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THE LONG-TERM IMPLICATIONS OF THE COVID-19 PANDEMIC AND RECOVERY MEASURES ON ENVIRONMENTAL PRESSURES: A QUANTITATIVE EXPLORATION

ENVIRONMENT WORKING PAPER N° 176

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Authorised for publication by Rodolfo Lacy, Director, Environment Directorate.

Keywords: Covid-19, general equilibrium, climate change, air pollution, materials use, land use change.

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Abstract

This paper analyses the long-term effects of the COVID-19 pandemic and associated government responses on the environment. It uses large-scale modelling to investigate the impact of sectoral and regional shocks to the economy until 2040. These detailed economic impacts are linked to a range of environmental pressures, including greenhouse gas emissions, emissions of air pollutants, the use of raw materials and land use change. The short-term reductions in environmental pressures are significant: in 2020, energy-related greenhouse gas and air pollutant emissions dropped by around 7%. Environmental pressures related to agriculture observed a smaller drop in 2020. The reduction in the use of non-metallic minerals, including construction materials, reached double digits. From 2021, emissions are projected to increase again, gradually getting closer to the pre-COVID baseline projection levels as growth rates recover fully. But there is a long-term – potentially permanent – downward impact on the levels of environmental pressures of 1-3%.

Keywords: Covid-19, general equilibrium, climate change, air pollution, materials use, land use change.

JEL codes: D58, O44, Q53, Q54.

Résumé

Ce papier analyse les effets à long terme de la pandémie de COVID-19 et des mesures de relance sur l'environnement. Il s'appuie sur un outil de modélisation à grande échelle pour étudier l'impact des chocs sectoriels et régionaux sur l'économie jusqu'en 2040. Ces impacts économiques détaillés sont liés à une série de différentes pressions environnementales, notamment les émissions de gaz à effet de serre, les émissions de polluants atmosphériques, l'utilisation des matières premières et le changement d'affectation des terres. Les réductions à court terme des pressions environnementales sont importantes : en 2020, les émissions de gaz à effet de serre et de polluants atmosphériques liées à la consommation d'énergie ont diminué d'environ 7 %. Les pressions environnementales liées à l'agriculture ont connu une baisse moins importante en 2020. La réduction de l'utilisation des minéraux non métalliques, y compris les matériaux de construction, a atteint un pourcentage à deux chiffres. À partir de 2021, les émissions devraient à nouveau augmenter, se rapprochant progressivement du scénario de référence antérieur à l'apparition du COVID, à mesure que les taux de croissance se rétablissent pleinement. Cependant, il y a un impact à long terme – potentiellement permanent – à la baisse sur les niveaux de pressions environnementales de 1-3%.

Mots clés: équilibre général, changement climatique, pollution de l'air, utilisation de matériaux, changement d'affection des terres.

Codes JEL: D58, O44, Q53, Q54.

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This report was prepared under the guidance of Shardul Agrawala, Head of the Environment and Economy Integration Division at OECD Environment Directorate.

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Executive Summary

The Covid-19 pandemic and the associated restrictions to combat it, not least lockdowns, have had severe economic consequences, leading to a significant drop in economic activity. Recovery will be a long-term process and economic activity will likely be affected even after the health crisis is over. The effects of Covid-19 on economic growth will affect the pressure of economic activity on the environment.

This paper provides a first numerical assessment of the effects of the Covid-19 pandemic on medium- and long-term environmental pressure. It uses the state-of-the-art large-scale modelling tool ENV-Linkages to investigate the impact of sectoral and regional shocks to the economy until 2040. The unique features of ENV-Linkages allow it to further link these detailed impacts on economic activity to a range of environmental pressures, including greenhouse gas emissions, emissions of air pollutants, the use of raw materials and land use change.

The modelling analysis shows that there are significant differences in the economic impacts across regions, driven to some extent by the severity of the pandemic in the region and the strictness and duration of the lockdowns, but also by differences in the structure of these economies, as well as shifts in international trade patterns. Sectoral differences are pronounced: while for example transport activities and certain services are substantially hurt in 2020, pharmaceuticals are projected to boost production levels in the short run. After 2020, the reduced short-term economic growth and reduced investments start affecting all sectors negatively. In the longer run, the burden shifts towards the more capital-intensive industries – due to a slower build-up of the capital stock – while services and especially agriculture rebound more quickly to pre-Covid baseline levels.

The short-term reductions in environmental pressures caused by the Covid-19 emergency response measures like lockdowns and social distancing are significant: greenhouse gas emissions, as well as emissions of some of the most important air pollutants, drop by around 7% below the pre-Covid baseline level in a single year. Other air pollutants, including those more strongly related to agriculture, observe a smaller drop in 2020. The reduction in materials use varies across the type of material: biotic resources decline by merely 2%, whereas the reduction in the use of non-metallic minerals, including construction materials, is projected to reach 11%.

After 2020, emissions are projected to increase again, as economic activity resumes and vaccines begin to be deployed, gradually getting closer to the pre-Covid baseline levels. But there is a long-term – potentially permanent – downward impact on the levels of environmental pressures of 1-3%, depending on the indicator: roughly 2% for emissions and materials use related to energy use and industry, less than half of that for land use change, emissions and materials use that are more closely linked to agriculture. Growth rates do recover fully.

1. Introduction

The Covid-19 pandemic and the lockdown measures put in place to address the health crisis have severe economic consequences, leading to a significant drop in economic activity. Recovery will be a long-term process and economic activity will likely be affected even after the health crisis is over. In turn, changes in economic activity will affect environmental pressures, such as emissions of greenhouse gases and air pollutants, and the use of raw materials. For example, the lockdown measures have led to a temporary improvement of local air quality (Berman and Ebisu, 2020[1]; Granella et al., 2020[2]; Pei et al., 2020[3]). Early analyses of the effects of lockdown and other COVID-19 measures on economic activity and environmental pressure have shown a wide range of possible results, as modelling groups have had to make very bold assumptions on the impacts of the pandemic (see e.g. the *Environmental and Resource Economics* special issue (EaRE, 2020[4]; Lahcen et al., 2020[5])). But gradually more clarity emerges on the main channels through which economic activity and environmental pressure are affected by the lockdowns and stimulus and recovery packages.

Recent work from the OECD has focused on short-term impacts of the Covid-19 pandemic. This has included short-term economic projections for GDP (OECD, 2020[6]) and the impact of the pandemic on global supply chains (OECD, 2021[7]). Work on the environmental implications of the pandemic has looked at the links between economic recovery and climate change mitigation (Buckle et al., 2020[8]) and taking consideration of green measures in the response to and recovery from the Covid-19 pandemic (Agrawala, Dussaux and Monti, 2020[9]). Quantitative work was carried out by the OECD Trade and Agriculture Directorate on the implications of the crisis for economic activity, trade and resilience (OECD, 2020[10]), and on the impact of Covid-19 on agricultural markets and associated greenhouse gas emissions (OECD, 2020[11]). While this work contributes towards an analysis of the economic and environmental impacts of the pandemic, there is a need for an analysis of the longer-term impacts of the crisis.

This paper contributes to this emerging literature on the effects of the Covid-19 pandemic and recovery on environmental pressures by using a state-of-the-art large-scale modelling tool to identify sectoral and regional shocks to the economy from the pandemic and the associated lockdown and stimulus (recovery) packages. By linking economic activity and environmental pressures, projections can be made of the medium- and long-term impacts on greenhouse gas emissions, air pollution, materials use and land use change. These linkages are made by associating environmental pressures to the specific input in production and consumption. For example, CO_2 emissions are associated with fossil energy use, and metals use with mining products (metal ores) in production (see Annex A).

The implications of the pandemic and response measures are determined by comparing a counterfactual pre-Covid baseline scenario with a scenario where the Covid-related shocks are included. These shocks are based on an assessment, as of April 2021, of the shocks to GDP, unemployment, labour productivity, trade barriers, stimulus packages to firms and households, and final demand. These shocks occurred from 2020 and are assumed to gradually phase out over time. As the speed of recovery is highly uncertain, an alternative scenario with a slower paced recovery is investigated to shed light on how dependent the effects on environmental pressures are on the initial shock and on the speed of recovery.

The results presented in this paper are surrounded by significant uncertainties. Most importantly, the analysis does not capture the effects of green recovery packages. To what extent government support will affect environmentally relevant sectors remains to be seen

and further research on this topic is needed. Furthermore, an analysis of the environmental consequences (e.g. changes in concentrations of greenhouse gases and air pollutants or changes in ecosystem services driven by land use change) or health implications (e.g. changes in air pollution-related mortality) of changes in environmental pressures are beyond the scope of the current paper. These caveats notwithstanding, this paper sheds light on how the economic consequences of the Covid-19 pandemic and government response measures affect environmental pressures in the medium and long run.

2. Methodology

2.1. Modelling framework

The analysis relies on the ENV-Linkages computable general equilibrium (CGE) model (Chateau, Dellink and Lanzi, 2014[12]), which describes economic activities in different sectors and regions and how they interact. The model relies on a consistent set of data (the GTAP database) describing the behaviour of production sectors and consumers in the different regions, with a focus on energy and international trade.

The regional and sectoral structure of the ENV-Linkages model, the use of full production functions, as well as the detailed representation of the energy system, are exploited to produce projections of environmental pressures linked to specific elements of economic activity (see Annex A).

CO_2 emissions from fossil fuel combustion are directly linked to the use of different fuels in production. Other greenhouse gas (GHG) emissions, including process emissions of CO_2 and emissions of other GHGs such as methane (CH_4) and nitrous oxide (N_2O), are linked to sectoral output. More details can be found in (OECD, 2015[13]).

Emissions of air pollutants have been included in ENV-Linkages by linking them to production activities in different key sectors. The main emission sources are similar to those of GHG emissions. The air pollutants tracked in the model are the following: sulphur dioxide (SO_2), nitrogen oxides (NO_x), black carbon (BC), organic carbon (OC), carbon monoxide (CO), non-methane volatile organic compounds (NMVOCs) and ammonia (NH_3). More details can be found in (OECD, 2016[14]).

Material flows, covering 60 different materials including biotic resources (those from agriculture, fisheries and forestry), fossil fuels, metals and non-metallic minerals, are linked to the economic flows at the detailed sectoral level. See (OECD, 2019[15]) for more details.

Land use change is proxied through harvested cropland area and output of the forestry sector. These are two key determinant of land use change (OECD, 2017[16]), and the ones that are most likely to be affected by the Covid-19 pandemic and response measures.

2.2. Scenarios

The reference point for the evaluation of the implications of the Covid-19 pandemic and response measures on economic activity and environmental pressures is a counterfactual pre-Covid scenario in which the economy follows earlier trends. This hypothetical scenario reflects the projections of future economic activity and environmental pressures outlined in the 2019 Global Material Resources Outlook, as described in (OECD, 2019[15]).

The Covid-19 pandemic and recovery scenario (hereafter referred to as Covid scenario) incorporates a detailed assessment as of January 2021 of the shocks caused by the pandemic, the lockdown measures and the government stimulus packages on GDP, unemployment, labour productivity, trade barriers, taxes on firm production and household income, and final demand. The macroeconomic impacts of the shocks in 2020 and 2021 follow OECD (2020[6]; 2021[17]) for OECD countries and selected emerging economies, and IMF (2020[18]) for other non-OECD countries; the sectoral shocks are based on Arriola and Van Tongeren (forthcoming[19]). Annex B provides more details on the shocks that are included and the way they have been used in the analysis.

All shocks are assumed to gradually phase out over time after 2020, using the short-term macroeconomic forecasts by OECD and IMF cited above as basis to identify regional recovery speeds. However, long-term economic activity levels – and the associated environmental pressures – do not necessarily return to the levels as projected in the baseline excluding the Covid shocks; the main reason is that the shocks alter savings and investment behaviour and thus long-term economic growth and environmental pressures.

To assess a more pessimistic recovery from the crisis, the assumptions in the Slow recovery scenario are that the recovery from the initial 2020 shock to the economy will be roughly twice as slow as in the core scenario. The shock in 2020 is identical to the Covid scenario.

Table 1. Summary of scenario assumptions

	Assumptions for year 2020	Assumptions for period 2021-2040
Pre-Covid baseline	Pre-Covid economic growth projections, following OECD (2019[15])	Pre-Covid economic growth projections, following OECD (2019[15])
Covid scenario	Range of shocks, detailed in Annex B	Moderate recovery, following OECD (2020[6]; 2021[17]) and IMF (2020[18])
Slow recovery scenario	Same as Covid scenario	Recovery twice as slow as in Covid scenario

3. The effects of the Covid-19 pandemic and response measures on environmental pressures

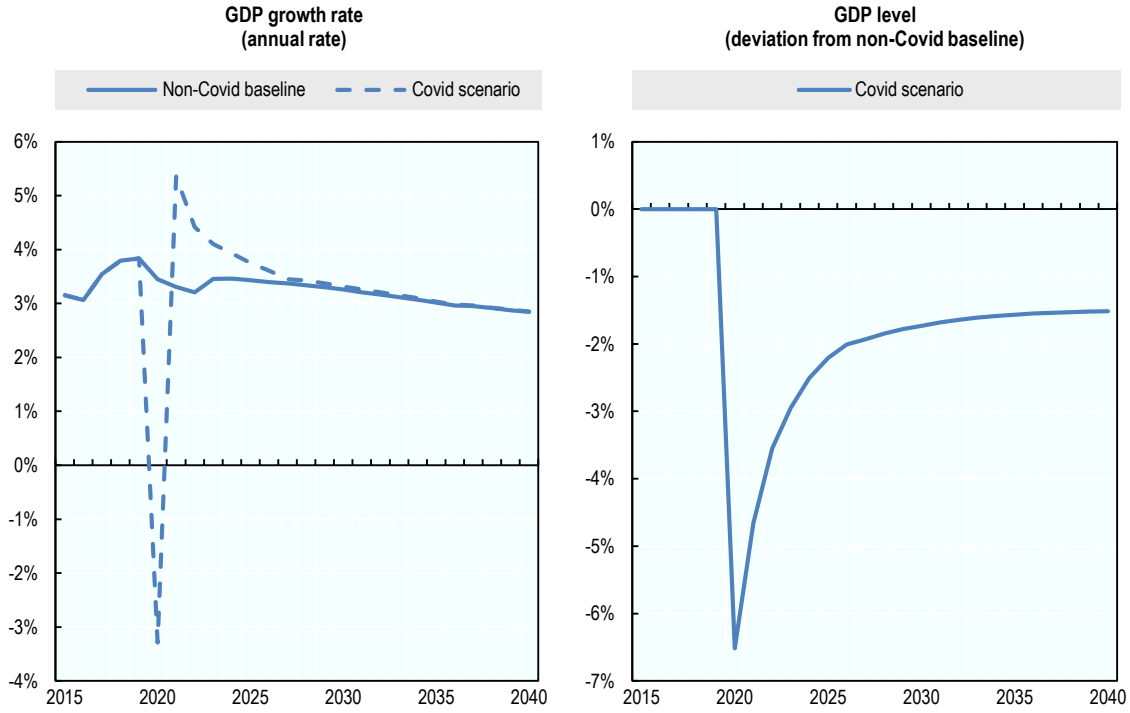
3.1. Effects on domestic economic activity

As mentioned above, the effects of the Covid-19 pandemic and response measures on environmental pressures are determined by the changes in economic activity. Increased unemployment, reduced labour productivity, a collapse in demand for certain commodities and higher trade costs all depress economic activity. This is only partially compensated by government support to firms and households. The result is a significant contraction of global GDP in 2020, with the annual global GDP growth rate dropping from around +4% in 2019 to -3.5% in 2020 (Figure 1).[1]

[1] OECD (2020[6]) provides a more detailed discussion of the macroeconomic implications of the pandemic. The global numbers presented here differ slightly from the official OECD projections, as the IMF forecasts are used for countries not covered in the OECD database.

Figure 1. Effects of the Covid scenario on global GDP

Annual rate of growth (left panel); deviation from the pre-Covid baseline projection (right panel)



Source: ENV-Linkages model.

The projections for global GDP in 2021 follow the short-term forecasts of the OECD Economics Department for OECD countries and selected emerging economies and the International Monetary Fund (IMF) for the other non-OECD countries; these are more optimistic. Although unemployment levels are projected to remain at their high 2020 level, demand and productivity will at least partially rebound, leading to a catch-up effect that causes a short spike in the global growth rate of GDP (around +5.5% in 2021 and above 4% in 2022). However, this growth spurt starts from a depressed GDP level, and – as the right panel shows – GDP levels remains well below the counterfactual pre-Covid baseline for decades.

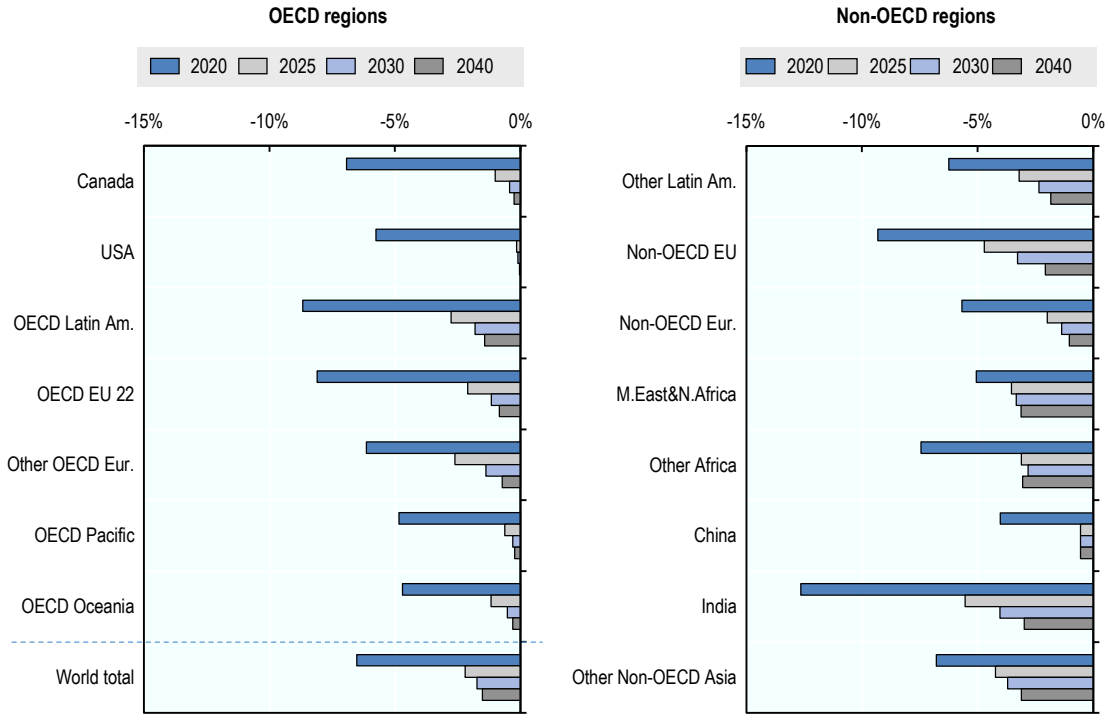
In the longer run, GDP *growth* is projected to return to pre-Covid levels. But there is a long-term impact on GDP levels of almost 2% below the pre-Covid baseline. This is caused by effects of the short-term shocks on savings and investment, that in turn decelerate long-term capital growth.

Regional differences in the effects of Covid-19 on GDP are significant, though the short-term effects are significant in all regions (Figure 2) and the shape of recovery – though not the speed – is similar across countries. The pandemic is truly global and affects all economies directly. Moreover, economic integration means that regional economic effects propagate through all economies. Most OECD economies are projected to mostly recover within a decade or so, but the long-term effects are more significant in parts of Africa and Asia, especially India, where the pandemic reversed a +8% expected growth rate in 2020

into a 6% contraction.[2] In the long run, GDP growth in Africa is projected to surpass the levels seen in the current emerging economies, building on an increased integration in the global economy, and thus Africa has more to lose from the long-term effects of the global economic contraction than most.[3]

Figure 2. Effects of the Covid scenario on regional GDP

Deviations from the pre-Covid baseline projection



Note: For an explanation of the regional aggregation see Annex A.
Source: ENV-Linkages model.

The structure of the economy plays a key role in how economic effects translate into changes in environmental pressures. Services sectors, which are among the most severely hit by the pandemic (Figure 3), are much less emissions- and materials-intensive than most industrial sectors. This suggests that overall reductions in environmental pressure in the short run could be smaller than the reductions in GDP. For the energy sectors, which are linked to many sources of GHG and air pollutant emissions, the effects are mixed: the reductions in demand for fossil fuels are quite large, not least through the effects of the lockdown measures on transport. Electricity demand also declines, especially in

[2] The forecasts for India of OECD and IMF are aligned to the Reserve Bank of India forecasts for the fiscal year running from April to April. The sharp contraction is followed by a significant rebound, with Indian GDP growth in 2021 forecast to be above 10%. This forecast may be revised as India is currently (April 2021) struggling with world's worst ongoing COVID-19 outbreak.

[3] Gross exports from Africa to the rest of the world are projected to increase by more than 60% between 2030 and 2040, more than double the global rate. Only India has a stronger export growth projection over this period.

production, as firms close down temporarily, but less than fuel use. Construction activities are among the most severely affected in the short term, while the metals sectors are mostly indirectly affected, not least through the negative effects on construction and motor vehicles. Such indirect effects are significant however: iron and steel production is projected to decline by 5% below the pre-Covid baseline in 2020. The only sector that is projected to have a short-term increase in output is pharmaceuticals (as well as some subsectors that are aggregated in larger sectors in the modelling, such as online retail).[4] But this boost is temporary, as the overall slump in economic growth also drags down production growth in this sector to below pre-Covid baseline levels after 2024 (while the sector can still grow in absolute terms); it is projected to remain performing better than other manufacturing sectors.[5] In the longer run, services and agricultural sectors are projected to recover faster and more completely than manufacturing. This is directly related to the capital intensity of these sectors (and the basic goods nature of food): according to the ENV-Linkages model simulations, in the short run the negative effects are largest in labour intensive sectors (as labour productivity is directly affected), while in the long run the opposite is true (as capital growth is affected).

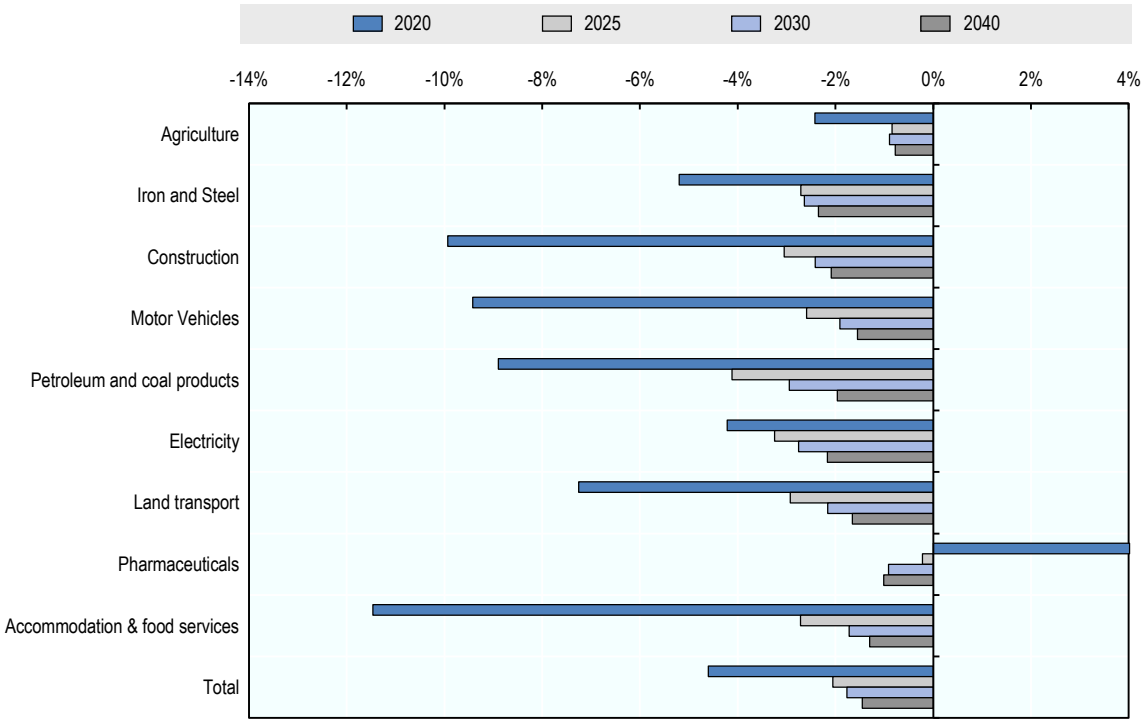
These sectoral effects may be significantly affected by recovery packages that are currently being implemented or considered; the analysis presented here includes short-term stimulus packages already implemented, but no longer-term recovery packages.

[4] The pharmaceuticals sector comprises around 0.7% of total output of the global economy, and above 1% in the European OECD countries (on average).

[5] The sector that according to the simulations is projected to perform best in the longer run is the health sector.

Figure 3. Effects of the Covid scenario on global output of selected sectors

Deviations from the pre-Covid baseline projection



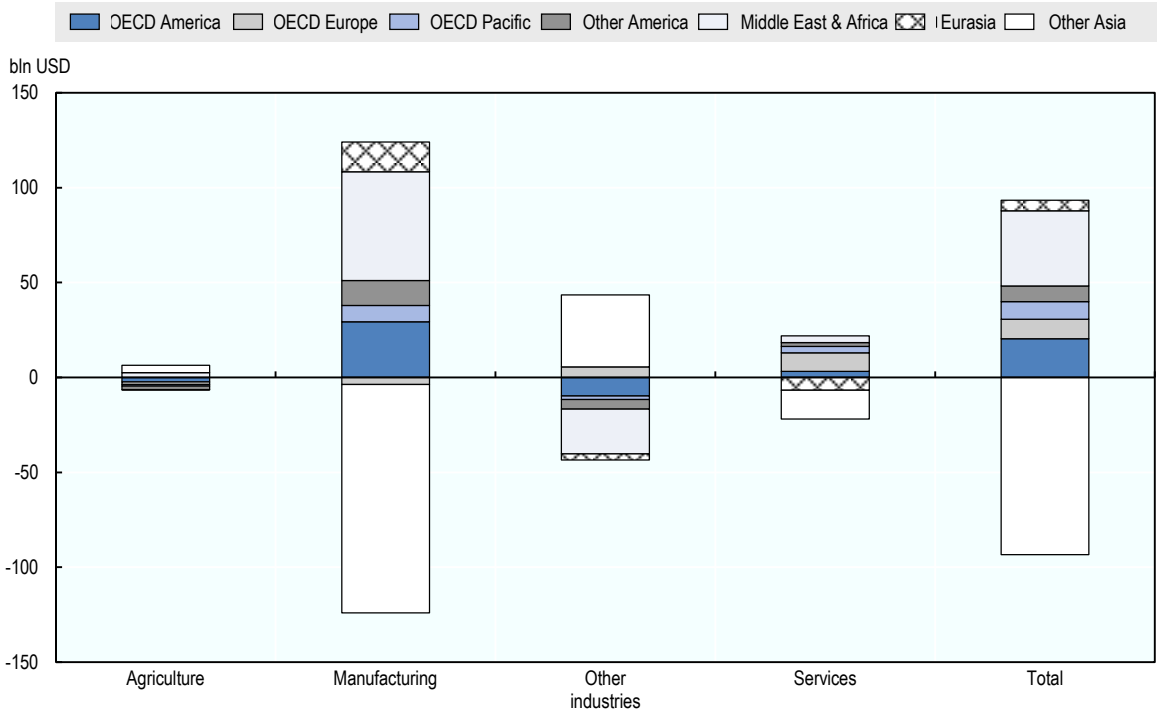
Source: ENV-Linkages model.

Finally, as the economic effects diverge across sectors and regions, and trade barriers increase more for some commodities than for others, trade balances also shift (Figure 4). This is driven by sectoral and regional changes in competitiveness. On balance, in 2020 the Asian economies were harder hit by the pandemic than the African economies and recovery is projected to be somewhat slower (except in China). Thus, the African trade balance for manufacturing goods is projected to increase, at the expense of Asian competitors. The trade balance of other industries (which encompass energy, construction and utilities) moves in the opposite direction.[6] As emission intensities differ across regions, even for the same commodities, this has consequences for global environmental pressures, as the regional composition of these pressures shifts.

[6] Such shifts depend crucially on the modelling framework and assumptions regarding e.g. the speed of recovery. Small perturbations of regional and sectoral impacts can have significant effects on relative competitiveness and thus lead to significantly different results for shifts in trade patterns. The results presented here are therefore merely a snapshot of a possible projection, and are surrounded by significant uncertainties.

Figure 4. Effects of the Covid scenario on regional trade balances in 2040

Deviations from the pre-Covid baseline projection



Note: For comparison, the total trade balance on the OECD vis-à-vis non-OECD countries in 2040 is projected to amount to -2 trillion USD, i.e. the OECD is a net importer.
Source: ENV-Linkages model.

3.2. Effects on environmental pressure

The reductions in economic activity caused by the Covid-19 pandemic led to lower emissions of greenhouse gases. Emissions of CO_2 from fossil fuel combustion dropped more than 7% below baseline levels in 2020 (Figure 5; top-left panel). This reduction is in line with the projections in the 2020 World Energy Outlook (IEA, 2020[20]), as these emission impacts directly follow the assumed energy demand reductions that are aligned with the World Energy Outlook. Other greenhouse gases are projected to decline less: methane (CH_4) by 4.6% and nitrous oxide (N_2O) by 2.3%. Until 2040, global GHG emissions remain more than 2% below baseline levels (while global GDP becomes less than 2% below the pre-Covid baseline by 2026, cf. Figure 1). This indicates that the long-term restructuring of the global economy outlined in Section 3.1 – activity levels in manufacturing that are more significantly below baseline levels than activity levels in agriculture and services – leads to a small but possibly permanent reduction in the emissions intensity of the global economy.

Air pollutant emissions follow a similar trend to GHG emissions (Figure 5; top-right panel), especially the gases that are most closely linked to energy use, i.e. nitrogen oxides (NO_x) and sulfur dioxide (SO_2). The other gases, that have different emission sources, tend to be less affected and recover more quickly. Ammonia (NH_3) is the least affected (at least until 2030), as this gas is more strongly connected to agricultural activity, and given the essential goods nature of food, agricultural activities are less affected than most sectors (cf. Figure

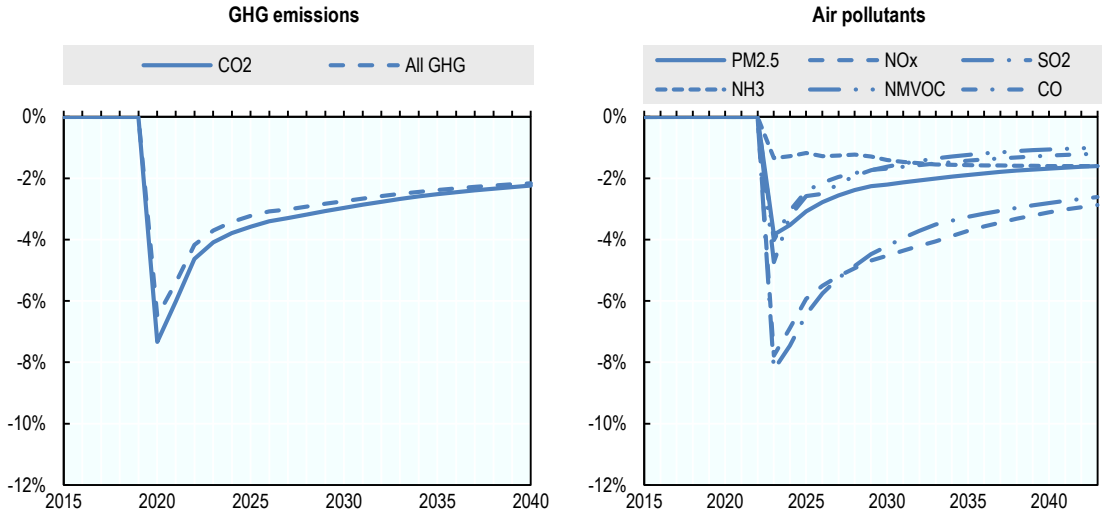
3). Emissions of particulate matter (PM2.5), which includes black carbon and organic carbon, are somewhere in between.[7]

The drivers of materials use are quite different than those of GHG or air pollutant emissions, except for the drivers of fossil fuel use. There are significant differences between the biotic (agricultural) materials and metals on the one hand, and fossil fuels and non-metallic minerals on the other (Figure 5; bottom-left panel). The former two are linked to agriculture and industrial activities, respectively, and these sectors are less severely affected in the short run – this is especially visible for metals use where the immediate decline is very small. But the slowdown of manufacturing production in the coming years gradually brings down metals use further below baseline levels. The effect for non-metallic minerals is linked to the sharp decline in construction activities in 2020. The larger permanent effects on energy and manufacturing are also reflected in the associated materials use, which remain around 2.5% below baseline levels until 2035, whereas biotic resources quickly rebound to around 1% below baseline.

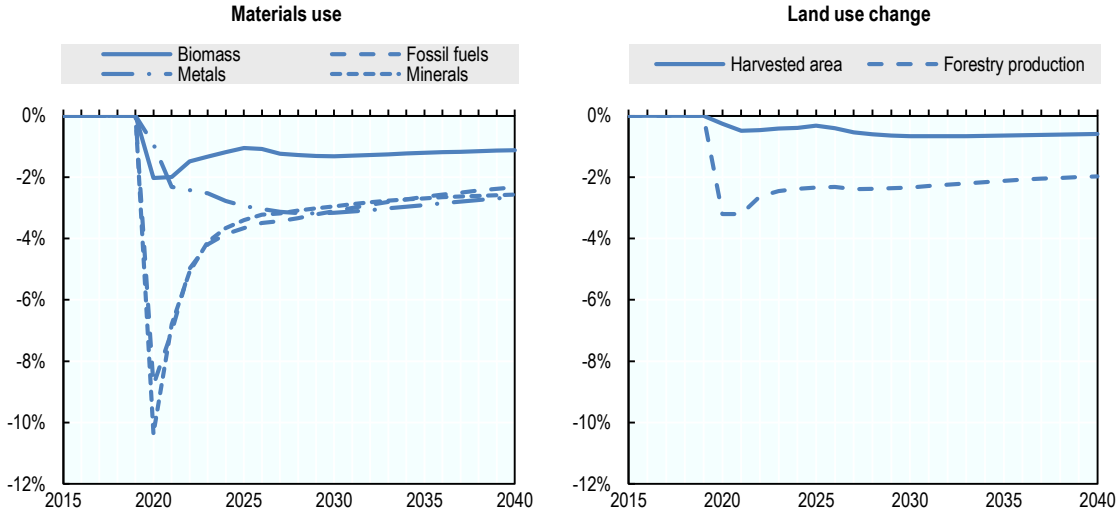
Finally, while the effects of the pandemic and associated government responses on biodiversity and ecosystem services cannot be measured in this modelling framework, the implications for land use change can be assessed. The slow-down in economic activity may lead to a small reduction in land use change, but the effect is almost negligible (Figure 5; bottom-right panel). In the short run, the area devoted to cropland (harvested area) is more or less fixed, and the relatively rapid rebound of food demand ensures land use change remains very close to the baseline levels. Effects on output of the forestry sector, the second indicator of land use change, are somewhat larger, but this indicator measures economic activity, and the implied effects on afforestation and deforestation are likely to be very small.

Figure 5. Effects of the Covid scenario on global environmental pressures

Deviations from the pre-Covid baseline projection



[7] Emissions of PM2.5 reflect primary emissions and exclude secondary particles that are formed in the atmosphere.



Source: ENV-Linkages model.

The regional differences in the effects on environmental pressures are significant (Figure 6). For climate change, this does not matter as GHG emissions uniformly mix in the atmosphere and the origin of the emissions does not matter. But for air pollution, these differences have significant effects on local air quality. As India is one of the countries with very high concentration levels of particulate matter ($PM_{2.5}$), the relatively large decline in emissions of air pollutants in this country may reduce premature deaths from air pollution.[8]

Regional changes in environmental pressures are only partially driven by what happens to the regional macro economy. In the short run (2025, as shown in Panel A), the pandemic and response measures lead to reductions in environmental pressures – or at least in GHG emissions and materials use – that are larger than reductions in economic activity in almost all regions, and these include many of the economically most severely affected regions.[9] For $PM_{2.5}$, seven regions have higher emission reductions than GDP loss, while for harvested area this happens in none of the regions. Striking is the large reduction in GHG emissions and materials use in India, which is largely driven by the effects on the energy system in the region.

By 2040, both the economic losses and the reduced environmental pressures have partially faded away everywhere, but in most regions a small reduction in the carbon intensity and materials intensity of the economy remains. Reductions in environmental pressure are below the global average in all OECD regions, implying that the net environmental gains are mostly reaped outside the OECD.

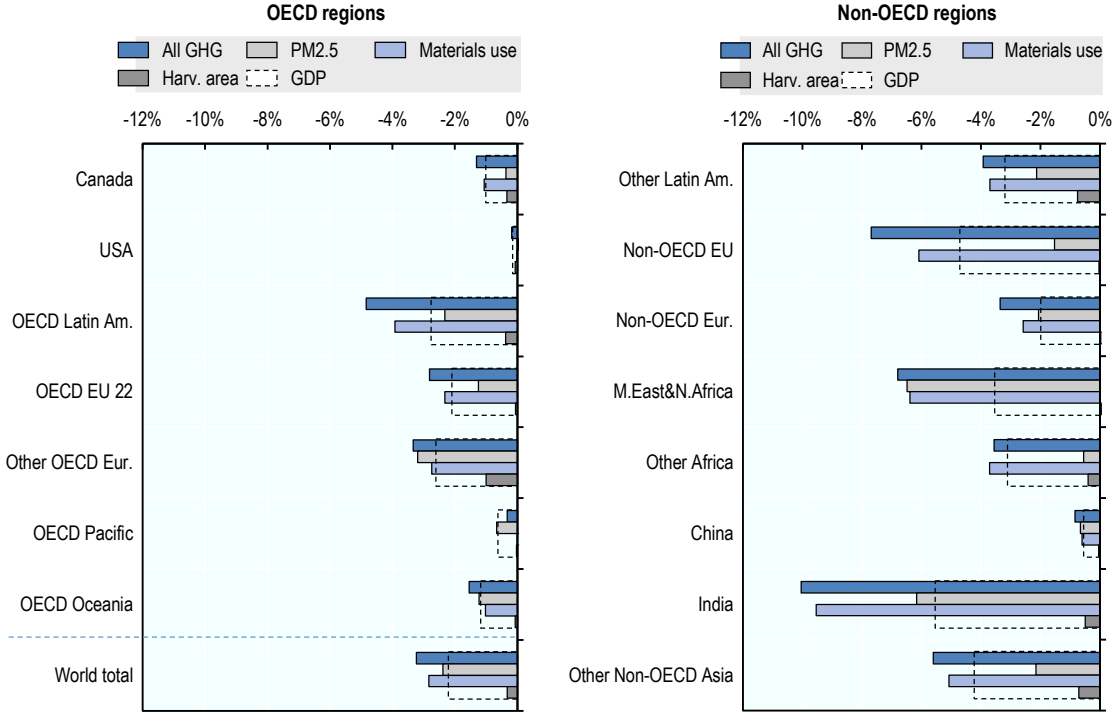
[8] Of course, this positive effect is not the result of a cost-effective policy measure. The economic costs associated with this environmental benefit are huge, and the result of an external shock, not a deliberate policy action.

[9] The focus here is on the economy; other counties may be more severely affected in terms of mortality and other health impacts.

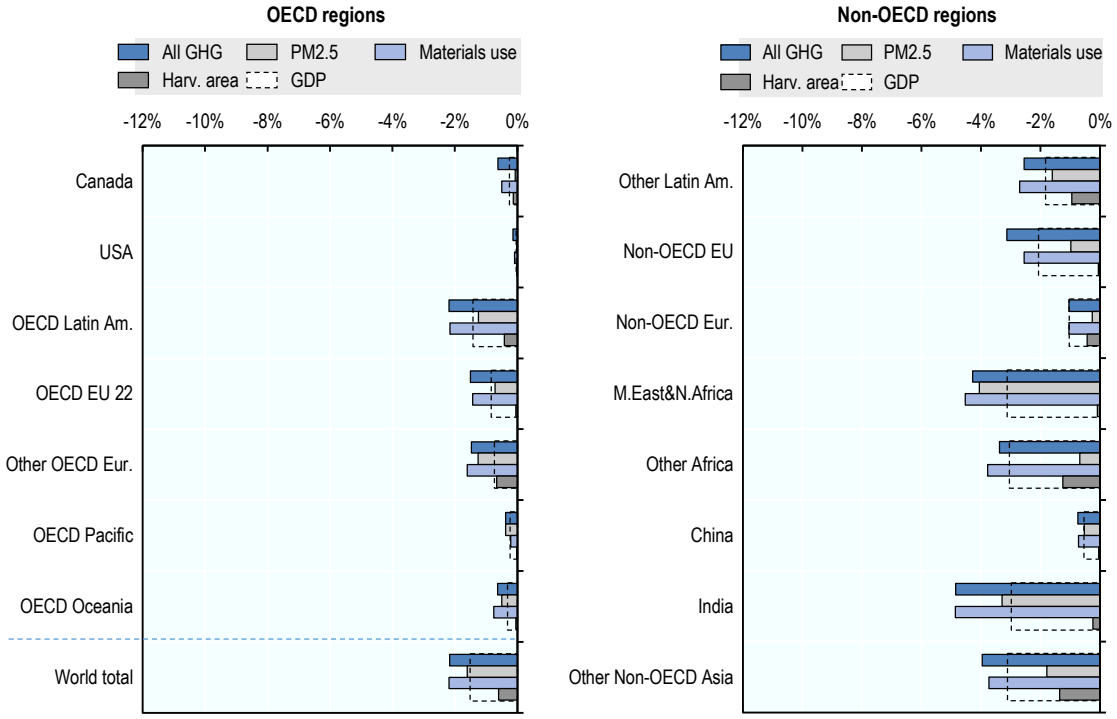
Figure 6. Effects of the Covid scenario on selected regional environmental pressures

Deviations from the pre-Covid baseline projection

Panel A. Results for 2025



Panel B. Results for 2040



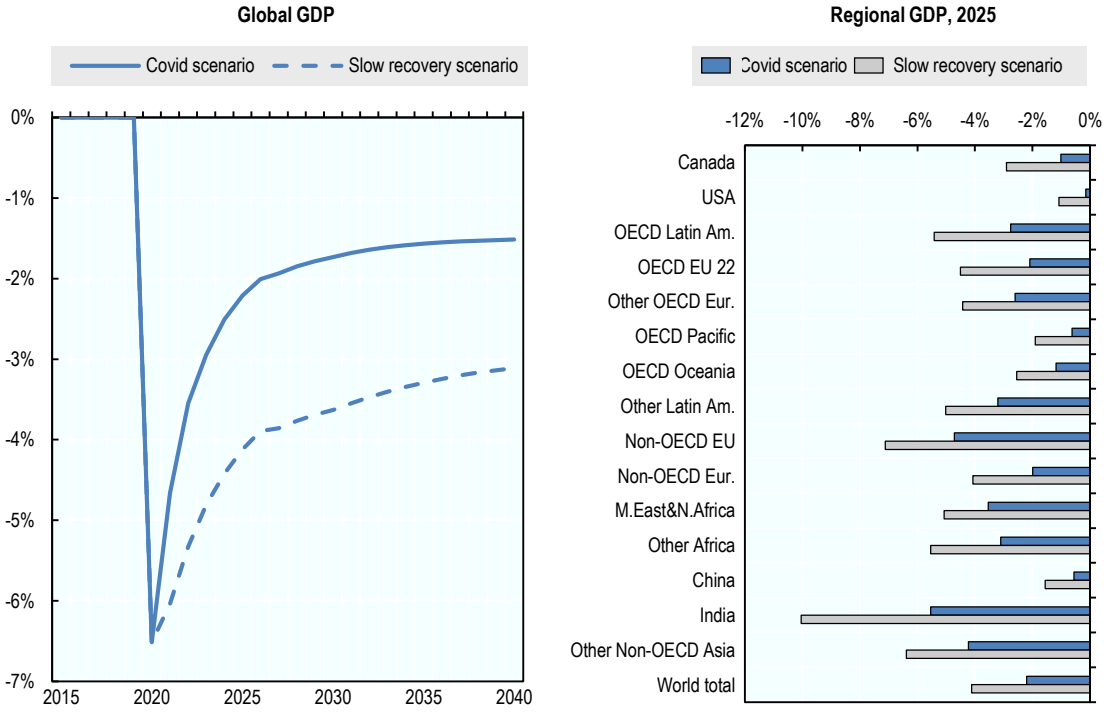
Note: For an explanation of the regional aggregation see Annex A.
Source: ENV-Linkages model.

4. The Slow recovery scenario

The speed with which the global economy will recover from the pandemic, and the medium-term effects are highly uncertain.[10] Therefore, an alternative scenario is briefly explored to highlight the implications of a slower recovery.[11] In this scenario, the rebound of GDP is slower, and by 2040, the economy is still substantially further below the counterfactual pre-Covid baseline level than the Covid scenario (Figure 7, left panel). Although the shocks simulated in the model are assumed to diminish at half the speed of the Covid scenario, the effect on economic activity is much longer-lasting, and remain roughly double those of the Covid scenario for at least the coming two decades. At regional level, the differences in 2025 (right panel) are relatively large for countries that are assumed to recover fast in the main Covid scenario and that are forecast to have a rebound effect in 2021. In absolute terms, slow recovery implies the GDP loss in India remains very large, at 10% below the pre-Covid baseline projection (a small recovery from -12.6% in 2020). The main reason for this is that the world economy remains more heavily affected and this is especially detrimental to major exporters such as India and China.

Figure 7. Effects of the Slow recovery scenario on global and regional GDP

Deviations from the pre-Covid baseline projection



Source: ENV-Linkages model.

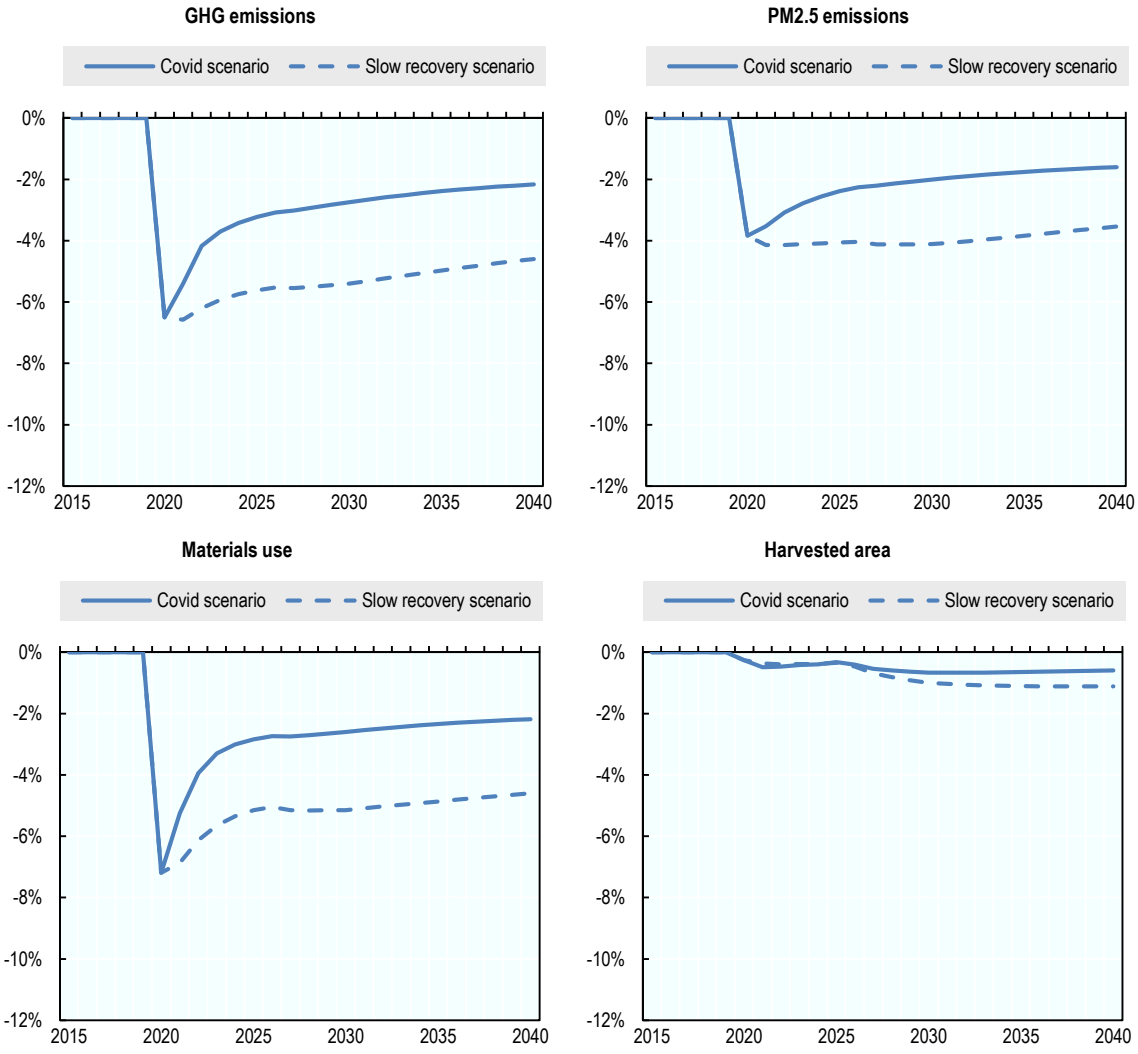
[10] As mentioned above, specific green recovery packages are not included in the analysis.

[11] In the slow recovery scenario, the rebound effect in 2021 is excluded, and the recovery rates for all shocks are halved.

Correspondingly, the decline in environmental pressures is also projected to last longer (Figure 8). The slower recovery also drives a larger wedge between sectors in terms of the consequences for production levels. Consequences for environmental pressures linked to more capital-intensive sectors, especially energy and manufacturing, therefore persist longer than those pressures that are linked to for example agriculture. Other pollutants, not shown in the figure, follow similar patterns, depending on their key emission sources. As the speed of recovery differs by region, these global trends are only partially indicative of the implications at regional level. For instance, the differences between both scenarios tend to be smaller in regions where the main Covid scenario assumes faster recovery, but bigger in the regions where the GDP forecast includes a rebound effect for 2021; similarly, the difference is smaller in regions where the effects on environmental pressure are smaller, such as the OECD Pacific region (see Annex C).

Figure 8. Effects of the slow recovery scenario on global environmental pressures

Deviations from the pre-Covid baseline projection



Source: ENV-Linkages model.

5. Discussion

The results presented in this paper are surrounded by significant uncertainties. The impacts of the pandemic on sectoral economic activity are not clearly distilled yet. In addition, recovery packages are yet to be defined in many countries. Furthermore, while the start of vaccine campaigns implies that there is a lesser risk of a prolonged pandemic, the speed with which life "returns to normal" remains to be seen.

There are also uncertainties regarding the projections of environmental pressures. The modelling above looks only at the economic drivers of environmental pressure, but does not include any change in the composition of economic activity *within sectors* towards more or less polluting activities. In reality, the composition of for example the plastics sector may have altered given the increased demand for protective equipment.

While many countries have announced that their recovery packages will be "green", the model does not include specific support to environmental goods and services. Indeed, the extent to which recovery packages steers government support to specific environmentally relevant sectors should be further investigated.

Finally, the paper focuses on the implications of the Covid-19 shocks for environmental pressures. Assessing what these imply for environment quality, ranging from concentrations of GHGs and particulate matter, to sea level rise, air pollution-related mortality, biodiversity and ecosystem services, is beyond the scope of the current paper.

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Annex A. Description of the modelling tools

Modelling economic activity

The OECD ENV-Linkages model is a computable general equilibrium (CGE) model based on the GTAP national accounting database (Chateau, Dellink and Lanzi, 2014[12]). It describes economic activities in different sectors and regions and how they interact. It is also a global economic model featuring all the main regions and countries of the world. The model relies on a consistent set of data describing the behaviour of production sectors and consumers in the different regions, with a focus on energy and international trade. The sectoral and regional aggregation of the model is given in Table A.1 and Table A.2, respectively.

Table A.1. Sectoral aggregation of ENV-Linkages

Agriculture, Fisheries and Forestry	Manufacturing
Paddy Rice	Food Products
Wheat and Meslin	Textiles
Other Grains	Wood products
Vegetables and Fruits	Chemicals
Oil Seeds	Basic pharmaceuticals
Sugar Cane and Sugar Beet	Rubber and plastic products
Fibres Plant	Pulp, Paper and Publishing products
Other Crops	Non-metallic Minerals
Cattle and Raw Milk	Fabricated Metal products
Other Animal products	Electronics
Fisheries	Electrical equipment
Forestry	Motor Vehicles
Non-manufacturing Industries	Other Transport Equipment
Coal extraction	Other Machinery and Equipment
Crude Oil extraction	Other Manufacturing incl. Recycling
Natural Gas extraction	Iron and Steel
Other Mining	Non ferrous metals
Petroleum and Coal products	**Services**
Gas distribution	Land Transport
Water Collection and Distribution	Air Transport
Construction	Water Transport
Electricity Transmission and Distribution	Insurance
Electricity Generation (8 technologies)	Trade services
Electricity generation: Nuclear Electricity; Hydro (and Geothermal); Solar; Wind; Coal-powered electricity; Gas-powered electricity; Oil-powered electricity; Other (combustible renewable, waste, etc).	Business services n.e.s.
	Real estate activities
	Accommodation and food service activities
	Public administration and defence
	Education
	Human health and social work

Table A.2. ENV-Linkages model regions

Macro regions		ENV-Linkages countries and regions	Most important comprising countries and territories
OECD	OECD America	Canada	Canada
		USA	United States of America
		Other OECD America	Chile, Colombia, Costa Rica, Mexico
	OECD Europe	OECD EU 22	Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden
		Other OECD Europe	Iceland, Israel[1], Norway, Switzerland, Turkey, United Kingdom
	OECD Pacific	Australia and New-Zealand	Australia, New-Zealand
		OECD Pacific	Japan, Korea
Non-OECD	Other America	Other Latin America	Non-OECD Latin American and Caribbean countries
	Eurasia	Other EU	Bulgaria, Croatia, Cyprus[2], Malta, Romania
		Other Europe and Caspian	Non-OECD European and Caspian countries, incl. Russian Federation
	Middle East and Africa	Middle East and North Africa	Algeria, Bahrain, Egypt, Iraq, Islamic Rep. of Iran, Kuwait, Lebanon, Lybia, Morocco, Oman, Qatar, Saudi Arabia, Tunesia, United Arab Emirates, Syrian Arab Rep., Western Sahara, Yemen
		Other Africa	Sub-Saharan Africa
	Other Asia	China	People's Rep. of China, Hong Kong (China)
		India	India
		Other non-OECD Asia	Other non-OECD Asian and Pacific countries

Notes:
[1] The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.
[2] Note by Turkey: The information in this document with reference to "Cyprus" relates to the southern part of the Island. There is no single authority representing both Turkish and Greek Cypriot people on the Island. Turkey recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of the United Nations, Turkey shall preserve its position concerning the "Cyprus issue".
Note by all the European Union Member States of the OECD and the European Union: The Republic of Cyprus is recognised by all members of the United Nations with the exception of Turkey. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

One of the main strengths of the model is that it links economic activity to environmental pressures, such as greenhouse gas (GHG) emissions (OECD, 2015[13]), air pollutant emissions (OECD, 2016[14]), and the environmental impacts related to materials use (OECD, 2019[15]). The most recent model enhancement is a detailed calculation of the production, consumption and waste of plastics, differentiated by polymer and application. The ENV-Linkages model can also shed light on the medium- and long-term impact of environmental policies, such as resource efficiency and circular economy policies (OECD, 2020[21]; Chateau and Mavroeidi, 2020[22]; Dellink, 2020[23]).

ENV-Linkages is a carefully calibrated dynamic CGE model, thus ideal to better understand the drivers of environmental pressures. Its sectoral and regional details can be exploited to assess the benefits of policy action, considering policy-induced changes in

sectoral production and trade. Production is assumed to operate under cost minimization with perfect markets and constant return to scale technology.

The model adopts a putty/semi-putty technology specification, where substitution possibilities among factors are assumed to be higher with new vintage capital than with old vintage capital. In the short run, this ensures inertia in the economic system, with limited possibilities to substitute away from more expensive inputs, but in the longer run, this implies relatively smooth adjustment of quantities to price changes. Capital accumulation is modelled as in the traditional Solow-Swan neo-classical growth model.

The energy bundle is of particular interest for analysis of environmental issues. Energy is a composite of fossil fuels and electricity. In turn, fossil fuel is a composite of coal and a bundle of the "other fossil fuels". At the lowest nest, the composite "other fossil fuels" commodity consists of crude oil, refined oil products and natural gas. The value of the substitution elasticities are chosen as to imply a higher degree of substitution among the other fuels than with electricity and coal.

Household consumption demand is the result of static maximization behaviour which is formally implemented as an "Extended Linear Expenditure System". A representative consumer in each region– who takes prices as given– optimally allocates disposal income among the full set of consumption commodities and savings. Saving is considered as a standard good in the utility function and does not rely on forward-looking behaviour by the consumer. The government in each region collects various kinds of taxes in order to finance government expenditures. Assuming fixed public savings (or deficits), the government budget is balanced through the adjustment of the income tax on consumer income. In each period, investment net-of-economic depreciation is equal to the sum of government savings, consumer savings and net capital flows from abroad.

International trade is based on a set of regional bilateral flows. The model adopts the Armington specification, assuming that domestic and imported products are not perfectly substitutable. Moreover, total imports are also imperfectly substitutable between regions of origin. Market goods equilibria imply that, on the one side, the total production of any good or service is equal to the demand addressed to domestic producers plus exports; and, on the other side, the total demand is allocated between the demands (both final and intermediary) addressed to domestic producers and the import demand.

Market goods equilibria imply that, on the one side, the total production of any good or service is equal to the demand addressed to domestic producers plus exports; and, on the other side, the total demand is allocated between the demands (both final and intermediary) addressed to domestic producers and the import demand.

ENV-Linkages is fully homogeneous in prices and only relative prices matter. All prices are expressed relative to the numéraire of the price system that is arbitrarily chosen as the index of OECD manufacturing exports prices. Each region runs a current account balance, which is fixed in terms of the numéraire. One important implication from this assumption in the context of this paper is that real exchange rates immediately adjust to restore current account balance when countries start exporting/importing emission permits.

As ENV-Linkages is recursive-dynamic and does not incorporate forward-looking behaviour, price-induced changes in innovation patterns are not represented in the model. The model does, however, entail technological progress through an annual adjustment of the various productivity parameters in the model, including e.g. autonomous energy efficiency and labour productivity improvements. Furthermore, as production with new capital has a relatively large degree of flexibility in choice of inputs, existing technologies

can diffuse to other firms. Thus, within the CGE framework, firms choose the least-cost combination of inputs, given the existing state of technology. The capital vintage structure also ensures that such flexibilities are large in the long-run than in the short run.

Linking economic activity to environmental pressure

The regional and sectoral structure of the ENV-Linkages model, the use of full production functions, as well as the detailed representation of the energy system, can be exploited to produce projections of environmental pressure: environmental pressures are linked to specific elements of economic activity. CO_2 emissions from combustion of energy are directly linked to the use of different fuels in production. Other GHG emissions are linked to output in a way similar to Hyman et al. (2003[24]). The following non-CO_2 emission sources are considered: i) methane from rice cultivation, livestock production (enteric fermentation and manure management), fugitive methane emissions from coal mining, crude oil extraction, natural gas and services (landfills and water sewage); ii) nitrous oxide from crops (nitrogenous fertilizers), livestock (manure management), chemicals (non-combustion industrial processes) and services (landfills); iii) industrial gases (SF_6, PFCs and HFCs) from chemicals industry (foams, adipic acid, solvents), aluminium, magnesium and semi-conductors production. Over time, there is, however, some relative decoupling of emissions from the underlying economic activity through autonomous technical progress, implying that emissions grow less rapidly than economic activity (OECD, 2015[13]).

Emissions of air pollutants have been included in ENV-Linkages by linking them to production activities in different key sectors. The main emission sources are similar to those of GHGs emissions: power generation and industrial energy use, due to the combustion of fossil fuels; agricultural production, due to the use of fertilisers; transport, especially due to fossil fuel use in road transport, and emissions from the residential and commercial sectors. The air pollutants tracked in the model are the following: sulphur dioxide (SO_2), nitrogen oxides (NO_x), black carbon (BC), organic carbon (OC), carbon monoxide (CO), volatile organic compounds (VOCs) and ammonia (NH_3). Even if this list does not cover all air pollutants, it includes the main precursors of Particulate Matter (PM) and ground level ozone (O_3), the concentration levels of which are the main causes of impact on human health and on crop yields. The data on air pollutants used for this report is the output of the GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) model (Amann, Klimont and Wagner, 2013[25]; Wagner, Amann and Schoepp, 2007[26]). The emissions per unit of the related economic activity (i.e. the emission coefficients) are time-, sector- and region-specific to reflect the different implementation rates of respective technologies required to comply with the existing emission legislation in each sector and region (OECD, 2016[14]).

Material flows, covering 60 different materials including biotic resources, fossil fuels, metals and non-metallic minerals, are linked to the economic flows at the detailed sectoral level (see Table A.3 for details). The dataset on physical material flows from the International Resource Panel (UNEP, 2018) is used as the basis for the projection of primary material extraction. The basic principle for linking is that physical flows (materials use in tonnes) for each material is attached to the corresponding economic flow (materials demand in USD). A coefficient of physical use per USD of demand is calculated and used to project materials use in the coming decades, i.e. efficiency improvements are assumed to affect both the physical and monetary material flows, and leave the physical use coefficient unchanged (OECD, 2019[15]).

Table A.3. Overview of materials included in the model

Category	Materials	Corresponding economic flow
Biotic resources	Grazed biomass, Other crop residues (sugar and fodder beet leaves etc.), Straw, Sugar crops, Timber (Industrial round wood), Wood fuel and other extraction, All other aquatic animals, Aquatic plants, Wild fish catch, Fruits, Nuts, Vegetables, Oil bearing crops, Fibres, Wheat, Rice, Cereals n.e.c., Other crops n.e.c., Pulses, Roots and tubers, Spice - beverage - pharmaceutical crops, Tobacco	Production of the corresponding agricultural sector
Fossil fuels	Anthracite, Other Bituminous Coal, Peat, Natural gas, Natural gas liquids, Crude oil, Oil shale and tar sands	Extraction of coal, gas and oil, respectively
Non-metallic minerals	Gypsum, Limestone, Sand gravel and crushed rock, Structural clays	Non-metallic minerals used in construction*
	Ornamental or building stone	Mining inputs used in construction
	Chemical minerals n.e.c., Fertiliser minerals n.e.c., Salt	Mining inputs used in chemicals, rubber, plastics production
	Chalk, Dolomite, Industrial minerals n.e.c., Industrial sand and gravel, Other non-metallic minerals n.e.c., Specialty clays	Mining inputs used in non-metallic minerals production
Primary metals	Iron ores	Mining inputs used in iron and steel production
	Bauxite and other aluminium ores	Mining inputs used in aluminium production
	Copper ores	Mining inputs used in copper production
	Chromium ores, Gold ores, Lead ores, Manganese ores, Nickel ores, Other metal ores, Platinum group metal ores, Silver ores, Tin ores, Titanium ores, Zinc ores	Mining inputs used in other non-ferrous metals production

Note: * The non-metallic minerals sector is not an extraction sector, but the assumption is made here that construction materials that need to be processed (e.g. cement) follow the economic flow of the non-metallic minerals processing sector into construction rather than the mining sector into non-metallic minerals.
Source: OECD (2019[15]).

Land use change is captured through two key indicators: harvested area and output of the forestry. Land use change is governed by a multi-level substitution tree that differentiates between the types of land use, i.e. it is easier to switch between crops than from grassland to cropland, and easier to switch from grassland to cropland than to cultivate currently unmanaged land (OECD, 2017[16]),. The harvested area is directly linked to the land use by the crop sectors, using value to area coefficient calibrated to the IMPACT model (Robinson et al., 2015[27]). Output of the forestry sector is measured in value terms.

Annex B. Details of the Covid-19 pandemic and recovery scenario

The implications of the Covid-19 pandemic and response measures are based on the following modelling assumptions:

- Increases in regional unemployment levels in 2020 are based on the OECD Economic Outlook 108 (OECD, 2020[6]), the updates on GDP forecasts in the Interim Outlook (OECD, 2021[17]) and on the IMF Economic Outlook for the countries that are not covered by the OECD forecasts (IMF, 2020[18]). For the few countries missing in both databases, ad-hoc assumptions are made based on effects in similar countries.
- Sectoral demand shocks are implemented for 2020 following Arriola and Van Tongeren (forthcoming[19]). For energy sectors, the shocks are based on (IEA, 2020[20]).
- Government stimulus packages are implemented as a reduction in capital and labour taxes for firms, and as a reduction in income taxes for households. These are based on Arriola et al. (forthcoming[19]).
- Trade shocks are implemented as an increase in the costs of international trade ("iceberg costs"), with a differentiation between services sectors and agriculture and manufacturing. This mimics the trade shocks in Arriola et al. (forthcoming[19]).
- Reductions in regional labour productivity reflect productivity losses during lockdown (incl. effects of teleworking) and is included crudely as a uniform decline in productivity in all sectors and regions, based on Arriola et al. (forthcoming[19]).
- Finally, regional total factor productivity shocks reflecting the combined effects of all elements not captured explicitly above are added based on the macroeconomic decline in GDP (OECD, 2020[6]). This approach ensures that the immediate effects of the pandemic on the macro economy are scaled to reach the GDP growth rates for 2020 as forecast by (OECD, 2020[6]) and by the IMF for the countries that are not covered by the OECD forecasts (IMF, 2020[18]). In addition, a rebound effect on total factor productivity is included for 2021 and 2022 for those countries where the short-term forecasts are more optimistic than can be explained by the recovery rates calibrated in the model.

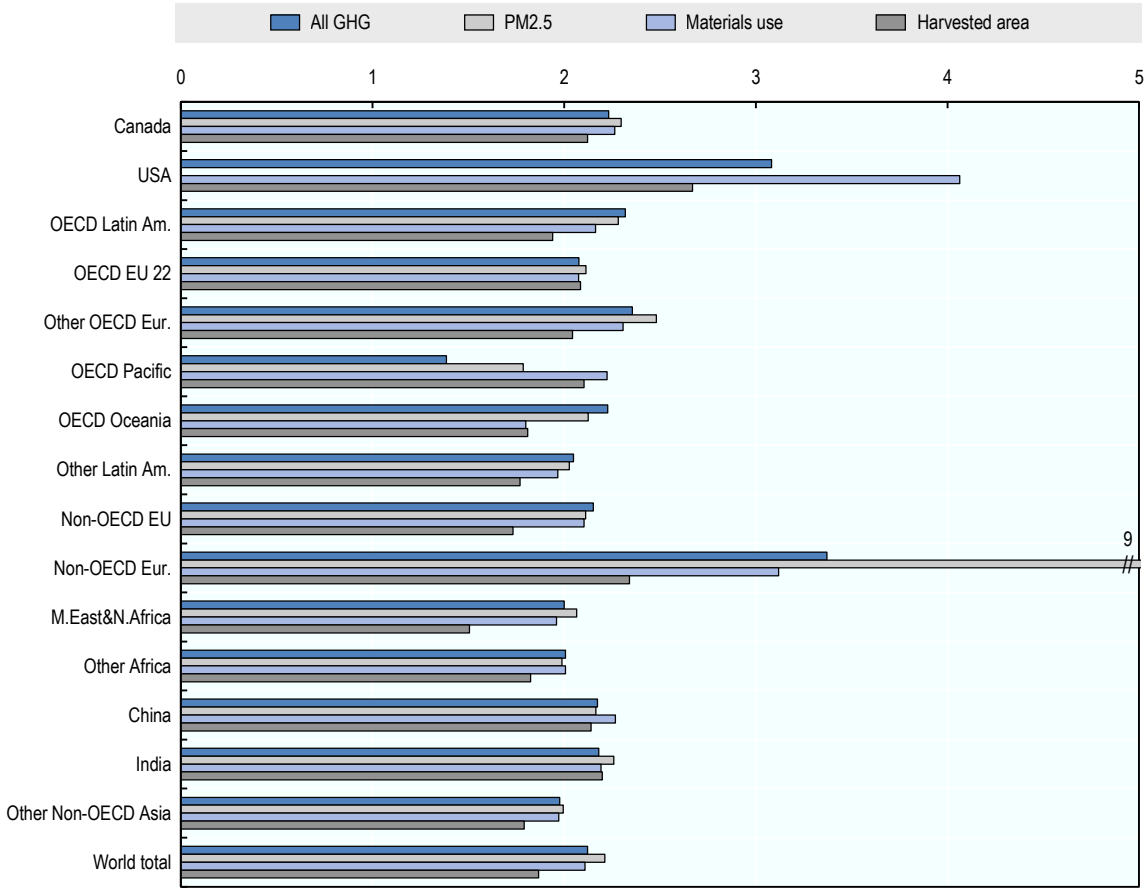
All shocks are assumed to gradually fade over time after 2020, each year becoming less strong than the year before. These recovery rates are region-specific and based on the GDP forecasts until 2025 made by IMF. However, long-term economic activity levels – and the associated environmental pressures – do not necessarily return to the levels as projected in the baseline excluding the Covid shocks; the main reason is that the shocks alter savings and investment behaviour and thus long-term economic growth and environmental pressure.

The analysis focuses on economic drivers and environmental consequences, and does not include e.g. excess mortality or changes in life expectancy. Estimates of demographic impacts and resulting changes in education and human capital are to the knowledge of the author not available and are thus not included in the analysis.

Annex C. Regional results for the Slow recovery scenario

Figure C.1. Effects of the slow recovery scenario on regional environmental pressures

Ratio of the deviations from the pre-Covid baseline projection in 2040 between the Slow recovery and main Covid scenarios



Source: ENV-Linkages model.