAgPIE. The latter are complex models that are less suitable, and less practical, for capturing the pandemic's short-term impacts, for the reasons outlined below.

Firstly, using integrated assessment models (IAMs) for estimating the pandemic's impact on emissions in the short-term would be a very complex exercise, as this would require in-depth analyses of the impact of national government policies on energy demand and activity changes. Such analyses would need to be based on individual country studies to a great level of detail, and the individual country results would then have to be aggregated in order to be used as input for IAMs, which operate on a regional level (e.g. EU-28 is considered as a single region in the IMAGE model).

Secondly, IAMs are generally used to explore the long-term effects of climate policies and structural changes. They are less suitable to explore short-term (1-5 year) dynamics such as sub-sectoral interactions and feedbacks of various processes and technologies and implementation dynamics. The price effect of oil and coal is an example of such short-term feedbacks: the sharp reduction in demand for these fuels due to COVID-19 containment measures led to a decline in market prices that, in turn, led to a significant decrease in fossil fuel investment projections. These effects are much better captured by price investment models that operate on a daily or weekly time step, than by IAMs that operate on a yearly time step.

Thirdly and finally, IAMs are steered by macro-indicators such as income and GDP, long-term policies and structural changes, and construct 'what-if' scenarios to explore long-term impacts and effects. Even if we forced the short-term shock effect of the pandemic into an IAM, e.g. by reducing aviation traffic by 60% in 2020, the model would not be able to generate an accurate long-term result. Conversely, solely inputting the 2020 GDP reduction (~5%) would not capture the huge short-term effects of the pandemic on aviation traffic (~60% reduction), surface transport and other sectors affected by the containment measures.

Thus, for assessing short-term effects, trend analyses and ex-post methods such as presented in Chapter 2.2 or Climate Action Tracker (2020) are more suitable and more practical than modelling with IAMs. However, IAMs could be used in conjunction with other approaches, provided that a series of inputs representing different long-term future scenarios are carefully constructed beforehand. A short analysis of this approach is presented in Chapter 4.2.

4.2 Modelling long-term effects: the way forward

Collaboration between different model types would be the best way to capture the impacts of the COVID-19 pandemic on the economy and emissions trajectories. Models that can capture the relationship between GDP and investments more accurately than IAMs are better suited for the first stages of this modelling approach, since the majority of the recovery measures announced so far are fiscal in nature, seeing that national governments are eager to get the economy up and running again. Based on the above, macroeconomic models such as the E3ME model of Cambridge Econometrics (Mercure, Pollitt, Edwards, *et al.*, 2018; Mercure, Pollitt, Viñuales, *et al.*, 2018) or the GEM-E3-FIT model of E3-Modelling (Fragkos *et al.*, 2017, 2018) can be used to project post-COVID economic pathways and economic growth rates that can be used as input in IAMs such as IMAGE.

More in general, IAMs can be used to model the combined, long-term impact of climate policy and COVID recovery packages on economic growth and structural changes in the economy, permanent changes in energy demand and lifestyle, and societal changes (Kriegler, Riahi and van Vuuren, 2020). Structural changes that can be expressed in terms of emissions over longer time periods, such as long-term governmental policies, changes in global trade and consumption patterns, and changes in surface transport due to a greater percentage of the population working from home, can be aggregated to produce different scenarios. These long-term 'what if' scenarios can be used to explore numerous different future pathways, for example:

- Comparing decarbonisation paths towards 2050 in a green recovery scenario versus a grey recovery scenario (rescue policies favouring the fossil fuel industry, bailouts without green conditions attached, negative sectoral rebound effects etc.);
- Exploring pre-COVID-19 versus post-COVID-19 current policies scenarios out to 2030 (or 2050), to evaluate the ability of IAMs to interpret long-term structural changes following extreme events;
- Creating more 'realistic' scenarios where the detailed economic projections of macroeconomic models are used together with expert projections on systemic changes in policy, energy, and lifestyle in order to provide a more 'middle of the road' scenario approach.

This way, IAMs can provide valuable input on the feasibility of post-COVID transition pathways towards zero carbon emissions, and identify the socio-economic and societal challenges and their effects on these pathways.

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Annex A.1 Short-term GDP projections

Short-term GDP projections

The results in Chapter 2.2 are based on ex-post calculations for the current policies scenario, using IMF's GDP growth projections (2020-2024) published in April 2020 (IMF, 2020c) for the their *Baseline* scenario and *Longer and New Outbreak* scenario.

In IMF's *Baseline* scenario, the global economy is projected to contract sharply as a result of the pandemic, by −3% in 2020, which is much worse than during the 2008–2009 financial crisis. This scenario assumes that the pandemic fades in the second half of 2020 and containment efforts can be gradually relaxed; the global economy is projected to grow by 5.8 percent in 2021 as economic activity normalises, supported by countries' recovery packages (IMF, 2020c).

Alternative IMF scenarios: The first alternative estimates the impact of the fight against the spread of the virus in 2020 taking roughly 50 percent longer than assumed in the baseline. The second alternative considers the impact of a second, but milder, outbreak occurring in 2021. The third alternative, the so-called *Longer and New Outbreak* scenario, estimates the potential impact of both the outbreak taking longer to contain in 2020 and a second outbreak occurring in 2021.

This study focusses on two scenarios, i.e. IMF's *Baseline* and IMF's *Longer and New Outbreak* scenario, to cover a wide range in GDP projections (see Figure below).
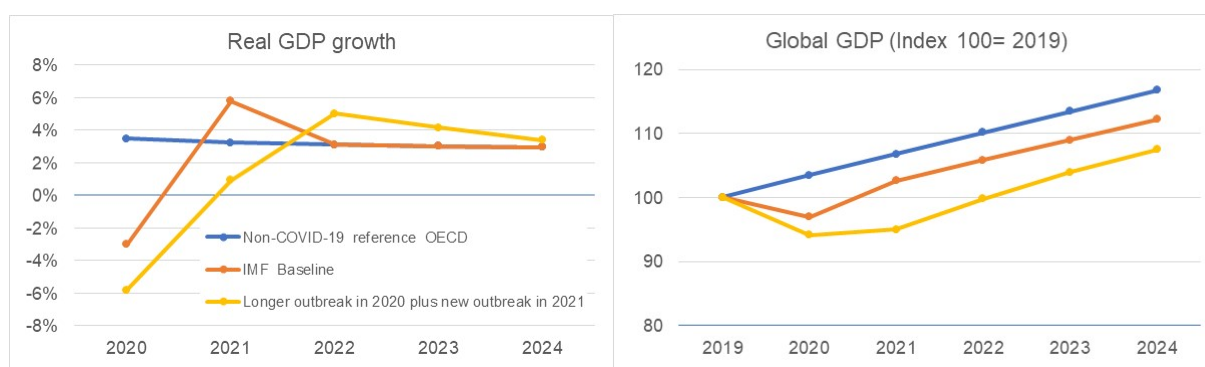

Figure 9: Short-term GDP projections of the IMF *Baseline* and *Longer and New Outbreak* scenario.

Annex A.2 Defining 'green' and 'grey' policy archetypes

Table 6: Classification of 'green' policy archetypes. Source: Vivid Economics (2020) for sector-specific measures and the present study for economy-wide measures.

Sector	Archetype	Description
Economy-wide (without an explicit sector-level focus specified)	Subsidies or tax reductions for green products	Tax rebates and other subsides for households and/or companies to purchase low-carbon/zero-carbon products and services.
	Loan and grants for green investments	Direct investment in the form of loans or grants for low-carbon/zero-carbon investments such as public infrastructure and production technologies.
	Green R&D subsidies	Loans or research grants available to academic institutions, research centres, think tanks and private firms to develop low-carbon/zero-carbon technologies, products, and infrastructure.
	Corporate bailouts with green strings attached	Conditional bailouts (and respective budget lines) specifying requirements on emissions, pollutions, supply chain requirements, compliance to voluntary agreements and/or reporting standards.
Agriculture	Bailouts with green strings attached	Requiring limits to emissions and waste in return for direct funding.
	Nature based solutions	Afforestation programmes, restoration of wetlands, or forest management investments.
	Loan and grants for green investments	Direct loans or tax rebates and subsidies for low- water irrigation systems.
	Wildlife Trade Ban	Making the sale of endangered animals illegal.
Energy	Bailouts with green strings attached	Direct loans and guarantees towards energy providers (renewables, nuclear) or oil and gas and coal with commitments for improvement on emissions or energy efficiency.
	Loan and grants for green Investments	Direct investment in the form of loans or grants towards renewable energy including solar, wind, biofuels and hydrogen.
	Green R&D subsidies	Grants for research institutes, academic institutes, and private firms to develop new renewable energy technologies and systems.
	Subsidies or tax reductions for green products	Extending tax rebates to households for solar, making green energy products including utilities with renewable targets available at a subsidised cost.
Industry	Bailouts with green strings attached	Conditions on firms on emissions, pollutions, supply chain requirements, or compliance to voluntary agreements or reporting standards.
	Loan and grants for green investments	Low carbon or low emissions public infrastructure for industry including CCS projects for industry, energy efficiency programs for existing buildings, investment in hydrogen economy and electrification of industry.
	Green R&D subsidies	Direct grants or loans available to research institutions, academic institutions, and private firms to develop low-carbon industrial infrastructure including natural based solutions, hydrogen, and electrification technologies.

	Subsidies or tax reductions for green products	Taxes for the use of primary materials in supply chain, subsidies offered to firms who undertake compliance in supply chain.
Transport	Bailouts with green strings attached	Conditional bailouts to air carriers, car manufacturers, or navigation for emissions reduction pledges or commitment to biofuel or renewable fuel standards in exchange for loans.
	Loan and grants for green Investments	Building public infrastructure projects including cycleways, low-carbon rail or transit, public walkways, and railroads with considerate to climate mitigation and adaptation.
	Green R&D subsidies	Loans or research grants available to academic institutions, research centres, think tanks and private firms to develop electric vehicles, hydrogen vehicles, and low-carbon fuel alternatives for shipping, aviation and vehicle transport.
	Subsidies or tax reductions for green products	Tax rebates available to consumers for EVs, subsidisation of low carbon transportation including light rail, developing HOV lanes or low-emission zones fees.
Waste	Bailouts with green strings attached	Directing grants or loans to firms who open incinerate waste without provisions for more sustainable waste management strategies.
	Loan and grants for green investments	Direct investment in recycling, MSW, waste-to-energy, or methane recapture on existing facilities or new waste management facilities.
	Green R&D subsidies	Loans or grants for academic institutions, research centres, think tanks, or private firms for the development of advancement waste management include waste-to-energy and methane recapture technologies.
	Subsidies or tax reductions for green products	Tax reductions or rebates for recycling, composting including buy-back programs or subsidisation of environmental producer responsibility (EPR) programs.

Table 7: Summary of 'grey' policy archetypes. Source: Vivid Economics (2020) for sector-specific measures and the present study for economy-wide measures. Note: where Vivid Economics' (2020) used 'brown' we have replaced this with 'grey'.

Sector	Archetype	Description
Economy-wide (without an explicit sector-level focus specified)	Roll-back of economy-wide regulation and environmental standards	Removal, elimination, weakening or (temporary) suspension of existing regulation and/or environmental standards, including the postponed introduction of planned regulation and standards.
	Subsidies, waived fees, or tax reductions for grey products	Waiving, reducing, or directly subsidizing fees for households and/or companies to purchase high-carbon products and services.
	Loan and grants for grey investments	Direct investment in the form of loans or grants for high-carbon investments such as public infrastructure and production technologies.
	Grey R&D subsidies	Loans or research grants available to academic institutions, research centres, think tanks and private firms to develop high-carbon technologies, products, and infrastructure.

Agriculture	Subsidies or waived fees for environmentally harmful activities	Waiving, reducing, or directly subsidizing fees associated with point and non-point source pollution in agriculture, logging, and timber. Removal of conservation or preservation laws around forest management and access.
	Deregulation of environmental standards	Removing, repealing, increasing the quantity of pollutants allowed or extending the compliance period for pollution, emissions, or land use in agriculture and forestry sectors.
	Environmentally related bailout without green strings	Loans, guarantees or grants provided to agriculture producers including farmers, fishers and cattle ranchers that do not require improvement in sustainable practices.
	Subsidies or tax reductions for grey products	Introducing subsidies on high emissions agriculture products including cattle and sheep, reducing existing carbon taxes or environmental taxes on high-impact agriculture and harvested wood products.
Energy	Subsidies or waived fees for environmentally harmful activities	Subsidising utilities, producers, or developers of oil and gas or coal production plants, covering the cost of pollution taxes including carbon taxes, delaying the development or deployment of emissions taxes for energy producers.
	Grey infrastructure investments	Direct investment in coal or oil and gas sector, or loans, grants and guarantees made available to private firms exclusively to build oil and gas or coal production plants.
	Deregulation of environmental standards	Removal or elimination of carbon trading schemes, increasing the cap on emissions or pollution trading schemes, decreasing the number of firms required to participate in emissions trading schemes, removing mandates for environmental reporting or disclosure, suspending enforcement of environmental regulation.
	Environmentally related bailout without green strings	Extending loans, grants, guarantees, or other financing capacity to oil and gas or coal producers without conditions on emissions intensity, emissions output, or energy mix.
	Subsidies or tax reductions for grey products	Subsidisation for consumers or producers of oil and gas and coal including diesel, home electricity, and utilities and reducing existing fuel taxes or carbon taxes.
Industry	Subsidies or waived fees for environmentally harmful activities	Waiving permitting and environmentally-related fees for mining, construction or other heavy industrial sectors.
	Grey infrastructure investments	Direct government investment or procurement of high emissions public infrastructure including factories, data centres, and non-energy efficient building stock or heating systems
	Deregulation of environmental standards	Removal of reporting or mandatory disclosure of environmental impact by industrial firms, suspension of enforcement of environmental laws and regulations, removal of permit or use requirements for industry, fast-tracking of grey industrial project development by removing environmental assessments.
	Environmentally related bailout without green strings	Direct unconditional support through grants, loans, guarantees, or other financial mechanisms to high-emissions industrial sectors without requirements for efficiency, energy use, or reporting improvements.
	Subsidies or tax reductions for grey products	Reducing taxes on grey products including manufactured goods and chemicals which have a high environmental impact.

Transport	Subsidies or waived fees for environmentally harmful activities	Direct subsidisation of combustion engines made available to consumers or producers, removal or reduction of the fees related to tailpipe emissions or fuel taxes.
	Grey infrastructure investments	Direct government investment into infrastructure supporting grey transport, such as airports or car transport infrastructure.
	Deregulation of environmental standards	Removal of regulations governing the transport sector, such as for ships and aviation and largely relating to emissions.
	Environmentally related bailout without green strings	Direct unconditional support through grants, loans, guarantees, or other financial mechanisms to high emissions transport providers, such as airlines.
	Subsidies or tax reductions for grey products	Reducing taxes on the sale of grey products such as automobiles, with no preferential treatment of 'green' alternatives such as electric vehicles.
Waste	Subsidies or waived fees for environmentally harmful activities	The removal of fees relating to the environmentally harmful disposal or treatment of waste.
	Grey infrastructure investments	Investments into waste infrastructure that does not improve the environmental impact of waste disposal or treatment.
	Deregulation of environmental standards	Removal of regulations governing the disposal and/or treatment of waste.
	Environmentally related bailout without green strings	Extending bailouts to waste industry who openly incinerate or do not use methane recapture, MRV systems, or other advanced waste management systems without requirements for meeting environmental reporting standards.

Annex A.3 Germany's fiscal stimulus package announced on 3rd of June 2020

Table 8: Classification of the measures included in Germany's fiscal stimulus package announced on 3 June 2020 in response to the COVID-19 pandemic (Government of Germany, 2020b). For an explanation of the classification method, see Chapter 3.1.

Measure	Sector	'Green' / 'Grey' / 'Colourless'	Volume (in EUR billion)	Period
Support programme for animal stable renovations	Agriculture	Colourless	0.30	2020-2021
Support of R&D programmes - General (32.-33.)	Economy-wide	Colourless	2.00	2020-2021 [?]
VAT cut from 19% to 16% (1.)	Economy-wide	Colourless	20.00	07/2020 to 12/2020
Support of social security contributions (2.)	Economy-wide	Colourless	5.30	2020
Temporary tax revisions (Einfurhumsatzsteuer, steuer. Verlustrückgang, deg. Abschreibung, Körperschaftssteuerrecht, Mitarbeiterbeteiligung) (4.-8.)	Economy-wide	Colourless	0.40	2020-2021
Investments in digitalisation of administration, security projects, and new armaments projects (10.)	Economy-wide	Colourless	10.00	2020-2021
Short-term bridging loan programme (13.)	Economy-wide	Colourless	Other programme	2020
Support for non-for-profit organisations (14.)	Economy-wide	Colourless	0.90	2020-2021
Support for cultural organisations (15.)	Economy-wide	Colourless	1.00	2020-2021
Support of municipalities (to compensate for lower tax revenues) (18.-19.)	Economy-wide	Colourless	9.90	2020
Other support of municipalities (23. and 25.)	Economy-wide	Colourless	0.49	Not specified
Support of educational and family support measures (26.-31.)	Economy-wide	Colourless	9.05	2020-2021
Several measures on digitalisation, KI, and G5 (40.-49.)	Economy-wide	Colourless	16.30	Not specified
Several measures to support health care system (50.-54.)	Economy-wide	Colourless	9.75	Not specified
Budget extension for humanitarian aid (57.)	Economy-wide	Colourless	3.00	Not specified
Wireless connectivity along railways (35.)	Transport	Colourless	0.15	2020-2021
Extra funding for energy efficient building renovation programme (39.)	Buildings	Green	2.00	2020-2021
Extra funding for access the national climate protection initiative (20.)	Buildings	Green	0.10	2020-2021

Support of R&D programmes - Energy Systems (34.)	Energy	Green	0.30	
Cutting the renewable energy levy on electricity bills (3.)	Energy	Green	11.00	2020-2021
National hydrogen strategy: investment in domestic hydrogen production (36.)	Energy	Green	7.00	Not specified
Support of German hydrogen technology to countries with geographical resources for cheap production (37.)	Energy	Green	2.00	Not specified
National solar capacity cap removed, and offshore wind expansion target raised from 15 to 20GW in 2030	Energy	Green	Not specified	2020-2030
Funds for the conservation and sustainable management of forests (16.)	Forestry	Green	0.70	Not specified
Modernisation fund for shipping (35.)	International bunkers	Green	1.00	2020-2021
Aircraft fleet exchange with BAT (35.)	International bunkers	Green	1.00	Not specified
Support for electric and hybrid car purchase subsidy (35.)	Transport	Green	2.20	2020-2021
Car tax reform to account for emission levels (35.)	Transport	Green	Budget neutral	Indefinitely
Fleet exchange programme for social services (35.)	Transport	Green	0.20	2020-2021
Investment in EV charging infrastructure, R&D on electromobility and batteries (35.)	Transport	Green	2.50	Not specified
Support of DB / railways (35.)	Transport	Green	5.00	Not specified
Extra funding for electric buses and trucks and associated charging stations (35.)	Transport	Green	1.20	2020-2021
Funding for public transport in the regions (22.)	Transport	Green	2.50	2020
Support for auto industry transformation (35.)	Transport	Green	2.00	2020-2021

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